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Land suitability evaluation for rice and maize based cropping systems for Kilosa kwa Mpepo proposed irrigation scheme using FAO maximum limitation approach

Abstract

Despite the growing interest in irrigated agriculture in Malinyi District in Morogoro Region, its practice in Kilosa kwa Mpepo traditional irrigation scheme remains low in production and productivity compared with medium to modern irrigated agriculture. Since construction of medium to modern irrigated agriculture is expensive, matching crop requirement with resources available through land suitability evaluation is necessary to improve production and productivity in the area. Such important study however,ha.s not been undertaken in Kilosa kwa Mpepo traditional irrigation scheme proposed for modernization. This study, evaluates the land suitability of Kilosa kwa Mpepo traditional irrigation scheme for rice (*Oryza sativa* L.) and maize (*Zea mays* L.) cropping systems using FAO maximum limitation method. After matching land qualities with land use requirements, results indicated that soil wetness, soil physical characteristics, and soil fertility status were the major limiting factors affecting land quality within the proposed irrigation scheme. Results also showed that of the total area surveyed (i.e. 1,117 Ha) 25% was rated as highly suitable (S1), 37% as moderately suitable (S2) and 37% as marginally suitable (S3) for irrigated rice based cropping systems. However, after controlling floods the highly suitable (S1) to marginally suitable (S3) land observed was to a large extent related to soil physical property, leading to inadequate capacity to retain nutrients. Similarly, results of land suitability for irrigated maize based cropping systems indicated that of the total study area, 37% was rated as highly suitable (S1) and 63% as moderately suitable (S2). The moderately suitable land in the surveyed area was related to soil physical property and poor soil fertility status (*i.e.* texture and low pH). Taken together, these data suggest that well-designed irrigation infrastructures along with flood protection band and drainage structures may control and or reduce the incidence of floods and waterlogging conditions in the study area. Long-term fertility management requires consideration of use of organic materials such as manure and compost. Such programs need to maximize use efficiency and minimize environmental losses. Implementation of the proposed approach to optimizing land management will reverse the suitability of land from marginally suitable to highly suitable land thus delivering a range of socio-economic and agro-environmental benefits to the farmers in Kilosa kwa Mpepo village in Malinyi District

Keywords: land evaluation, land-use optimization, land capability classification, small-scale irrigated farming, physical characteristics

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Introduction

The national population census conducted in Tanzania in 2012 puts the population at 44,928,923.[1] However, the current estimate by FAO puts the population at about 61.7million. The rapid surging of population numbers in Tanzania,ha.s added stress on both natural and agricultural resources. To meet the economic demands of the surging population, a high economic return from agricultural production is obligatory. This is because both population increases and rural urban migrationha.ve increased the pressure on agricultural resources.[2] The Agriculture sector in Tanzania contributes about 25.7% of GDP, 30.9% of its export earnings, and employs over 70% of the nation's work-force. Although the sector continues to drive economic growth in the country, agricultureha.s however remained unpredictable and of low production and productivity due to among others, lack of land suitability evaluation, low soil fertility, and the sole dependence on rainfall which is erratic, unreliable and non-uniformly distributed. In this regard, Tanzania needs to provide and or improve her irrigation infrastructure for efficient and sustainable water utilization to take advantage of the identified irrigation potential area amounting to 29.4 million hectares. Apparently, irrigation development is a very expensive undertaking such that dependable and accurate land evaluation is indispensable to facilitate the decision-making processes involved in developing land use policies that leads to irrigation investment, and so, support sustainable rural development. If self-sufficiency in agricultural production through irrigation schemes development is mandatory in Tanzania, land suitability evaluation techniques will be required for predicting the land's suitability for different land utilization types.[3] Land suitability evaluation is a process of predicting land performance over time according to land utilization types,[4–11] It is similarly a foundation for sustainable land resource planning and management since it help us to know whether the resources are degraded or enhanced in quality or not Dumanski et al,[12] and Mohana et al.[13] The major reason of land suitability evaluation prior to irrigated agriculture is to predict the potential and limitation of the land for crop production and productivity,[14] and provide information on the constraints and opportunities for the use of the land and therefore guides decisions on optimal utilizations of resources, whose knowledge is an essential prerequisite for irrigation development. Moreover, it also allows identification of the main limiting factors for the agricultural production under irrigation and enables decision makers such as land users, land use planners, and agricultural support services to develop a crop management plan to overcome such limiting factors, thus, increasing the crop production and productivity in the area. This study therefore evaluates the land in Kilosa kwa Mpepo for its suitability for rice and maize crops under the proposed irrigation development.

Materials and methods

Location of the study area

The Kilosa kwa Mpepo irrigation scheme is located in Kilosa kwa Mpepo village, Kilosa kwa Mpepo Ward, Ngoheranga division, Malinyi District in Morogoro region. The project is about 65km from Malinyi district council along Malinyi Songea main road. The area is bordered by Mahenge District in the East, Ihoanje Ward in the North, Ruhuji River/Kilombero in the West and Songea in the South. Geographically, the project is located at 35°58'28'' E, 09°09'22'' S (0826966 E 8986626 N UTM coordinates) (Figure 1).

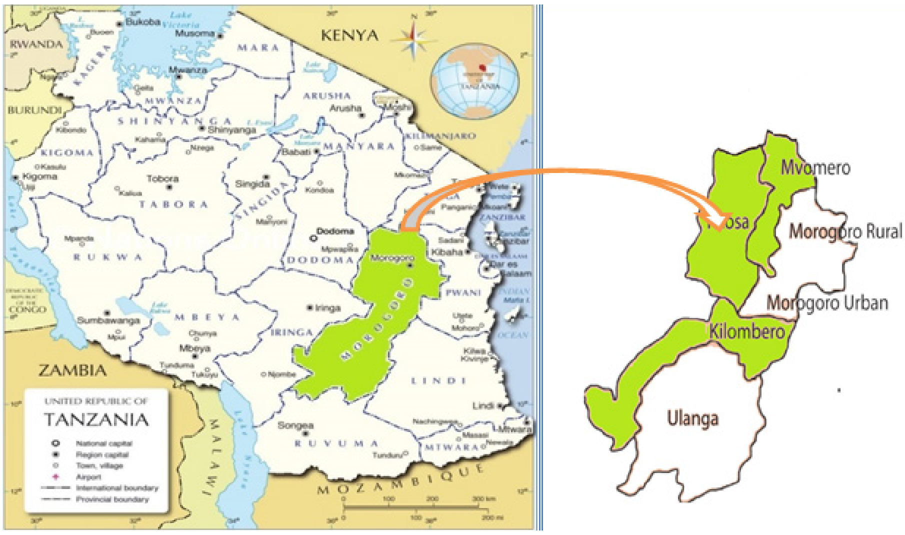

Figure 1 Location of the study area.

