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Soil and land Suitability Assessments towards Sustainable Rice Production in the Northern Zone of Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Author PMG conceptualized and wrote the first draft of the manuscript. Authors PMG and JAB conducted the literature searches. Authors JAB and BTK conducted the fieldwork. Authors SOM and KAP conducted the laboratory works. All authors read and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Rice has become the second most important cereal crop and a primary staple food in Ghana. However, domestic rice production falls below its demand, resulting in over 50% rice import per annum. The Government of Ghana has responded by introducing policies to intensify domestic rice production, especially in Ghana's northern zone, where over 50% of local rice is produced. Therefore, this study was conducted to identify and classify soils within the catchment areas of Lonto, Sabonjida, Buntum, Djadema and Wiesi towns in Northern Ghana. The soils were then evaluated for their suitability for valley rice production, under irrigation. The study identified eight soil types (*Lima*, *Lima-variant*, *Sirru*, *Lapliki*, *Kpelesawgu*, *Changnalili*, *Kasele* and *Wenchi series*) in the selected study areas. *Lima series* was the most extensive soil type and was found at all the sites except Djadema site. The soils were generally rated moderately suitable for rice, with the most

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suitable soils being *Sirru* and *Lapliki series*. Groundwater lateritic soils of *Changnalili* and *Kasele series* were rated not to be suitable. The general fertility of the soils was low, which calls for sound soil nutrient and water management. The study is expected to serve as baseline information to help guide decisions of improving per capita rice yield and reducing household food insecurity and poverty levels in Northern Ghana.

Keywords: Soil classification; soil suitability; rice; irrigation; Northern Ghana.

1. INTRODUCTION

Several countries in Africa have semi-arid conditions that make agriculture challenging in Sub-Saharan Africa [1,2] as readily available water is in short supply. Even though the total annual rainfall in an area may be enough to tolerate farm needs, its distribution may be unevenly such that long dry periods are interspersed with periods of intense rainfall. As a result, a crop may not be able to use a high proportion of the water since much of it is lost through runoff or leaching. It may also cause erosion and soil nutrients depletion, especially in soils deficient in soil binding agents such as clay, organic matter, and many more. Given this, an estimated 250 million people in Africa are exposed to increased water stress and a 50% reduction in crop yields from rain-fed agriculture [3].

Rice is an essential staple in Ghana, which has been contributing to reducing the food insecurity status of households. It is therefore cultivated across all agro-ecological zones of the country. Production for paddy rice increased by about 10 per cent per annum from 2008 to 2019 with a sharp increase of 25 per cent covering about 960 thousand tons in 2019 [4]. However, domestic production continues to fall short of demand with the import share of rice consumed remaining above 50 per cent [5,4]. The trend shows a growing preference for rice among Ghanaian households, heightening concerns around foreign exchange imbalances and vulnerability to international rice price shocks. Therefore, the Government introduced the National Rice Development Strategy of 2009 and the Planting for Food and Jobs campaign in 2017 to make households prioritise rice consumption. The Government also set ambitious expansion targets for domestic rice production [6,5] to improve its trade status balance.

To achieve the targets, the Government of Ghana has introduced irrigation schemes to mitigate the challenges aimed at boosting smallholder rice productivity in selected areas of the country to curtail low rice crop yields faced by smallholder farmers [7]. Since Ghana's three northernmost regions account for half of paddy rice production [8,9], irrigation schemes' intensification in these areas is well placed. As a result, through its Design and Construction Supervision of Water Harvesting Schemes in the Northern Zone of Ghana, the Government seeks to identify and develop inland valleys in Northern Ghana. It has led to identifying and selecting five [10] valleys for development across three regions in the Northern Zone.

For the sustainability of any program related to agriculture, forestry or the environment in general, the knowledge and information on the nature of the selected sites' soil resources cannot be over-emphasised. Knowledge of the soil types of the area helps to structure schemes that will be well fitted to the conditions of those soils. A land suitability assessment will also guide the farmer to the best options of crops to grow to ensure suitable household food security. In this vane, this paper aimed to evaluate the soils of the selected sites in the Northern Zone of Ghana. It is hoped that the outcome will aid decision making in the quality of works towards the design and construction supervision of contour bunds and land development for lowland rice valley. Therefore, this research aims at assessing the suitability of the soils in the Northern zone of Ghana for rice production.

This study is significant as it will improve the per capita rice yield and, consequently, reduce households' food insecurity and poverty levels in the study sites. Women would immensely benefit from any proposed rice project at the study sites, as most of them are usually involved in rice production. The national average yield for valley rice cultivation is 4.5Mt (90 bags)/Ha at 50kg per bag. Proposed rice projects are likely to increase the percentage of rice bags from approximately 100 to 230% in the study sites of Lonto, Sabonjida, Djadema, Buntum, and Wiesi, in the Northern zone of Ghana, based on the inherent properties of the soils and other factors.

2. MATERIAL AND METHODS

2.1 Study Area

The study sites (Fig. 1) comprise Djadema in the MoaduriMamprugu District of North East Region and Wiesi in the Builsa South District of the Upper East Region. Lonto, Sabonjida and Buntum sites are in the Kpandai District of the Northern Region of Ghana. All the sites fall within the Guinea savanna agro-ecological zone of Ghana. The dominant vegetation cover is savanna grassland and savanna woodland (closed and opened) dominated by shea butter trees (*Butyrospermumparkii*), *Anogeissus leiocarpus* and *Lophira alata* tree species. On poorly drained soils and wetlands, the most familiar tree species include *Gardenia spp, Cambretum spp*. and *Mitragynaenermis* [11].

Average annual rainfall amount ranges between 1000 - 1200 mm. Generally, rainfall starts in April, gets established in May when planting begins and ends by late October [12]. The peak of the rains is in August and September [13]. Due to the unimodal nature of rainfall, there is only one cropping season in a year except in areas where irrigation facilities are provided. Most crops produced under rainfed occur in the grassland and open savanna woodlands, in the study areas. The dominant crops on lowlands to uplands are sorghum, millet, maize, cowpea, soyabean and yams. Rice cultivation is concentrated in the valleys.

