Assessment of the Irrigation Potential of Ampidong Crater Lake, Soil Characteristics, and their Effects on the Irish Potato Value Chain in Ampang West District, Mangu Local Government Area, Plateau State, Nigeria

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ABSTRACT

Agriculture remains one of the most important sectors of the Nigerian economy, providing livelihoods for a large proportion of the rural population while contributing significantly to national food security and economic development. However, agricultural productivity in many parts of the country is constrained by seasonal rainfall variability, climate change, declining soil fertility, and inadequate irrigation infrastructure. Ampidong Crater Lake, located in Ampang West District of Mangu LGA, represents an important natural freshwater resource with considerable potential for agricultural development. This study aimed to assess the irrigation potential of the lake, evaluate soil characteristics, and determine their effects on the Irish potato value chain in Ampang West District of Mangu Local Government Area, Plateau State, Nigeria. The study adopted an integrated multidisciplinary research design combining hydrological assessment, soil quality assessment, irrigation suitability analysis, agricultural survey, value chain analysis, Geographic Information Systems (GIS) and Remote Sensing. Soil pH, texture, organic carbon, nitrogen, phosphorus, potassium, and derived fertility indices were mapped and their spatial patterns compared with irrigation suitability across the study area. Based on the total mappable area and a documented regional yield-potential benchmark, full irrigated development of the 62.32 km^2 area of study could theoretically exceed 120,000 metric tonnes annually, provided irrigation infrastructure, certified seed, and other production inputs are secured; this figure is a planning-level projection rather than a measured yield, and is presented alongside the assumptions from which it was derived.

Keywords: Irish Potato, Soil Characteristics, irrigation Potential, Ampidong Crater Lake, GIS, Remote Sensing

INTRODUCTION

Agriculture remains one of the most important sectors of the Nigerian economy, providing livelihoods for a large proportion of the rural population while contributing significantly to national food security and economic development. However, agricultural productivity in many parts of the country is constrained by seasonal rainfall variability, climate change, declining soil fertility, and inadequate irrigation infrastructure. These challenges are particularly evident in the northern and central regions of Nigeria, where crop production is highly dependent on rainfall. The development and sustainable management of alternative water resources for irrigation therefore remain critical to improving agricultural productivity and strengthening rural livelihoods.

Plateau State occupies a unique position in Nigeria's agricultural landscape because of its cool climate, fertile volcanic soils, and favorable environmental conditions for the cultivation of temperate crops, particularly Irish potato (Solanum tuberosum L.). The state contributes a substantial proportion of Nigeria's annual Irish potato production, with Mangu Local Government Area serving as one of the principal production zones. Irish potato is both an important food crop and a major source of income for farming households, supporting a value chain that includes input suppliers, producers, transporters, processors, wholesalers, retailers, and consumers.

Despite its strategic importance, Irish potato production continues to experience significant constraints arising from unreliable rainfall, prolonged dry seasons, declining soil fertility, soil erosion, and limited access to irrigation facilities. These factors often result in reduced yields, unstable market supply, and income losses for farmers. Sustainable irrigation, coupled with appropriate soil management, offers considerable potential for improving productivity, extending the growing season, and stabilizing the potato value chain.

Ampidong Crater Lake, located in Ampang West District of Mangu LGA, represents an important natural freshwater resource with considerable potential for agricultural development. Formed through ancient volcanic activity characteristic of the Jos Plateau, the lake is perennial and has long served surrounding communities for domestic use, livestock watering, fishing, and small-scale irrigation. Equally important is the role of soil in determining irrigation efficiency and crop productivity. Soil physical properties such as texture, structure, porosity, and water-holding capacity influence water infiltration and availability to crops, while chemical properties including pH, organic matter, nutrient status, cation exchange capacity, and salinity directly affect Irish potato growth and tuber quality. Understanding the interaction between irrigation water and soil characteristics is therefore essential for developing sustainable irrigation systems that maximize agricultural productivity while minimizing environmental degradation.

The Irish potato value chain encompasses all activities involved in the production, harvesting, storage, transportation, processing, marketing, and consumption of potatoes. Productivity at each stage of the value chain depends largely on reliable water supply, soil quality, infrastructure, and market access. Improvements in irrigation supported by favorable soil conditions can increase yields, enhance tuber quality, reduce seasonal production fluctuations, improve market supply, create employment opportunities, and increase farmers' incomes. Conversely, poor water management and degraded soils may lead to declining productivity, increased production costs, and reduced competitiveness within the value chain.

The aim of this study is to assess the irrigation potential of Ampidong Crater Lake, evaluate soil characteristics, and determine their effects on the Irish potato value chain in Ampang West District of Mangu Local Government Area, Plateau State, Nigeria. This will be accomplished by achieving specific objectives which include: determining the physical and chemical characteristics of agricultural soils within the study area, assessing the hydrological characteristics and irrigation potential of Ampidong Crater Lake, assessing the current utilization of Ampidong Crater Lake for irrigation by Irish potato farmers and recommending sustainable irrigation and soil management strategies for improving the Irish potato value chain in the study area.