Agricultural practices and production

During this study, agricultural practices in Kilosa kwa Mpepo irrigation scheme was rice cultivation under rainfed and when possible or necessary supplementary irrigation. Other crops grown outside the proposed area include maize (*Zea mays* L), sorghum (*Sorghum bicolor* L), sesame (*Sesamum indicum* L), groundnuts (*Arachis hypogea* L), banana (*Mussa* spp) and some limited vegetables such as water melon (*Citrullus lanatus*). According to the interviewed farmers, hand hoe is the overall dominant tool for land preparation. Reduced crop yields in the area are due to prolonged flood during rainy season, nutrient leaching and inadequate irrigation water in the dry season, suggesting irrigation and drainage development. Generally, when irrigation water is needed it is not sufficiently available. For rice (*Oryza sativa* L) cultivation, early planting starts in December andha.rvested in May while late planting starts in January andha.rvested in June. The current average production of paddy is on the average of 1.8tha^{-1}. Among others low crop productivity in the area is attributed to low or no use of agricultural inputs, poor agricultural practices, lack and or poor irrigation infrastructure and lack of drainage during the rainy season.

Climate

The project falls in a humid climate and it receives a seasonal rainfall ranging from 900mm–1,500mm annum^{-1}. Average yearly rainfall amounts to about 1,463mm annum^{-1} as compared to 1,835mm year^{-1} as annual evapotranspiration. The rainfall pattern is a weak bi-modal with two rain seasons. Short rains begin toward mid of November and ends in January while long rains usually start in March and ends between May and June. The district experiences seasonal flooding in some years on the most of its basin. Farmers in the area do practice supplementary irrigation through traditional irrigation furrows. Lack of efficient irrigation and drainage infrastructure is the main cause for this problem. Temperature, RH (%), potential evaporation (ET_o) and other climate variables representative of the study areas are presented in Table 1. The mean temperature varies from 22.4ºC in July to 27.8ºC in December. The monthly average relative humidity (RH) varies from 67.8 (i.e. October) to 78.2% (i.e. April). The potential evaporation is about 1,835mm per annum and varies widely throughout the year from 116.7 to 195.2mm per month in April and November respectively.

Soil survey and land suitability evaluation

Soil survey process

In order to prepare a pedogeoform map and establish land qualities for the Land Suitability Evaluation, standard topographical sheets (1:50,000), a geological map,[15,16] obtained from the National Irrigation Commission, Morogoro Regional Office and an interpretation of

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aerial photos (1:50,000 from Ministry of Lands, Dar es Salaam),[1] were performed based on the expert opinion, the systematical structure of geopedology,[14] and the geology of the study area. According to the pedogeomorphic approach,[14] only one landscape i.e. the Plain was identified in the study areas. To determine the lithology layer however, a geological map of the area with a scale of 1:100,000 was used. Soil survey on the plain landscape was then planned by means of gridlines. A GPS device was used to set out grid lines, prepare or reconfirm a base map, as well as recording the coordinates and elevations of all field observations. During the soil survey fieldwork, two kinds of observations were made, that is, auguring and opening of master pits. Auger observation was taken as an identification of the taxonomic unit for which a particular pedon belong. The standard depth was taken as 120cm but extended further to 150cm whenever necessary. Master pits were done after the establishment of the important soil sets. A total of 8 Master pits were opened and described. The approximate volume of a full pit was 150cm x 150cm x 120/150cm. These observations were concisely described according to the FAO guidelines for soil description and were carefully entered abreviatively on a pre-prepared data form. Soil classification was done by using the FAO–UNESCO soil map of the world.[17] Overall, 50 disturbed soil samples were collected for physical-chemical characterization. Of the total disturbed samples, 41 were from master pits and 9 were collected from a soil depth of 0–30cm as composite soil samples

Table 1 Climatic data representative for Kilosa kwa Mpepo Irrigation scheme

Climate variable	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
R/fall (mm)	163.5	161.7	273.2	332.1	124.0	30.7	16.7	13.0	18.7	42.2	105.8	181.0
Mean Max Temp (°C)	32.8	32.6	31.5	30.1	29.1	28.2	28.0	29.1	30.8	32.5	33.6	33.5
Mean Min Temp (°C)	22.0	22.0	22.0	21.6	20.0	17.4	16.7	17.7	18.9	20.6	21.7	22.1
Mean Temp (°C)	27.4	27.3	26.8	25.8	24.6	22.8	22.4	23.4	24.9	26.6	27.6	27.8
Mean Max RH (%)	92.9	94.1	95.0	95.7	95.3	94.2	92.9	91.5	90.3	88.4	88.6	91.9
Mean Min RH (%)	54.1	56.0	58.0	60.8	58.0	53.1	50.6	50.3	46.7	47.2	47.4	51.0
Mean RH (%)	73.5	75.0	76.5	78.2	76.6	73.7	71.8	70.9	68.5	67.8	68.0	71.4
ETo (mm)	169.1	152.6	153.5	116.7	120.3	121.3	127.7	137.6	158.7	187.8	195.2	191.1
0.5ETo (mm)	84.6	76.3	76.8	58.4	60.2	60.7	63.9	68.8	79.3	93.9	97.6	95.5
SHrs	6.21	6.31	6.03	5.21	5.24	6.00	5.74	5.77	6.09	6.68	7.33	7.05
WS ($km.d^{-1}$)	226.1	230.8	218.0	236.0	229.6	246.4	247.5	227.3	230.8	233.1	249.3	223.6
WS ($m.s^{-1}$)	2.6	2.7	2.5	2.7	2.7	2.9	2.9	2.6	2.7	2.7	2.9	2.6

Source: Kilombero Illovo Meteorological weather Station, Period 1962–2011 (*Seems to have same altitude with Kilosa kwa Mpepo, Malinyi District*). Total annual rainfall≈1,462mm, Total annual Evaporation (Pan)≈1,835mm; 0.5ETo=917.4mm