The topography within the study areas is predominantly flat with a slope of 0-2%. The flood plains are characterised by well-developed terraces, alluvial flats and levees. The primary underlying geology in the Lonto, Butum and Sabonjida sites is the Upper Voltaian rocks, which are made up of mudstones, shale, quartz sandstone, conglomerates and some limestone [14]. TheVoltaian rocks overlie Precambrian sedimentary, igneous and metamorphic rocks. Within the survey areas specifically, the mudstones and shales were evident in the soils over most areas with few outcrops of ironpan observed on the fringes of the uplands at Lonto. The Djadema and Wiesi sites' geology comprises Middle Voltaian rocks (sandstones, mudstones and shales) typically suitable for rural water supply [14]. The areas are primarily covered by flat terrain. The district's most significant river is the White Volta, and its tributaries include Sissili and the Kulpawn rivers. The parent rocks and soils derived thereof are covered by old and new alluvium and alluvia-colluvium deposits within the flat plains.

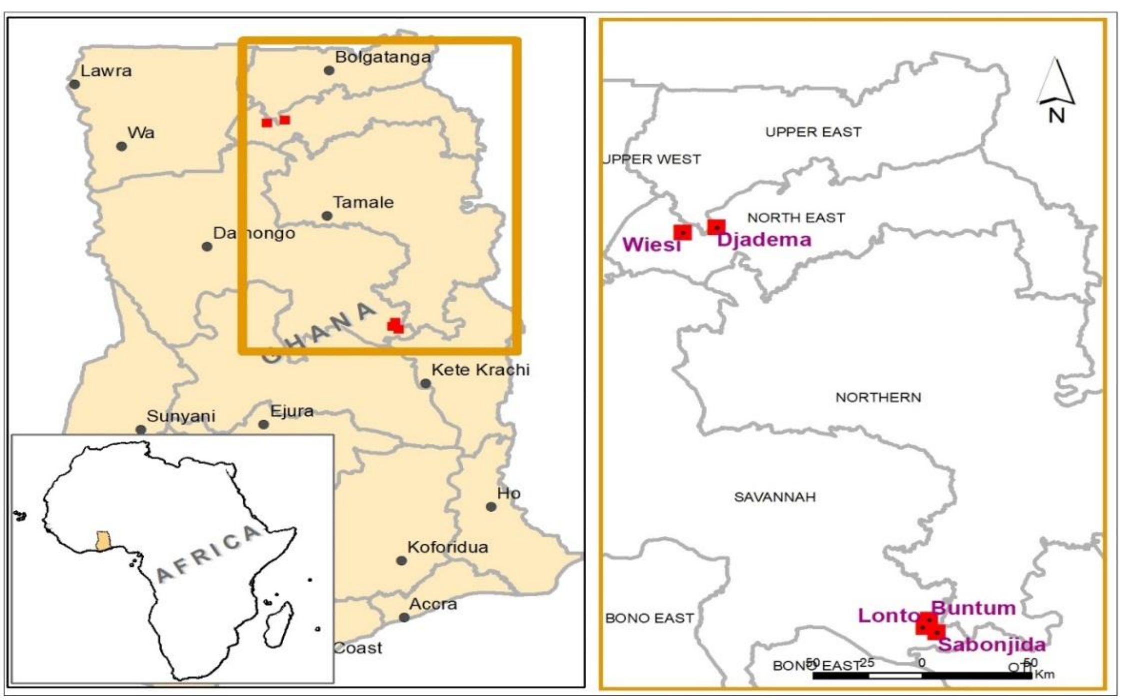

Fig. 1. Map showing study sites where samples were collected

2.1.1 Fieldwork

Base maps comprising the boundaries for each of the sites were processed in ArcMap. They were overlaid with a grid layer of 100m x 100m, and all points were geo-referenced and exported into a handheld Global Position System (GPS). The GPS was used to navigate on the field in a detailed soil survey involving auger-borings at regular intervals of 100m on each traverse line to identify individual soil types within each soil association. Soil physical characteristics such as colour, texture, structure, depth to impenetrable layer, concretions and mottles were recorded and used to provide an interim soil series identification [15]. Final soil series classification was arrived at after correlation was made to earlier survey works conducted byAdu&Asiamah [16] and Agyili [17]. The local series names were then converted to their respective FAO names [18].

Two profile pits were dug at each site, and soils were described and sampled using FAO guidelines for soil profile description [19].

2.1.2 Laboratory analysis

Soil samples that were collected from the profile pits were sent to the laboratory for analysis. The samples were air-dried, crushed and sieved to separate coarse fragments (>2 mm) from the fine fraction. The soil samples' physiochemical properties were determined using routine methods described by Allison [20] and Ibitoye [21]. Based on the soil properties determined in the field and laboratory, the soils were classified to their respective FAO/WRB [22] classification.

2.1.3 Criteria for soil suitability assessment for irrigation

The criteria for soil suitability assessment for irrigation were based on Guidelines: land evaluation for irrigated agriculture, FAO Soils Bulletin No.55 [23]. The bulletin provides 17 step-by-step guidelines for consideration to obtain a suitability assessment for irrigation. The report also provides guidelines for class determining requirements or limitations for land use requirements, land qualities and land characteristics and factor ratings to match a land utilisation type and a land unit. The suitability of the selected crops was based on the five (5) mapping units.

2.1.4 Criteria for land evaluation for the selected crop (rice)

Criteria for land evaluation for selected crops was based on the FAO methodology for land evaluation as presented in Land evaluation Part III: crops requirements by [23]. The manual provides crops and their growth and production requirements based on FAO land evaluation assessment.