Study Area

The study was conducted at Ampidong Crater Lake and its surrounding Irish potato farming communities in Ampang West District, Mangu Local Government Area (LGA), Plateau State, Nigeria. Mangu LGA lies within the Jos Plateau, an area characterized by volcanic geology, undulating topography, and elevations ranging from approximately 1,200 to 1,400 m above sea level. The area experiences a tropical highland climate with annual rainfall of about 1,200–1,500 mm, concentrated between April and October, and mean annual temperatures of 18–25°C. These climatic conditions are favorable for Irish potato cultivation.

The geology is dominated by the Younger Granite Complex and volcanic formations, resulting in soils that are generally fertile but susceptible to nutrient depletion under continuous cultivation. Ampidong Crater Lake is a perennial freshwater lake of volcanic origin which lies 9º12′11.421″E, 9º17′29.9592″N and serves as a potential source of irrigation water for surrounding agricultural lands.

A 5-kilometer (5000 m) buffer was used to identify an area around the lake as an area of interest for this study (Figure 1). The area lies between 9º9′26.017″E, 9º14′46.2″N and 9º14′57.367″E, 9º20′13.722″N.

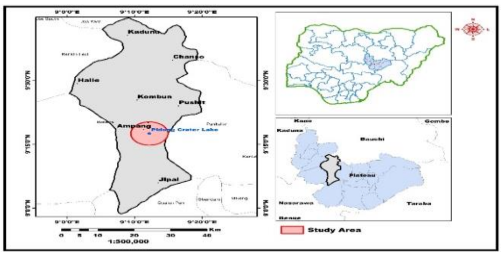

Figure 1: Map Showing Mangu L.G.A. and the Study Area (left) and Picture of Ampidong Crater Lake (right)

MATERIALS AND METHODS

The study adopted an integrated multidisciplinary research design combining: Hydrological assessment, Soil quality assessment, Irrigation suitability analysis, Agricultural survey, Value chain analysis, Geographic Information Systems (GIS) and Remote Sensing. Both quantitative and qualitative approaches will be employed.

Materials

Sources of Data

Primary Data: Soil samples, GPS coordinates, Key Informant Interviews (KIIs), Focus Group Discussions (FGDs), Field observations.

Secondary Data: Lake water sample data, Rainfall records, Geological maps, Soil maps, Topographic maps, Landsat 8/9 and Sentinel-2 satellite imagery, Digital Elevation Model (DEM), Meteorological records, Agricultural production statistics, Literature from FAO, UNESCO, National Bureau of Statistics (NBS), and Plateau Agricultural Development Programme (PADP).

Other materials include, Global positioning system (GPS) receivers, soil Auger, plastic buckets, polythene bags, hand trowels, permanent marker, masking tape, hardcover notebooks, and pens.

Methods

Soil Sampling

Composite soil samples were collected from fields within the 62.32 km² area of interest (AOI) at a depth of 0–30 cm, following a grid-based sampling design intended to give even spatial coverage of the buffer zone around Ampidong Crater Lake. Each sampling point was geo-referenced using a handheld GPS receiver. At each point, sub-samples were bulked into a single composite sample, air-dried, and sieved (2 mm) prior to laboratory analysis. Physical and chemical properties, particle-size/texture (hydrometer method), soil pH (1:1 soil–water suspension), organic carbon (Walkley–Black wet-oxidation method), organic matter, total nitrogen (micro-Kjeldahl digestion), available phosphorus (Bray-2 method), exchangeable potassium, calcium, magnesium and sodium (1 N ammonium acetate extraction, read by flame photometer/atomic absorption spectrophotometer), cation exchange capacity (CEC), base saturation, and electrical conductivity, were determined at the Centre for Dryland Agriculture, Bayero University, Kano, following standard laboratory procedures. Point-based laboratory results were interpolated across the AOI using Inverse Distance Weighted (IDW) interpolation in a GIS environment; the resulting continuous surfaces were classified into fertility classes using a natural-breaks (Jenks) classification, which is why the class boundaries reported in Tables 1–8 do not fall on round numbers.

Water Sampling and Hydrological Assessment

Several physical and chemical parameters were required for an assessment of water quality and irrigation capacity of the Lake. Physical parameters like temperature, turbidity, Total Dissolved Solids (TDS), Electrical Conductivity (EC) and corresponding chemical characteristics such as pH, dissolved oxygen, biological oxygen demand, calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate, phosphate, Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were obtained as secondary data from previous hydrogeochemical research on the lake, principally Longpia and Lar (2021), whose field measurements span the period 2014–2016**.** The lake surface area and perimeter were generated from satellite images (Landsat 8 and 9, Sentinel-2 and Google Earth Pro), while the lake depth and water-level fluctuations were obtained, as secondary data, from bathymetric studies reported in Patterson (1986) and Longpia (2021).