Land suitability evaluation

Production could be met through systematic survey of the soils, evaluating their potentials for a wide range of land utilization types and formulating land use plans which are economically viable, socially acceptable and environmentally sound.[18] Theoretically, land suitability for irrigated agriculture is determined by an evaluation process of the climate, soil, and water resources and topographical, as well as the environmental components based on maximum limitation method.[19,20] In this method, climatic and landscape requirements for the crops under consideration were grouped into different suitability classes (Table 2): highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Based on the literature and experts' opinions, seventeen (17) significant criteria for irrigated agriculture were considered in evaluating agricultural land suitability.[20–22] These criteria are categorized into two major categories i.e. physical and chemical. The physical (Table 3) category is further subdivided into eight major sub-groups (damaging floods; surface stoniness; soil depth; drainage; top soil texture; surface structure; infiltration rate (IR) and available water capacity (AWC). In the chemical (Table 4) category, it is similarly sub-divided into nine sub-groups: Organic carbon (OC); total nitrogen (TN); carbon to nitrogen ratio (C/N); potassium to sodium ratio (K/Na); pH (H_2O); apparent cation exchange capacity (CEC); base saturation (BS), total exchangeable bases (TEB) and Soil Sodicity. Depending on matching of the collected data for each land characteristic with the numerical range allocated to each of the above mentioned classes in Table 2, a suitability class is attributed to that land characteristic. By this way, different suitability classes were determined for different land characteristics. The suitability class of the land units is considered to be the lowest one among these classes. For development of a final suitability map, the criteria maps were reclassified based on the suitability classes (Table 2). These maps were crossed according to the lowest suitability class. According to the suitability degree for cultivation of rice and maize, values of each criterion are classified into five suitability classes ranging from highly suitable to not suitable (Table 2). This classification is based on the FAO,[23] framework, which is the most commonly used framework for classification of agricultural land suitability. Figure 2 and Table 4 show the major land/soil units and their characteristics in Kilosa kwa Mpepo. The main diagnostic land qualities and soil data considered in this study are briefly explained.

Table 2 Land suitability classes

Suitability class		Description
S1	Highly Suitable	Land having no or only slight limitations, which require minor land improvements that can be easily implemented at low cost
S2	Moderately suitable	Land with moderate limitations, which will reduce productivity and requiring special inputs or land improvements. Its use, although still attractive, will yield significantly lower than that expected under class S1.
S3	Marginally suitable	Land with severe limitations, which seriously reduce productivity or require corrections or inputs that will only be marginally justified.
N	Not suitable	Land with very severe limitations, which preclude its successful and sustained use.

Table 3 Land characteristics (physical) used in evaluating the soils of Kilosa kwa Mpepo Irrigation Scheme (0–20cm)

Mapping unit	Damaging floods	Surface stoniness	Soil depth (cm)	Drainage	Texture	Surface structure	IR ($cm.hr^{-1}$)	AWC (0 -100cm)
KKM–Pa1	Infrequent	None	Nr	MWD	**SL**	Moderate	Moderate	Medium
KKM–Pa2	Infrequent	None	Nr	MWD	**SL**	Strong	Moderate to high	Low
KKM–Pa3	Infrequent	None	Nr	MWD	**SCL**	Moderate	Moderate	Medium
KKM–Pa4	Infrequent	None	Nr	MWD	**SCL/CL**	Strong	Moderate	Medium
KKM–Pa5	Infrequent	None	Nr	WD	**SL**	Weak	High	Low
KKM–Pa6	Infrequent	None	Nr	MWD	**C**	Strong	Low	Medium

KKM, kilosa kwa mpepo; Nr, no restriction; IR, infiltration rate (IR); AWC, available water capacity; MWD, moderately well drained; WD, well drained; SCL, sand clay loam; CL, clay loam; C, clay; SL, sandy loam

Table 4 Land characteristics (Chemical) used in evaluating the soils of Kilosa kwa Mpepo Irrigation Scheme (0–20cm)

Mapping unit	OC (%)	TN	C/N	K/Na	pH (H_2O)	CEC_A (cmol (+) kg^{-1}.clay)	BS (%)	TEB	Soil sodicity
KKM–Pa1	14.5	0.9	12.5	1.5	6.3	154	71	29.2	0.4
KKM–Pa2	5.3	0.4	7.0	2.9	5.9	93	68	24.5	1.4
KKM–Pa3	13.8	0.7	15.0	2.0	5.8	123	62	26.1	0.7
KKM–Pa4	16.5	0.9	9.5	0.2	5.7	35	66	25.3	4.8
KKM–Pa5	16.0	0.8	15.0	1.3	5.7	227	65	17.6	0.4
KKM–Pa6	18.8	1.2	8.0	13.4	5.0	62	59	24.6	0.1

KKM, kilosa kwa mpepo; TN, total nitrogen; OC, organic carbon; BS, base saturation; Nr, no restriction; IR, infiltration rate (IR); AWC, available water capacity; MWD, moderately well drained; WD, well drained; SCL, sand Clay loam; CL, clay loam; C, clay; SL, sandy loam; CEC, cation exchange capacity; BS, base saturation; TEB, total exchangeable bases; C/N, carbon nitrogen ratio; K/Na, potassium sodium ratio

Description of the land utilization types (LUTs)

Irrigated rice (*Oryza sativa* L.) in bunded fields will be cultivated in pure stand. It will be part of a cropping system based on rice as the major food and cash crop. Other crops in the rice-based cropping system are maize (*Zea mays* L) and sugarcane (*Saccharum officinarum* L). Capital investments and material inputs will be moderate. There will be a moderate use of fertilizer (i.e. urea). Labour intensity will be high, including coasted, hired labour. Land preparation will be done using hired tractor services. Paddling and land levelling will be adequate. Rice will be transplanted from nursery seedbeds. Local as well as improved cultivars will be planted. There will be modest chemical pest and disease control. Irrigation water will be controlled and depth of water application will be according to crop stage and irrigation scheduling. Weeding will be done manually and timely. The average size of the land holding is 1.25ha with a plot size of about 0.1ha.. Recent yield levels are estimated at about 3-3.5tha^{-1} at current plant densities and under near-optimal conditions.

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Maize (*Zea mays* L.) will be cultivated in pure stand and or intercropped with beans or groundnuts. Irrigation water will be distributed from the border of temporary basins or tertiary furrows. Maize will be grown as food as well as cash crop whenever there is surplus. Capital investments will be moderate. Material inputs as well as use of fertilizer (i.e. urea) will be moderate. Labour intensity will be high, including coasted, hired labour. Land preparation will be done with hired tractor services. Land levelling and irrigation scheduling will be optimal. Local and improved short duration varieties will be planted. Weeding will be done manually and timely. There will be modest chemical pest and disease control. The average size of land holding is 1ha. and plot size is about 0.4ha. Maize yields are estimated at 1.5tha^{-1} (pure stand) at current plant densities and under farmers' conditions. Irrigated beans will be grown after the maize isha.rvested. Irrigation water will be controlled and depth of water application will be according to crop stage and irrigation scheduling.

Diagnostic land qualities for rice

Five main diagnostic land qualities (LQs)ha.ve been identified for irrigated rice-based cropping systems. These land qualities include land levelling (t), wetness (i.e. floodha.zard and drainage), soil physical characteristics (s) (i.e. surface texture, coarse fragments, $CaCO_3$, and gypsum); Soil fertility characteristics (f) (i.e. apparent CEC, per cent base saturation, sum of basic cations, pH and organic carbon) and Salinity and alkalinity (n) (i.e. ECe, ESP). Tables 3–5 list these LQs and presents sliding scales, used for the rating of the LQs. The LQs taken into account are briefly discussed below.