Two land suitability orders, namely, Suitable (S) and Non-Suitable (N), were used to rate the soils. These were subdivided into their respective orders, thereby consisting of five main classes (Table1), indicating the degree of suitability within the suitability orders [23].

Limitations and improvements required within the classes were also factored, in arriving at a final rating (Fig. 4) for the crop (rice). Types of limitations include the w (wetness, drainage and flooding), t (topography or slope %), s (physical soil characteristics), f (soil fertility characteristics) and n (soil salinity or sodicity).

3. RESULTS AND DISCUSSION

3.1 Soil Classification

The soils were classified into mapping units with each mapping unit represented by a soil series. Eight soils were identified (Table 2). Majority of the soils were identified and classified locally as Groundwater Laterites (Plinthosols), with other significant soils involving Savannah Ochrosols (Lixisols, and Planosols) and Alluvial soils (Fluvisols). The soils along the locations' catena include *Kpelesawgu*, *Changnalili*, *Lima*, *Volta* or *Lima/Volta series* (Fig. 2).

These soils have resulted from the prevailing climatic conditions of rainfall for half the year, with the rest being arid and hot, registering practically no rains. Besides, the general gentle relief is conducive to alternating wetness and dryness, resulting in the extensive occurrence of very shallow soils overlying impenetrable ironpan (ironpan soils). Soils identified through the field survey, which were already known not to be suitable for rice, were not sampled for laboratory analysis. Those soils include *Kpelesawgu series*, *Changnalili series*, *Kasele series* and *Wenchi series* (Fig. 3).

Table1. Suitability rating based on FAO land suitability classification [24]

ID	Suitability rating	Maximum Attainable Yield	Interpretation
1	S1	80-100	Highly suitable
2	S2	60-80	Moderately suitable
3	S3	40-60	Marginally suitable
4	S4	20-40	Currently not suitable
5	S5	0-20	Permanently not suitable

Table 2. Major soils of the project areas

Soil_ID	Soil_series	FAO/WRB (2014)	FAO/WRB _code
1	*Sirru*	Albic Chromic Lixisol	LXac
2	*Lapliki*	Albic StagnicLixisol	LXas
3	*Lima*	Dystric Planosol	PLd
4	*Lima variant*	Dystric Planosol (plinthic)	PLd
5	*Kpelesawgu*	Pisoplinthic Plinthosol	PTp
6	*Wenchi*	Lithic Leptosol	LPq
7	*Changnalili*	Stagnic Plinthosol	PTs
8	*Kasele*	Plinthic Stagnosol	STp

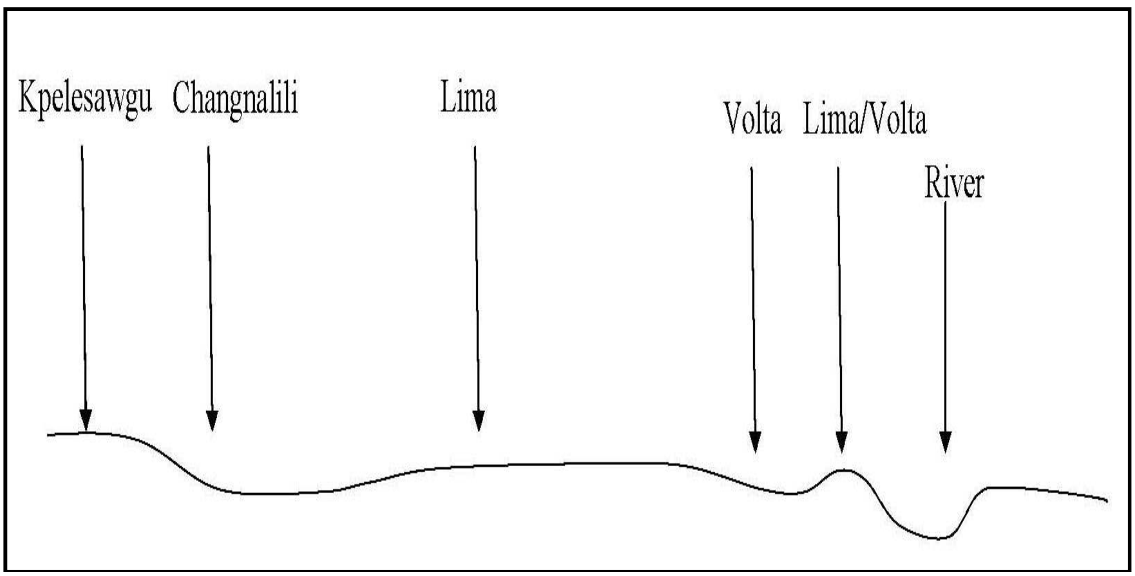

Fig. 2. A catenary arrangement of the soils in the landscape

Fig. 3. presents the soils found at the five study sites. Soils of Lonto site, developed over Voltaian shale and mudstone, comprise *Lima, Kpelesawgu, Changnalili* and *Kasele series.* Soils of Sabonjida site are developed over Voltaian shale and mudstone, and the major soils encountered were *Lima, Kpelesawgu,* and*Changnalili series.* Soils of Buntum site are developed over Voltaian shale and mudstone, and the major soils encountered were *Lima and Kpelesawgu series*. Soils of Djadema site have been developed from old alluvial deposits, and two major soil types, *Lapliki series* and its associate *Sirru series* were recorded. Soils of Wiesi site are developed over Voltaian shale and mudstones. A large portion of the Wiesi selected site is occupied by lateritic groundwater soils, namely *Kpelesawgu series*, and its shallower version, *Changnalili series*. In areas where there has been severe sheet erosion, iron pans have been exposed to the land's surface or covered by only a thin layer of topsoil (*Wenchi series*). The rest of the area is covered by two variants of *Lima series*.

Lima series is the most extensive soil encountered in this study, especially at the Sabonjida site, covering about 92%. *Lima series* covered about 40% of the total areas and was encountered at all the locations, except for

Djadema site (Table 3). The soils are developed over Voltaian shale and mudstone. Table 4 and 5 presents some physical and chemical properties of the soils. *Lima* soil is moderately deep and imperfectly to poorly drained. The topsoil consists of about 13-50 cm depth dark greyish brown, greyish brown, dark brown or brown, silt, silty loam or silty clay loam developed from Voltaian shale and mudstones. This depth overlies alight brown or brownish-grey to strong brown, mottled olive-yellow or yellow clay or silty clay or silt loam to a depth of about 90 to 100 cm. Bulk density of the soil generally increases with depth from 0.9-1.6 g/ cm^3 in the topsoil to 1.3-1.7 g/cm^3 in the sub-soil (Table 4). Up to the depth of 90-100 cm, the soil was free of concretions and gravels. The only exception was at the soils at the Wiesi site, where the quantity of fine iron concretions increases with depth from few to common and many within the horizons. Beyond 90 to 100 cm deep, the soils sit, abruptly, on a hard, compact iron oxide concretion which forms an ironpan or a petro-plinthic layer.

The pH values of *Lima series* (Table 5) generally indicated strongly to a medium acid condition in both top and subsoils. The soils have very low electrical conductivity throughout the profiles indicating the soils are non-saline. Total N and OC levels were also very low throughout the entire profiles. Available P and K levels were also low and very low, respectively, in all the *Lima* soils. Exchangeable cations, namely Ca, Mg, and K levels were generally low whiles exchangeable Na was moderate in all the horizons. Therefore, levels of eCEC, which is a derivative of the exchangeable cations and acidity, were very low. However, ESP levels were below the minimum threshold value of 15% in all horizons (Table 5), which indicates that the soils are currently non-sodic.

At the Wiesi site, a variant of *Lima series* was encountered. In this *Lima series*, the topsoil overlay directly on a parked iron concretion embedded in a sandy clay loam layer of thickness ranging from 8-14 cm. In turn, this layer overlies a clay layer (Table 4) up to a depth of over 120 cm from the topsoil. Bulk density recorded 1.4 g/cm^3 in the topsoil to 1.5 g/cm^3 in the subsoil (Table 5). The pH was medium acid throughout the profile. EC levels were very low in all the horizons, implying that the soil was non-saline. Total N and OC levels were very low in all the horizons. Available P and K levels in all horizons were below the minimum threshold values, implying they were very low. All exchangeable cations (Ca, Mg, and K), except Na, were very low in all horizons. Exchangeable Na was medium in all horizons. Exchangeable sodium percentage level showed an increasing level with depth such that the last horizon recorded value above the minimum threshold level, implying a sodic condition. The levels of eCEC fell far below minimum threshold values implying they were very low.

Kpelesawgu soils are classified as groundwater laterites developed from mudstones and shales. The soils appeared in all the sites, except Djadema site. They were dominant at the Sabonjida site, covering about 32% of the proposed project's land size. The series was moderately deep and consists of imperfectly drained, pale brown/yellowish-brown, porous, very fine sandy loam or silty clay topsoil, usually less than 30 cm thick, overlying ferruginous gravelly clay or hard ironpan. The layer may overly a brown, silty clay with strong brown to reddish-yellow mottles up to a depth of 45 to 60 cm which in turn overlies a ferruginous gravelly clay or hard ironpan. Depth of soil to pan or rock varies from 50-80 cm. Subsurface colours may vary from light yellowish-brown to light grey. Surface textures range from loamy sand to the subsoil textures which may vary from loam to clay loam.

Table 3. Soils identified and their respective coverages in hectares and percentages

ID	Soils	Selected Project Site					Total
		Lonto	Sabonjida	Buntum	Djadema	Wiesi	
1	*Lima series*	96 (47%)	59 (51%)	139 (92%)		15 (9%)	309 (40%)
2	*Lima-variant*					25 (16%)	25 (3%)
3	*Sirru*				31 (20%)		31 (4%)
4	*Lapliki*				122 (80%)		122 (16%)
5	*Kpelesawgu*	14 (7%)	32 (28%)	12 (%)		8 (5%)	65 (8%)
6	*Changnalili*	48 (23%)	24 (21%)			76 (48)	148 (19%)
7	*Kasele*	48 (23%)					48 (6%)
8	*Wenchi*					35 (22)	35 (4%)
Total		205	115	151	153	158	781