Land levelling (t)

Land leveling for irrigation is the process of modifying the surface relief by grading and smoothing to a planned grade and to certain specifications required to facilitate or improve the uniform application of water. It is the process of flattening or modifying existing slopes or undulations rather than necessarily creating a level surface. This LQ is mainly a function of slope of the terrain. The influence of landscape on agricultural land use is multiple including microclimate conditions and hydrology. In Kilosa kwa Mpepo, landform classes as defined in FAO guidelines for soil descriptions were used. The observed slopes were rated as flat to almost flat (<2%) an ideal condition for gravity-irrigated rice. This slope range however, requires minor land levelling to construct the horizontal paddy fields.

Wetness (i.e. floodha.zard and drainage) (w)

The floodha.zard land quality (LQ) is defined as damage by water above the ground surface either as a result of sudden deep ponding by excessive rainfall, river bank erosion, undercutting or by high river levels causing over bank flow and inundation of the river floodplain. As a result, crops and irrigation infrastructures are severely affected. Soil drainage refers to the flow of water due to irrigation and rainfall through the soil, and the frequency and duration of periods when the soil profile is free of saturation under natural conditions".[19] It is perhaps the most important LQ to consider since inadequate attention to drainage provisions has led to the downfall of many irrigation schemes particularly in areas where evaporation greatly exceeds rainfall. In the proposed Kilosa kwa Mpepo irrigation scheme, any difficulty of draining away irrigation water is directly related to the risk of building up harmful levels of exchangeable Na^+ in the soil leading to serious sodicityhazard. Generally, apart from drainage outlet possibilities and ground water levels, depth to drainage barrier and soil permeability is the most important factors in predicting drainability. In the surveyed areas, however, depth to drainage barrier is not a constraint, because soil depth was observed to be>150cm.In the soil survey data of Kilosa kwa Mpepo, drainagehas been classified into four general classes: well-drained, moderately well-drained, poorly drained and very poorly-drained.[24]

Physical soil characteristic (s)

During crop growth and development, LQs such as moisture availability, availability of oxygen and availability of foothold for root development depends on physical soil characteristics such as texture, coarse fragments, stoniness, depth of the soil and soil structure. To evaluate this land use requirement (LUR), texture/structure, coarse fragments (Vol.%), soil depth (cm), $CaCO_3$ (%), gypsum (%) were considered and are shown in Tables 3–5.

Table 5 Sliding scales for the land suitability evaluation for irrigated rice

Land quality and land characteristic	Degree of limitation			
	No or slight (S1)	**Moderate (S2)**	**Severe (S3)**	**Very severe (N)**
Topography (t)				
Slope (%)	<1	1–2	2–4	>4
Wetness (w)				
Flood hazard incidence of damaging river floods or damaging rainfall ponding	Once every 20 or more (never–very rare)	Once every 5–20y (rare)	Once every 1–5y. (infrequent)	Once or more every y. (frequent-v. frequent)
Drainage	ID, MWD	PD	VPD	-
Physical soil characteristic (s)				
Texture/Structure	*Cm, SiCm, C+60v, C+60v , C-60v, C-60s, SiCs **Cm, SiCm, C+60v, C+60s, C-60v, C-60s, SiCs, Co, SiCL, CL, Si	*Co, SiCL, CL, Si, **SiL, SC, L, SCL	*SiL, SC **SL, LfS, LS, LcS, fS	L and Lighter

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Table continue

Land quality and land characteristic	Degree of limitation			
	No or slight (S1)	Moderate (S2)	Severe (S3)	Very severe (N)
Coarse fragments (Vol. %)	<3	3–15	15–35	>35
Soil depth (cm)	>75	75–50	50–20	< 20
$CaCO_3$ (%)	<6	6–15	15–25	>25
Gypsum (%)	<3	3–10	10–25	>25
Soil Fertility Characteristics (f)				
CEC_A (cmol (+) kg^{-1}clay)	>16	< 16 (-)	< 16 (+)	-
% BS	> 50	50–35	35–20	< 20
∑EB (cmol (+) kg^{-1} soil)	> 4	4–2.8	2.8–1.6	< 1.6
pH (H_2O)	5.5–8.2	8.2–8.5	8.5–9.0	> 9.0
OC (%)	>1.5	1.5–0.8	< 0.8	-
Soil sodicity/Alkalinity (present status) (n)				
ECe (dS m^{-1})	<2	2–4	4–6	> 6
ESP in topsoil (%)	< 20	20–30	30–40	>40
Drainage	ID, MWD	PD	VPD	-

Cm, massive clay; SiCm, massive silt clay; C+60, v, very fine clay, vertisols structure; C+60, s, very fine clay, blocky structure; C–60, v, clay, vertisols structure; C–60, s, clay, blocky structure; SiCs, silt clay, blocky structure; Co, clay, oxisol structure; SiCL, silt clay loam; CL, clay Loam; Si, silt; SiL, silt loam; SC, sand clay; L, loam; SCL, sand clay loam; SL, Sandy Loam; LS, loamy Sand; LFS, loamy fine sand; LcS, loamy coarse sand; FS, fine sand; S, Sand; ID, imperfectly drained; WD, Well drained; MWD, moderately well drained, growing cycle 90–150 days; *, subsoil has an IR > 0.1cmhr^{-1} and groundwater is present within 50cmfrom the soil surface; **, Subsoil has an IR < 0.1cm hr^{-1} and groundwater is present within 50cm from the soil surface

Soil texture refers to the relative percentage of sand, silt and clay in a soil. Natural soils are comprised of soil particles of varying sizes. Soil texture is one of the most important characteristics with regard to soil physical quality. It influences such important soil properties as soil water availability, infiltration rate, drainage, tillage conditions and capacity to retain nutrients. The effect of texture on those properties may further be influenced by structure, clay mineralogy, organic matter content and lime content. From the viewpoint of efficient use of irrigation water, the capacity to maintain irrigation water on the surface of the paddy fields is an important factor. This capacity depends on the infiltration rates. Wet tillage and paddling of the topsoil prior to rice transplanting reduces the infiltration rate. Generally paddling is more effective in clayey soils than in sandy soils, whereas gravely soils are very difficult to puddle. Therefore topsoil texture was also used as an indication of the paddlability of the soils and hence of their capacity to maintain surface water. The original soil structure, deliberately destroyed by paddling, should be regenerated for the cultivation of vegetables (especially tomatoes and onions), maize and beans after rice. This regeneration is obtained through alternate wetting and drying and tillage at the appropriate moisture content. Soils high in OM are easier to regenerate than other soils. The depth of soil that may be exploited by plant roots is an important criterion for land evaluation. A deep well drained soil shows a root penetration until below 150cm for most crops. Experience has shown that most crops will produce excellent yields with an effective root zone of 90–100cm.