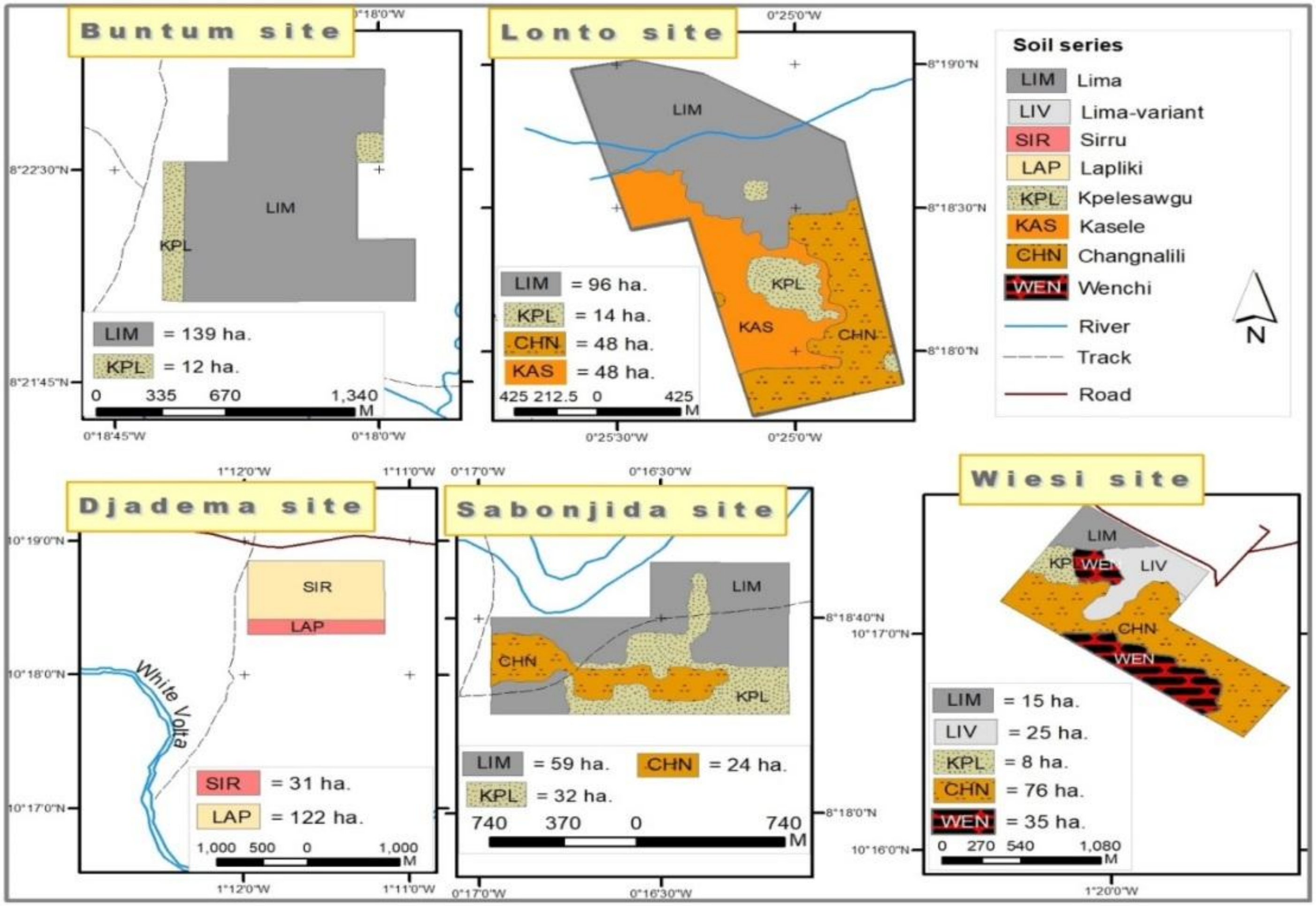

Fig. 3. Soil map of the selected sites

Table 4. Summary of some physical properties of soils

Soil series	Effective soil depth	Texture		Coarse fragments (>2mm)(%)		Drainage	Porosity (Topsoil)	BD (g/cm3)
		Topsoil	Subsoil	Topsoil	Subsoil			
Lima	MD	Si/SiL/SiC/CL	SiL/SiC/C	2-5	5-10	I/P	48-54	0.9-1.7
Lima-variant	D	L	SCL/C	0-2	18-59	I/P	47	1.4-1.5
Sirru	D	L/CL	SiC/C	0-2	0-2	MW	-	1.0-1.2
Lapliki	D	SiL/SiCL	SiC/SiL	0-2	0-2	I	54-60	1.1-1.3
Kpelesawgu	MD	fSL/SL/SiCL/SiC	CL/SCL/SiC	5-10	10-20	P	-	1.1
Changnalili	VS	fSL/SL	CL/SCL	5-10	10-20	P	-	-
Kasele	S	fSL	fSL	5	>20	P	-	-
Wenchi	VS	L/CL	SiC/C	0-2	0-2	-	-	-

D=deep; MD=moderately deep; VS=very shallow, S = shallow, C=clay; fSL=fine sandy loam; SCL=sandy clay loam; CL=clay loam; Si = Silt; Sil = silty loam; SiC = silty clay; SiCL = silty clay loam; CL = clay loam; P-poorly drained; I/P= imperfect to poor

Table 5. Summary of some chemical properties of topsoil

Soil series	Total N (%)	Available p (mg/kg)	Available K (mg/kg)	eCEC - (cmol(+)/kg soil)	pH	EC (dS/m)	OC (%)	BS (%)	ESP (%)
Lima	0.03-0.06	1.41-12.42	5.29-36.80	2.67-6.2	5.9-6.1	0.02-008	0.32-0.71	96-98	4.9-14.7
Lima-variant	0.02	7.74-10.11	11.96-38.64	6.3	5.9	0.37	0.25	98	5.8
Sirru	0.04-0.04	9.42-16.67	18.48-112.7	4.62-7.49	5.4	0.07	0.46	96	8.2
Lapliki	0.03-0.05	4.25-8.65	32.66-56.12	5.15	5.5	0.18	0.59	95	6.4
Kpelesawgu	0.04	7.82-8.11	12.12-24.51	4.5-5.5	5.7-6.2	0.03-0.15	0.33-0.84	94-97	6.5-13.4
Changnalili	-	-	-	-	-	-	-	-	-
Kasele	-	-	-	-	-	-	-	-	-
Wenchi	-	-	-	-	-	-	-	-	-

Sirru series was identified at only Djadema site, which covered about 20% (31 ha.) of soils of the site (Table 3). This soil type occurs on the higher terrace and is developed from old alluvial materials. The soils are deep (>100 cm), moderately to well-drained and are gravel free, except some few soft iron and manganese dioxide concretions mostly at lower depths. *Sirru series* consists of dark brown to dark greyish brown topsoil to a depth of about 10 cm with silty loam or fine sandy loam texture. This layer overlies a light olive-brown to greyish-brown clay or clay loam or loamy sand up to a depth of about 130 cm (Table 4). The subsoil contains common to many brownish yellow and dark red mottles. Like *Lima series*, the pH values of *Sirru series* generally indicated strongly to a medium acid condition in both top and subsoils (Table 5). The soils had very low EC levels throughout the profiles indicating the soils were non-saline. As the rest of the analysed parameters were all on the low side, the eCEC was very low. However, ESP levels were below the minimum threshold value of 15% in all horizons, which indicates that the soils are currently non-sodic.

Lapliki series is the lower slope associate of *Sirru series*, and it is differentiated from it by being less well or imperfectly drained (Table 4). It was dominant at Djadema site and was made up of 80% (122 ha.). Just like *Sirru series*, they are developed from old alluvial materials. The soils are deep (>120 cm) and are also free from gravel and stones. They have very dark greyish brown or dark brown with a silty clay loam or silty loam topsoil of about 10 cm deep. Below this depth up to 120 cm or more is a light brownish-grey or grey grading down to brown silty clay or clay with common fine brown mottles. This depth contains common soft iron and manganese dioxide concretions. Bulk density is moderate throughout the profile ranging from 1.05 to 1.33 g/cm^3. The Topsoil pH is strongly acidic (Table 5), and this increases gradually with depth to moderate acidic condition. EC levels in all horizons were very low, an indication that the soils are currently non-saline. Total N and OC levels were also very low throughout the profiles. Both Available P and K levels were also very low in all the horizons. All the Exchangeable cations (Ca, Mg, K) were low in all the horizons except Na. Exchangeable Na levels were generally moderate, accounting for low ESP that was generally below the minimum threshold value for a sodic condition. Levels of eCEC were very low in all the horizons.

Kasele series was recorded at Lonto site only, covering about 23% of the site with 48 ha. The soils have been developed from mudstone and shale along the fringes of valleys. They are shallow and poorly drained soils. The soil consists of about 10 cm (Table 4) of dark brown, fine sandy clay loam that overlies about 30 cm of massive, yellowish-brown silty clay loam with common iron and manganese dioxide concretions. Decomposing clay shales occur below 50 cm depth.

Iron-pan availability characterises *Wenchi series* at less than 10 cm from the surface, making it a very shallow soil (Table 4). Where erosion is severe, all the topsoils have been washed away, exposing the hard iron pan onto the surface. The soil may occur under any geological formation, mostly on low lying undulating lands. The surveyed area at Wiesi site accounts for about 22% of the total selected area.

3.1.1 Biophysical evaluation

Evaluation of the land (soil) units is based on major land/soil characteristics derived from the soil investigations. These are soil depth, texture, drainage, gravel content, slope and fertility/nutrient level based on Sys et al. model [24]. The requirements are presented in Table 6. The selected crops' suitability was based on the five (5) mapping units presented in Table 1.

Tables 7 and 8 give the suitability rating results after 'matching' growth and production requirements for irrigated rice against soil physical and chemical characteristics of the five (5) sites using the simple limitation method [25]. Table 7 shows ratings based on the current physical and chemical status of the soils. On the other hand, Table 8 and Fig. 4. show the potential ratings after possible amendments (i.e., final suitability rating after corrections to some of the limitation) are done on the soils.

Table 7 shows that *Lima* and *Lima-variant* soils rated marginally suitable (S3) in all the locations (Lonto, Sabonjida, Buntum and Wiesi). The soils were limited in physical soil characteristics (s) as the topsoils were lighter in texture. They were also limited in soil fertility characteristics (f) as almost the fertility parameters in terms of Total N, Available P and K, and OC were all low. If these fertility limitations are corrected with fertiliser application and good farming management practices maintained, the rating will improve to moderately suitable (S2s) as shown in Table 8. The physical limitations related to texture will be difficult to improve over a limited period. *Sirru* and *Lapliki* soils' limitations relate only to their fertility and therefore rated S1 for irrigated rice at their current and after their fertility amendments. *Kpelesawgu* soils rated S3 with sfw limitations (wetness, drainage and flooding). It can, however, be managed well enough to be rated S2s after amendments. *Changnalili*, *Kasele* and *Wenchi* soils rated *Not Suitable* for irrigated rice, before and after amendments, due to their physical and fertility status. Their strong plinthic to petroplinthic horizon close to the soils' surface is a substantial obstacle to successful rice production.

The soils of the five study sites at the Northern zone of Ghana, which were studied in this paper, included ferruginous soils formed from Volta shale deposits [26]. These geological deposits are highly weathered, have high Fe_2O_3 and Al_2O_3 contents, with their mineralogy being dominated by quartz and low activity clays, kaolinite, with low eCEC [26]. According to [24], common deficiencies of basic cations in topsoils within the Northern zone of Ghana is due to annual deposition of dust from the Sahara, carried by the Harmattan weather system. The assertion is confirmed by this study's results, which recorded low exchangeable or basic cations of Ca, Mg and K, except Na. According to [26], the general low basic cations could account for the low eCEC in Volta shale soils.

The general fertility of the soils, as consistent of most parts of the country, was low. However, the results reveal relatively better physical properties in the soils of *Lima*, *Lapliki* and *Sirru*. *Kpelesawgu* soils present marginal ratings as the depth of 40-60cm to the pan can limit rice production. [27] studied *Kpelesawgu*, *Wenchi* and *Changnalili*, among two other soils within the same Guinea Savannah agro-ecological zone. They concluded that these ironpan soils differed in their capacity to adsorb added inorganic phosphorus. Although this cannot explain the various soils' adsorption characteristics, the low levels of soil nutrients conform to studies on similar soils within Ghana's Northern zone. The low fertility level of soils of the northern part of Ghana has been documented since 1961 by Adu and others [28].

Based on soil and landscape assessment results, it can be inferred that mechanised tillage could be done on *Lima*, *Lapiliki*, *Sirru* soils, whereas *Kpelesawgu Wenchi*, *Changnalili* and *Kasele* soils are shallow to very shallow to be mechanically tilled. It is consistent with [29] findings where similar *Kpelesawgu* soils were shallow for mechanised farming. Shallow plinthic soils have been found to cause rapid ploughshare wear in the Northern zone of Ghana, thereby increasing the tillage cost to farmers. This information is valuable to guide farmers' decisions on their farms' specific locations and related crop type to adopt. This work has provided detailed information to data gaps in Ghana's soil database, especially in the Lonto, Sabonjida, and Buntum sites and its environs.