Presence of lime ($CaCO_3$) affects both physico-chemical characteristics of the soils. Although high $CaCO_3$ concentration may not severely restrict water movement, but may prevent root penetration. High $CaCO_3$ concentration particularly in the very fine fractions brings risks of lime induced chlorosis in many crops. It is also accepted that the physical characteristics of calcareous soils change when they are irrigated. So, $CaCO_3$ content affects suitability for irrigation, as irrigated land becomes more coherent and resistant to root penetration when $CaCO_3$ content increases. This parameter was considered in the evaluation since its assessment during field work indicated its presence. According to Sys and Riquier et al.[26] crops such as those considered in the surveyed areas are either tolerant (sugarcane) or moderately tolerant (maize, rice) to lime. Indirectly, gypsum ($CaSO_4.2H_2O$) affects soil physical properties. It improves the soil structure and prevents Na saturation, thus, favouring permeability and infiltration rate. A small amount of $CaSO_4$ $2H_2O$ is favourable for crops growth because it serves as a relatively soluble source of Ca as plant nutrient, replaces Na in the exchange complex and, thus, acts to preserve chemical and physical soil degradation. Under irrigation, highly gypsiferous soils may develop dissolution depressions, and for that reason such soils are not suitable for irrigation. In the surveyed area, just as the case with lime, $CaSO_4$ $2H_2O$ was not considered in the evaluation since its assessment during field work indicated no sign of gypsum. Similarly, crops such as those considered in the surveyed areas are moderately tolerant (maize, rice) to gypsum.[26]

Soil fertility characteristics (f)

Soil fertility includes Apparent CEC, Total exchangeable bases (TEB), soil pH, Soil Organic Carbon (SOC) and soil sodicity. CEC is a measure of negatively charged sites on the surface, which help in holding positively charged ions and nutrients such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and Zn.[27] It is a very important soil property that influence soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants.[28] With the exception of some soils with positive charge, the weathering stage rarely makes a soil unsuitable for cultivation. However, it will influence its suitability as it defines the presence or absence of a mineral reserve and influences the retention for nutrients and water. Total exchangeable base (TEB) is an expression of the quantity of cations or nutrients available for plant growth. Not only the total amount of cations is important, but also the ratio between cations. For this evaluation, the total exchangeable bases involved are sum of Ca, Mg, K and Na. This implies that soils with a limited leaching of basic cations will show almost no limitation; however, the cation balance may not be optimal. Soil pH or soil reaction is an indication of the acidity or alkalinity of soil and is measured in pH units. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. From pH 7 to 0 the soil becomes more acidic and from pH 7 to 14 the soil is more alkaline or basic. Soil acidity may be correlated with total exchangeable bases. Besides this relationship, soil acidity gives information about probable soil toxicities with a negative effect on crop development. Aluminium toxicities for example, refer to the harmful effects of Al^{3+} ions concentration in the exchange complex. Aluminium first enters the exchange complex below a pH of approximately 5.5, rising to some 20% Al^{3+} saturation at about pH of 5.0 and 50% or more below a pH of 4.0. Soil reaction may also be used as a diagnostic for Al-saturation. Whether under natural vegetation or otherwise, organic carbon (OC) content is often a good expression of the natural fertility of the soil. The OC of the soil is closely correlated with agro-ecological zones (AEZ). Soil sodicity or the degree of saturation of the soil's exchange complex with Na^+ (expressed by the ESP),has, not only a big influence on soil structure and permeability particularly in irrigated system, but alsoha.s a big impact on yield levels. Although no sodicity symptoms were observed during soil survey in the areas, some of the proposed crops i.e. maize, rice are known to be sensitive or moderately sensitive to high sodicity levels with a yield reduction of 50% at EC_e levels of between 4 to 10d S m^{-1} and ESP of between 15% and 25%.

Land qualities for irrigated maize-based cropping systems

Five (5) main diagnostic land qualities (LQ's) have been identified for irrigated maize-based cropping systems. Brief explanations of some of the LQs (i.e. levelling, flooding and soil drain ability) are similar to those discussed in irrigated rice-based cropping systems. Table 6 lists these land qualities and presents sliding scales used for the rating of the LQs as follows.

Table 6 Sliding scales for the land suitability evaluation for irrigated maize (0–30cm)

Land quality and land characteristic	Degree of limitation			
	No or slight (S1)	**Moderate (S2)**	**Severe (S3)**	**Very severe (N)**
Topography (t)				
Slope (%)	<2	2–4	4-6	>6
Wetness (w)				
Flood hazard incidence of damaging river floods or damaging rainfall ponding	Once every 20 or more (never–very rare)	Once every 5–20y. (rare)	Once every 1–5y. (infrequent)	Once or more every y. (frequent-v. frequent)
Drainage	WD, MWD	ID	PD	PD but drainable
Physical soil characteristic (s)				
Texture/Structure	C–60s, C–60v, Co, SiC, SiCL, Si, SiL, CL, L, SCL, SC	C+60v, SL, LfS, LS	fS, S, LcS	Cm, SiCm, cS
Coarse fragments (Vol %)	<15	15–35	35–55	>55
Soil depth (cm)	>75	75–50	50–20	< 20
CaCO3 (%)	<15	15–25	25–35	>35
Gypsum (%)	<4	4–10	10–20	>20
Soil Fertility Characteristics (f)				
Apparent CEC (cmol (+) kg^{-1}clay)	>16	< 16 (-)	< 16 (+)	-
Base Saturation (%)	> 50	50–35	35–20	< 20
Sum of Basic Cations (cmol (+) kg^{-1} soil)	> 5	5–3.5	3.5–2	< 2

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Table continue

Land quality and land characteristic	Degree of limitation			
	No or slight (S1)	**Moderate (S2)**	**Severe (S3)**	**Very severe (N)**
pH (H_2O)	5.8–7.8	7.8–8.2	8.2–8.5	> 8.5
Organic Carbon (%)	>2	2–1.2	1.2–0.8	< 0.8
K/Na ratio in topsoil	K/Na >1	K/Na ≤1		
Soil sodicity/alkalinity (n)				
ECe (dS m^{-1})	<4	4–6	6–8	> 8
ESP in topsoil (%)	< 6	6–15	16–25	>25

Cm, massive clay; SiCm, massive silt clay; C+60, v, very fine clay, vertisols structure; C+60, s, very fine clay, blocky structure; C–60, v, Clay, vertisols structure; C–60, s, clay, blocky structure; SiCs, Silt Clay, blocky structure; Co, clay, oxisol structure; SiCL, silt clay loam; CL, clay loam; Si, silt; SiL, silt loam; SC, sand clay; L, loam; SCL, sand clay loam; SL, sandy loam; LS, loamy sand; LfS, loamy fine sand; LcS, loamy coarse sand; fS, fine sand; S, sand; Growing cycle 90–130 days

Wetness (w)

The wetness LQ was assessed by flooding and drainage in the surveyed areas. Poor drainage has been reported to affect oxygen availability in many crops. Maize crop for example, requires well drained or well aerated soils and is very sensitive to water logging. So, assessment was done on the basis of drainage conditions in the surveyed areas.