Sirru, *Lapliki*, *Lima* and its variant and *Kpelesawgu* soils were found to be suitable to moderately suitable for rice cultivation. [29] studied *Lapliki series* and soils on the old levees of the Volta and Nasia rivers and evaluated the soils to be highly suitable for rice cultivation, under irrigation. It presents various farming households in the sites the opportunity to increase their plot holdings for rice. The average plot holdings for rice cultivation ranged from one to four at the time of the survey. On the other hand, *Changnalili*, *Kasele* and *Wenchi* soils rated not suitable for rice cultivation and must be excluded [30]. The most affected places included Lonto site (41%) and Djadema site (60%).

These plinthite soils are gradually becoming extensive in the drier regions of the tropics [31,32], and the Northern zone of Ghana, which includes the study sites are no exception. Climate change factors like elevated temperature regimes and abundant precipitation mobilise and accelerate the weathering of iron oxides. Soil pH and mineralogy are additional factors that could also promote plinthite formation. However, the formation of plinthite is promoted speedily by management practices [14]. Given this, any farming and soil management practices that would predispose the soils of the study sites to soil erosion should be avoided to prevent plinthization [14].

Table 6. Landscape and soil requirements [25]

Land Characterisation	**Class, degree of limitation and rating scale**					
	S1		**S2**	**S3**	**N1**	**N2**
	100	**95 1**	**85 2**	**60 3**	**40 4**	**25 0**
Topography (t)						
Slope (%)	0	< 1	1-2	2-4	-	> 4
Drainage	imperfect	moderate	Poor	Very poor	-	-
Physical soil						
Characteristics (s)						
Texture/structure (*)	Cm,SiCm, c+60v,c+60s,	C-60v, C-60s,SiCs,	Co,SiCL, CL,Si	SiL,SC,	-	L and Lighter
(**)	Cm,SiCm, c+60v,c+60s,	C-60v, C-60s,SiCs, Co,SiCL,CL,Si	SiL,SC, L,SCL	SL,LfS,LS, LcS,fS		S,cS
Coarse fragm. (vol %)	0	< 3	3-15	15-35	-	> 35
Soil depth (cm)	> 90	90-75	75-50	50-20	-	< 20
Soil fertility						
Characteristics (f)						
Apparent CEC	> 24	24-16	< 16 (-)	< 16 (+)	-	-
(cmol (+)/Kg clay)						
Base saturation (%)	> 80	80-50	50-35	35-20	<20	-
(cmol (+)/Kg soil	>6.5	6.5-4	4-2.8	2.8-1.6	<1.6	-
pH H_2O	6.5-6.0	6.0-5.5	5.5-5.0	5.0-4.5	< 4.5	-
	6.5-7.0	7.0-8.2	8.2-8.5	8.5-9.0	-	> 9.0
Alkalinity (n)						
Ece (dS/m)	0-1	1-2	2-4	4-6	6-12	> 12
ESP (%)	0-10	10-20	20-30	30-40	-	> 40

This study is significant as it is likely to help improve the per capita rice yield of rice and consequently reduce food insecurity and poverty levels of households in the study sites. Women, immensely, would benefit from any proposed rice project at the study sites as majority of them are usually involved in the production chain of rice [32-36,9]. The national average yield for valley rice cultivation is 4.5Mt (90 bags)/Ha at 50kg per bag [37-38]. Proposed rice projects are likely to increase the percentage of rice bags from approximately 100 to 230% in the study sites of Lonto, Sabonjida, Djadema, Buntum, and Wiesi, based on the inherent properties of the soils and other factors.

The slightly acid to the soils' moderate acid condition will require liming, if possible, to raise the pH above 6.5, to permit the growth of a wide range of crops, including rice. Application of organic or inorganic fertiliser to raise the nutrient status of the soil is a must. Urea, Rock phosphate and single or triple superphosphate may be used, together with other compound fertilisers, to support rice cultivation in these areas. Sulphate of Ammonia may further increase the acidity of the soils and must be avoided. Moreover, integrated soil fertility management methods and the adoption of sustainable and improved rice production technologies should be encouraged to conserve soil moisture and nutrients [39]. For example, the "Sawah" system [39] can be adopted as it is intrinsic and conservatively can help improve and maintain nutrient levels within the Northern zone environments to enhance crop yield sustainability. The "Sawah" concept involves improved rice fields with demarcated, bunded, levelled, and puddle rice fields with water inlets and outlets connected to various irrigation facilities such as canals, ponds, weirs, springs, dug-outs or pumps. Site-specific nutrient and water management options are, therefore recommended.

Table 7. Suitability ratings for Irrigated Rice (at current state)

Soil series	Suitability class with limitations				
	Lonto Site	Sabonjida	Buntum	Djadema	Wiesi
Lima	S3sf	S3sf	S3fw	-	S3sf
Lima-variant	-	-	-	-	S3sf
Sirru	-	-	-	S3f	-
Lapiliki	-	-	-	S3f	-
Kpelesawgu	S3sfw	S3sfw	S3sfw	-	S3sf
Changnalili	N1sfw	N1sfw	-	-	N1sf
Kasele	N1sfw	-	-	-	-
Wenchi	-	-	-	-	N1sf

Suitability Class: S1=Highly suitable, S2=Moderately suitable, S3=Marginallysuitable, N1=Currently not suitable and N2=Permanently not suitable
Limitations: w =wetness, drainage and flooding, t =topography or slope %, s =physical soil characteristics, f =soil fertility characteristics and n =soil salinity or sodicity