Physical soil characteristics (s)

Maize cultivation in the surveyed areas will be mechanised and will be ploughed by tractor before planting. This farm operation will depend on the ease with which the soil can be ploughed by using tractor or any other agricultural implement. Relevant soil characteristics used in the assessment of this LQ include soil texture, soil structure and presence of gravel or stones in the plough layer or on the surface. Generally the sandy areas in the surveyed areas will be easier to work with compared with areas with clayey soils.

Soil Fertility Characteristics (f)

Soil fertility is the quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants or crops. Soil fertility decline is the decline in chemical soil fertility, or a decrease in the levels of soil organic matter, pH, cation exchange capacity (CEC) and plant nutrients. Most of the mineral elements in the surveyed areas are generally insufficient, thus, threatening plant growth and development. This LQ was assessed based on the base saturation, sum of basic cations, pH, organic carbon, K/Na ratio in topsoil, and apparent CEC (Tables 3–5). Based on these parameters nutrient availability ratings for maize in the proposed Kilosa kwa Mpepo irrigation schemes were low and yield–limiting in nearly all soils. Although N requirement for maize is relatively high, it is not considered a severely limiting factor, as this can easily be corrected by applying fertilizer (and/or manure). Generally nutrient availability to the maize crop is highest in the pH range of 5.5–7.5. Cultivation is also possible on moderately alkaline soils with a pH to about 8.4.

Soil sodicity (n)

Soil sodicity, or the degree of saturation of the soil's exchange complex with Na ions (expressed by the ESP), has a big impact on yield levels. Maize is known to tolerate moderate to high sodicity levels with a yield reduction of 50% at ESP between 15% and 25%. Although this LQ was assessed, there was no sign of soil sodicity observed in the surveyed areas.

Results and Discussion

The sliding scale for land suitability evaluation for the irrigated rice (*Oryza sativa* L) and maize (*Zea mays* L) in Kilosa kwa Mpepo is presented in Table 5 and Table 6. Likewise, results of ratings of the land qualities (LQs) for each MU as determined by the most limiting LQ (s) (indicated as letter suffixes in the final suitability codes) for rice both before and after correction of floods are presented in Tables 7 and Table 8 respectively. Similarly, Table 9 and Table 10 summarize the results of the land suitability evaluation for maize based cropping system. Data showed that the final land suitability evaluation before controlling floods ranged from highly suitable (S1), moderately suitable (S2) and marginally suitable (S3). Land suitability for rice was rated as marginally suitable (S3) with the major limitation as wetness (flooding) and physical soil characteristics in 37% and wetness (flooding) in 63% of the total study area (Table 11), (Figure 2). If flooding is controlled through the proposed irrigation development however, land suitability is expected to improve to highly suitable (S1) in 26%, moderately suitable (S2) in 37% and marginally suitable (S3) in 37% of the total land area with major limitation as physical soil characteristics (Table 11). With regards to maize crop, land suitability evaluation revealed that of the total land area, 37% was marginally suitable (S3) due to wetness (flooding) and physical soil characteristics as major limitations and 67% as marginally suitable due to flooding alone (Figure 3). However, if these major limitations are controlled through the proposed irrigation development, land will be improved to highly suitable (S1) in 37% and moderately suitable (S2) in 25% of the total area with soil pH as major limitation. Furthermore, the land will be improved to moderately suitable (S2) in 37% of the total area with physical soil characteristics as major limitation (Table 11). Taken together, it was found that wetness (w), soil texture (s) and fertility (f) were the main factors affecting land quality and limiting the implementation of the proposed land utilization types in the proposed Kilosa kwa Mpepo irrigation scheme. In order to improve production and productivity of the mapping units and reverse the effects of the identified limitations, it is suggested that flood control measures, soil texture and soil pH management should be implemented. Flood control in the study area may be implemented by incorporating flood protection band or similar structures during the overall design of all the irrigation infrastructures in the area. If the flood protection band does not result into pH management, then it should be managed by liming with appropriate materials so as to bring the pH at the required levels. The decrease in soil pH observed in Kilosa kwa Mpepo as a land suitability limitation is ascribed to highly reduced soil conditions during flooding, which leads to an increase in the mobility of soil nutrients such as P, N, Mg, Ca, Na and K.[29] These mineral elements include those deposited by the previous flood and those released from organic matter decomposition accumulated during dry periods.[30] These measures along with soil texture management will bring the marginally or moderately suitable land into a highly suitable (S1). Additionally, soil physical conditions can be improved by application of organic or compost manures which translates to overall increase in SOM content and fertility status of the soil and favor soil nutrients supply, water infiltration and workability.[31–35]

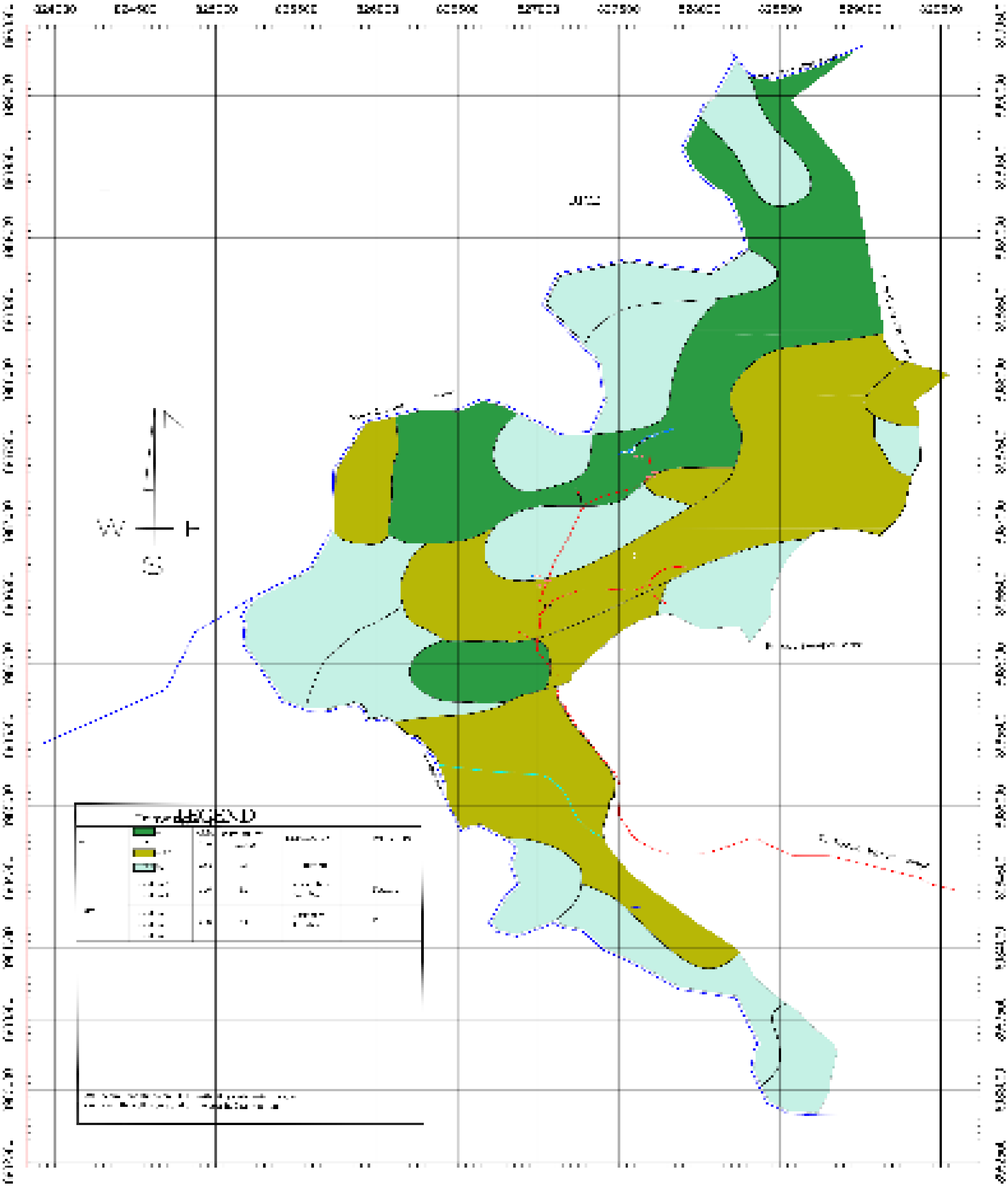

Figure 2 Land suitability classification map for rice (*Oryza sativa* L) based cropping system in Kilosa Kwa Mpepo, Malinyi, Morogoro Region, Tanzania.

Table 7 Final land suitability evaluation results for irrigated rice in Kilosa kwa Mpepo (Before controlling floods)

MU/land characteristics	t	w		s			f					n		Final suitability
		Flooding	Drainage	Texture	Coarse fraction	Soil depth	CEC	%BS	TEB	pH	%OC	ECe ($dS.m^{-1}$)	ESP (%)	
KKM–Pa1	S1	**S3**	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w,s)**
KKM–Pa2	S1	**S3**	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w,s)**
KKM–Pa3	S1	**S3**	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w)**
KKM–Pa4	S1	**S3**	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w)**
KKM–Pa5	S1	**S3**	S2	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w,s)**
KKM–Pa6	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w)**

MU, mapping unit; SO, KKM, kilosa kwa mpepo; S1, highly suitable (not or slightly limiting); S2, moderately suitable (moderately limiting); S3, marginally suitable (severely limiting); N, not suitable (very severely limiting); w, wetness; t, topography; s, Physical soil characteristic; f, soil fertility characteristics; n, Soil sodicity/ Alkalinity (present status); CEC, cation exchange capacity; BS, base saturation; TEB, total exchangeable bases; ESP, exchangeable sodium percentage; ECe, electrical conductivity of the saturated paste; OC, organic carbon

Table 8 Final land suitability evaluation results for irrigated rice in Kilosa kwa Mpepo (after controlling floods)

MU/land characteristics	t	w		s			f					n		Final suitability
		Flooding	Drainage	Texture	Coarse fraction	Soil depth	CEC	%BS	TEB	pH	%OC	ECe (dS/m)	ESP (%)	
KKM–Pa1	S1	S1	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(s)**
KKM–Pa2	S1	S1	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(s)**
KKM–Pa3	S1	S1	S1	**S2**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2(s)**
KKM–Pa4	S1	S1	S1	**S2**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2(s)**
KKM–Pa5 S1		S1	S2	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(s)**
KKM–Pa6	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S1**

MU, mapping unit; SO, KKM, kilosa kwa mpepo; S1, highly suitable (not or slightly limiting); S2, moderately suitable (moderately limiting); S3, marginally suitable (severely limiting); N, not suitable (very severely limiting); w, wetness; t, topography; s, physical soil characteristic; f, soil fertility characteristics; n, soil sodicity/ alkalinity (present status); CEC, cation exchange capacity; BS, base saturation; TEB, total exchangeable bases; ESP, exchangeable sodium percentage; ECe, electrical conductivity of the saturated paste; OC, organic carbon

Table 9 Land suitability evaluation results for maize in Kilosa kwa Mpepo (Before controlling floods)

MU/land characteristics	t	w		s			f					n		Final suitability
		Flooding	Drainage	Texture	Coarse fraction	Soil depth	CEC	%BS	TEB	pH	%OC	ECe (dS/m)	ESP (%)	
KKM–Pa1	S1	**S3**	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3 (w,s)**
KKM–Pa2	S1	**S3**	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3 (w,s)**
KKM–Pa3	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3(w)**
KKM–Pa4	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3 (w)**
KKM–Pa5	S1	**S3**	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S3 (w,s)**
KKM–Pa6	S1	**S3**	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	**S3 (w)**

MU, mapping unit; KKM, kilosa kwa mpepo; S1, highly suitable (not or slightly limiting); S2, moderately suitable (moderately limiting); S3, marginally suitable (severely limiting); N, not suitable (very severely limiting); w, wetness; t, topography; s, physical soil characteristic; f, soil fertility characteristics; n, soil sodicity/ Alkalinity (present status); CEC, cation exchange capacity; BS, base saturation; TEB, total exchangeable bases; ESP, exchangeable sodium percentage; ECe, electrical conductivity of the saturated paste; OC, organic carbon

Table 10 Land suitability evaluation results for maize in Kilosa kwa Mpepo (After controlling floods)

MU/land characteristics	t	w		s			f					n		Final suitability
		Flooding	Drainage	Texture	Coarse fraction	Soil depth	CEC	%BS	TEB	pH	%OC	ECe (dS/m)	ESP (%)	
KKM–Pa1	S1	S1	S1	**S2**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2 (s)**
KKM–Pa2	S1	S1	S1	**S2**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2 (s)**
KKM–Pa3	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S1**
KKM–Pa4	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S1**
KKM–Pa5	S1	S1	S1	**S2**	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2 (s)**
KKM–Pa6	S1	S1	S1	S1	S1	S1	S1	S1	S1	**S2**	S1	S1	S1	**S2 (f)**