Table 8. Final suitability rating after an amendment to soils

Soil series	Suitability class with limitations				
	Lonto Site	Sabonjida	Buntum	Djadema	Wiesi
Lima	S2s	S2s	S2w	-	S2s
Lima variant	-	S2s	-	-	S3s
Sirru	-	-	-	S1	-
Lapiliki	-	-	-	S1	-
Kpelesawgu	S2sw	S2sw	S2sw	-	S2s
Changnalili	N1sw	N1sw	-	-	N1s
Kasele	N1sw	-	-	-	-
Wenchi	-	-	-	-	N1s

Suitability Class: S1= Highly suitable, S2=Moderately suitable, S3=Marginally suitable, N1=Currently not suitable and N2=Permanently not suitable
Limitations: w =wetness, drainage and flooding, t =topography or slope %, s =physical soil characteristics, f =soil fertility characteristics and n =soil salinity or sodicity

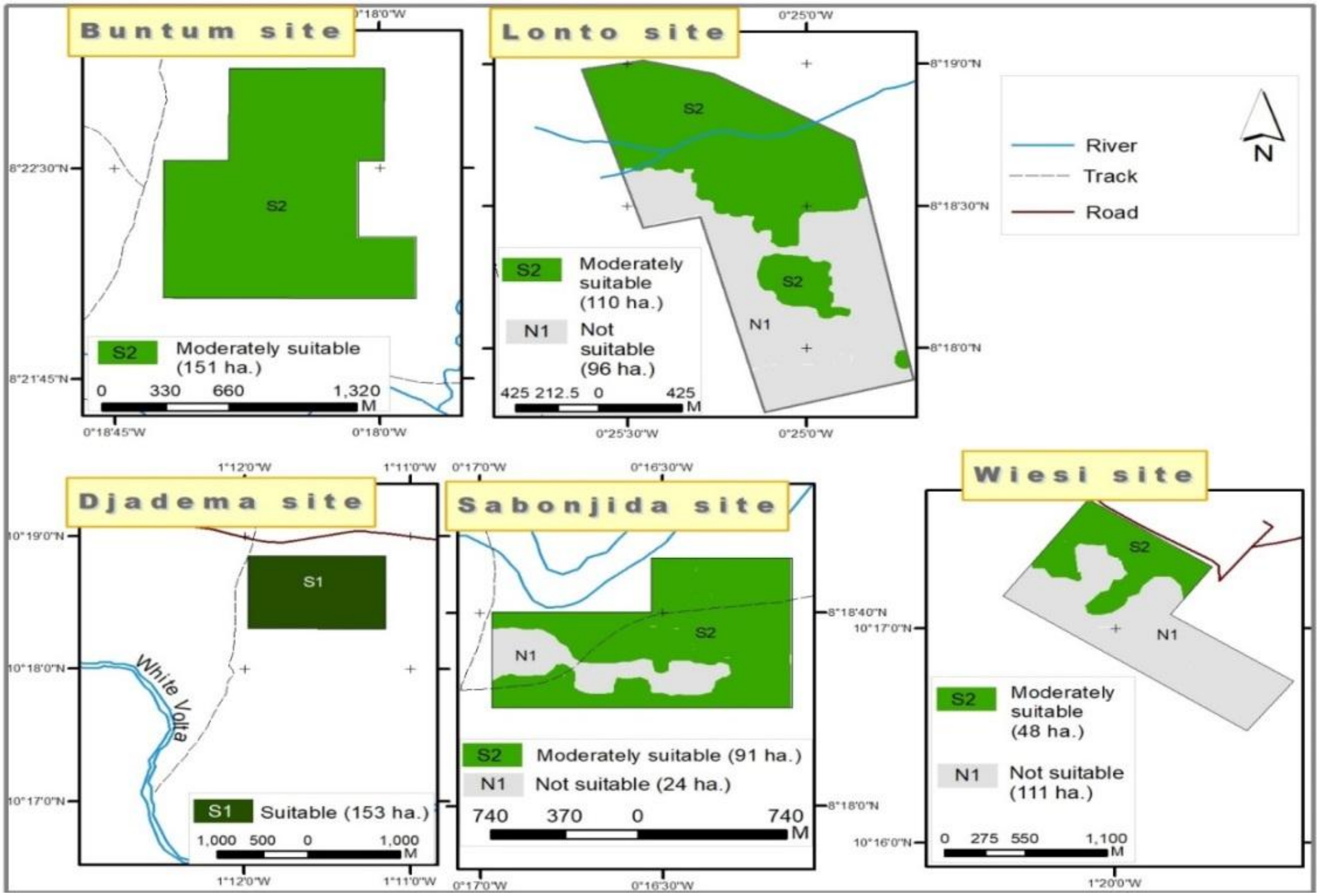

Fig. 4. Potential soil suitability ratings for rice

4. CONCLUSION

The landscape configuration of the five study sites (Lonto, Sabonjida, Djadema, Buntum and Wiesi) in the Northern zone of Ghana were relatively flat to gently undulating. The relatively upland soils comprised of *Sirru series* and *Lapliki series*. The lowland soils included *Lima series* and its variant, *Kpelesawgu series*, *Wenchi series*, *Changnalili series* and *Kasele series*. Generally, the physical properties of the soils involved medium to heavy textures in the top and subsoils. Therefore, the soil texture will permit slow infiltration of water, thereby retaining water in the soil for more extended periods, which is ideal for rice cultivation. The soils were non-saline and non-sodic, meaning that crop yield would not be affected by these two soil qualities. Data from the soil chemical analysis indicate that the soils were low in the basic nutrients, such as Total N, OC, Available P, and K.The low OC levels translate into low OM content. Coupled with low activity clay (kaolinitic clay) of the soils) reflect in the low levels of basic cations and hence low levels of effective cation exchange capacity. These levels imply a low soil fertility level in all the five proposed sites. *Sirru*, *Lapliki*, *Lima* and its variant and *Kpelesawgu* soils were evaluated to be potentially suitable to moderately suitable for irrigated rice production. Groundwater lateritic soils of *Changnalili*, *Kasele* and *Wenchi* soils were currently and potentially evaluated to be not suitable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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