MU, mapping unit; KKM, kilosa kwa mpepo; S1, highly suitable (not or slightly limiting); S2, moderately suitable (moderately limiting); S3, marginally suitable (severely limiting); N, not suitable (very severely limiting); w, wetness; t, topography; s, Physical soil characteristic; f, soil fertility characteristics; n, Soil sodicity/Alkalinity (present status); CEC, cation exchange capacity; BS, Base saturation; TEB, total exchangeable bases; ESP, exchangeable sodium percentage; ECe, electrical conductivity of the saturated paste; OC, organic carbon

Table 11 Summary of land evaluation for rice; maize cropping systems in Kilosa kwa Mpepo Irrigation scheme

Crop	Final suitability	Description	Major limitations	Mapping unit	Area (ha)	Total area (Ha)	% of total area
Rice	*Before flood control*						
	S3 (w; s)	Marginally suitable	Wetness (flooding) and physical soil characteristics (texture)	KKM–Pa1; KKM–Pa2; KKM–Pa5	418	1; 117	37
	S3 (w)	Marginally suitable	Wetness (flooding)	KKM–Pa3; KKM–Pa4; KKM–Pa6	699	1; 117	63
	After flood control						
	S3 (s)	Marginally suitable	physical soil characteristics (texture)	KKM–Pa1; KKM–Pa2; KKM–Pa5	418	1; 117	37
	S2 (s)	Moderately suitable	physical soil characteristics (texture)	KKM–Pa3; KKM–Pa4	416	1; 117	37
	S1	Highly suitable	None	KKM–Pa6			
Maize	*Before flood control*						
	S3 (w; s	Marginally suitable	Wetness (flooding) and physical soil characteristics (texture)	KKM–Pa1; KKM–Pa2; KKM–Pa5	418	1; 117	37
	S3 (w)	Marginally suitable	Wetness (flooding)	KKM–Pa3; KKM–Pa4; KKM–Pa6	699	1; 117	63
	After flood control						
	S2 (s)	Moderately suitable	physical soil characteristics (texture)	KKM–Pa1; KKM–Pa2; KKM–Pa5	418	1; 117	37
	S2 (f)	Moderately suitable	Soil fertility characteristics (soil pH)	KKM–Pa6	283	1; 117	25
	S1	Highly suitable	Not observed	KKM–Pa3; KKM–Pa4	416	1; 117	37

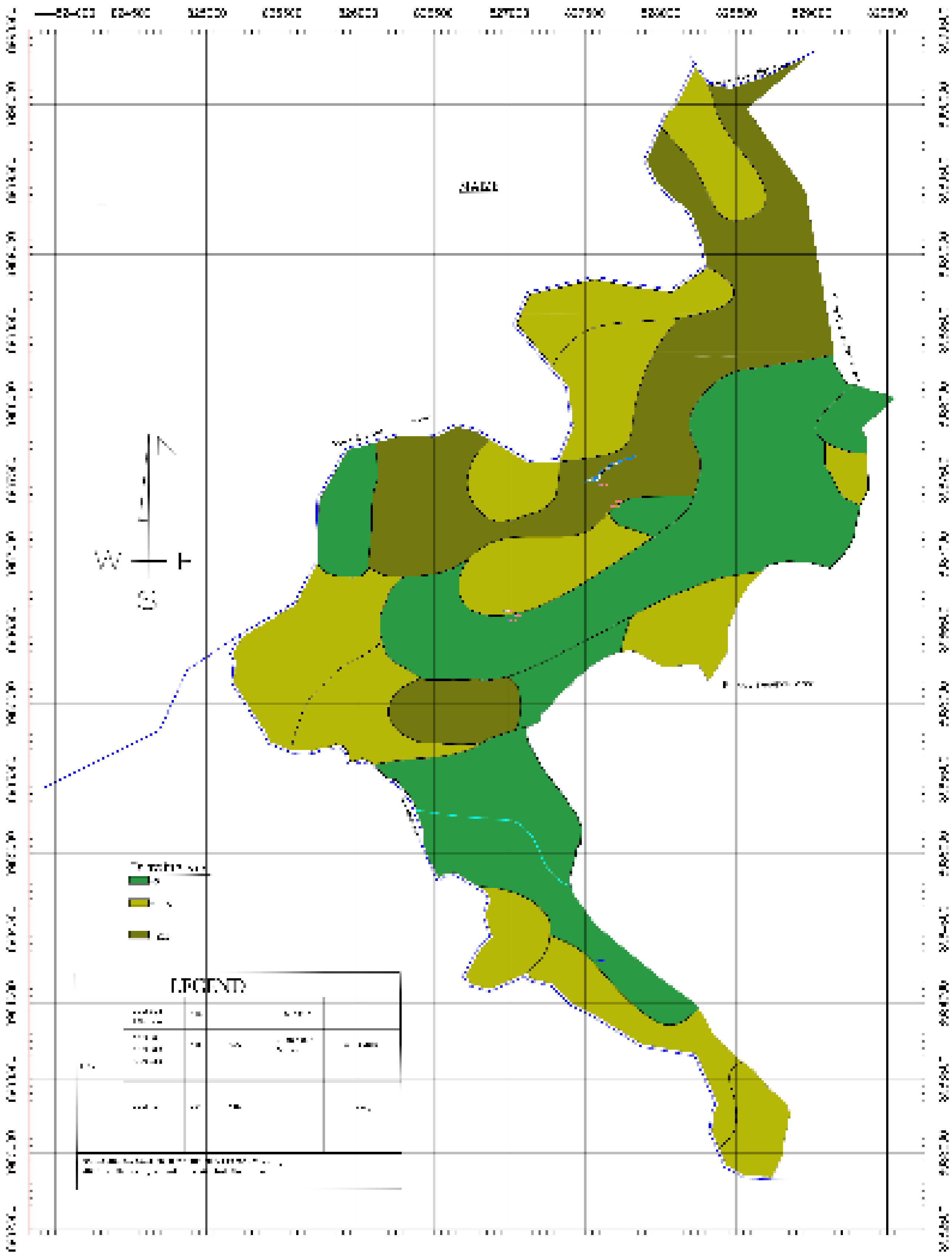

Figure 3 Land suitability classification map for maize (Zea mays L) based cropping system in Kilosa Kwa Mpepo, Malinyi, Morogoro Region, Tanzania.

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Conclusion

In conclusion, results of land suitability evaluation for the selected crops i.e. rice (*Oryza sativa* L) and maize (*Zea mays* L), showed that wetness (floods), soil texture/structure (as part of soil physical characteristics) and low soil pH (as part of soil fertility characteristics) were the major limitations. A set of land management practices were therefore suggested to overcome the identified limitations and optimize land-use. Management practices involving measures that protect floods in the area (i.e. flood protection bands and drainage networks), re.gulate pH to acceptable levels, and increase of SOM levels to improve soil physical conditions will transform the suitability of land from marginally suitable to moderately or highly suitable land, thus, a significant effect on crop production and productivity.

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Conflicts of interest

Authors declare that there is no conflict of interest.

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