Storage capacity was calculated as the product of surface area and mean depth. Because the water-quality and bathymetric datasets used here are secondary and were collected up to a decade or more before this study, and because the surface-area figure (6,219 m²) is very small relative to the 62.32 km² AOI, these values should be treated as indicative rather than current or exhaustive; a contemporary bathymetric and water-quality survey of the lake is recommended to validate the storage-capacity and irrigation-supply estimates used in this study (see Limitations of the Study).

GIS and Remote Sensing Analysis

Satellite datasets that were required for this study include Sentinel II, Landsat 8 and 9, SRTM DEM and Google Earth Pro. The GIS analyses employed include Land use/land cover classification, Inverse Distance Weighted (IDW) analysis, Soil spatial variability mapping, Raster Mathematics (for generating Fertility Ratios) etc. Software used include ArcGIS 10.8, QGIS, ENVI and Google Earth Engine.

Irish Potato Value Chain Assessment

Key Informant Interviews (KIIs), Focus Group Discussions (FGDs) and field observations provided valuable information about the production (average farm size, expected yield, Irrigation practice and farm Inputs), post-harvest practices (storage methods, losses, transportation, marketing, selling price and other market channels) and value addition (income, production cost, gross margin and profitability) of Irish potato within the AOI.

Irrigation Water-Demand and Yield-Potential Estimation

The production-potential figure reported in this study (see Recommendations) was derived as follows: the total mapped AOI (62.32 km², equivalent to 6,232 ha) was multiplied by a documented regional yield-potential benchmark of 2,000 tonnes/km² (200 t/ha) that the Plateau State Government and Sahel Consulting have targeted for the Jos Plateau through certified-seed multiplication and improved agronomic practice. This gives 62.32 km² × 2,000 tonnes/km² ≈ 124,640 metric tonnes, reported conservatively in this study as “over 120,000 metric tonnes.” The figure is therefore a theoretical production ceiling under full irrigated development of the mapped area, not a directly measured or forecast yield, and it rests on three explicit assumptions: (i) that the entire 62.32 km² AOI is brought under irrigation; (ii) that certified, disease-resistant seed and adequate agronomic inputs are available; and (iii) that the crop water requirement of Irish potato over a typical 90–120-day growing cycle (on the order of 500–700 mm of water, depending on local climate and crop-coefficient values; Allen et al., 1998, FAO Irrigation and Drainage Paper 56) can be met from the lake and/or supplementary sources. This third assumption has not yet been verified against the lake’s actual storage capacity. Using the reported surface area (6,219 m²) and depth, the resulting storage volume is on the order of tens of thousands of cubic metres, several orders of magnitude below the volume that would be required to irrigate 6,232 ha through a full growing season from lake water alone. The 120,000-metric-tonne figure should therefore be read as an area-based production target that is contingent on irrigation infrastructure combining lake water, groundwater, and rainfall harvesting, rather than as evidence that Ampidong Crater Lake alone can supply the full irrigation water demand of the AOI. A hectare-by-hectare water balance, matching crop water requirement against verified lake storage, recharge rate, and any supplementary water sources, is recommended before this projection is used for investment or infrastructure-financing decisions.

Statistical Analysis

Zonal descriptive statistics (mean, minimum, maximum, and percentage area) were computed for each soil parameter and derived fertility index from the interpolated raster surfaces using GIS zonal-statistics tools (ArcGIS 10.8/QGIS), and these are the basis of Tables 1–8. To move beyond descriptive, class-based interpretation of these spatial patterns and establish statistically defensible relationships between soil properties, irrigation conditions, and Irish potato productivity, the underlying point-level laboratory dataset (soil-test values by sample coordinate) and plot-level or farmer-reported yield data should be analysed using Pearson or Spearman rank correlation between individual soil parameters (pH, organic carbon, total N, available P, exchangeable K, Ca, Mg) and yield, together with one-way ANOVA (with post-hoc comparison) of yield across soil-texture and pH classes. Such tests, reported with sample size, test statistic, degrees of freedom, and p-value (α = 0.05), and accompanied by effect-size estimates, would allow the qualitative associations described in the Results and Discussion section to be confirmed or revised quantitatively; they are recommended as the next step in this line of research and can be incorporated once the point-level dataset is made available.

RESULTS AND DISCUSSIONS

Soil pH

The soil pH values across the study area ranged from approximately 4.0 to over 7.0, as presented in Table 1. The spatial variability in soil pH indicates that 22.19%, 31.95%, 24.76%, 13.77%, and 7.33% of the soils were classified as very strongly acidic, strongly acidic, moderately acidic, slightly acidic, and neutral, respectively (Figure 2; Table 1). The distribution of very strongly acidic soils was predominantly concentrated in the southwestern and northeastern parts of the study area. In contrast, neutral and slightly acidic soils exhibited a northwest–southeast trend and were located closer to the volcanic caldera. This pattern is likely attributable to the relatively basic nature of the lava flows and volcanic ejecta associated with the now-dormant volcano, which may have contributed to higher soil pH levels in these areas.

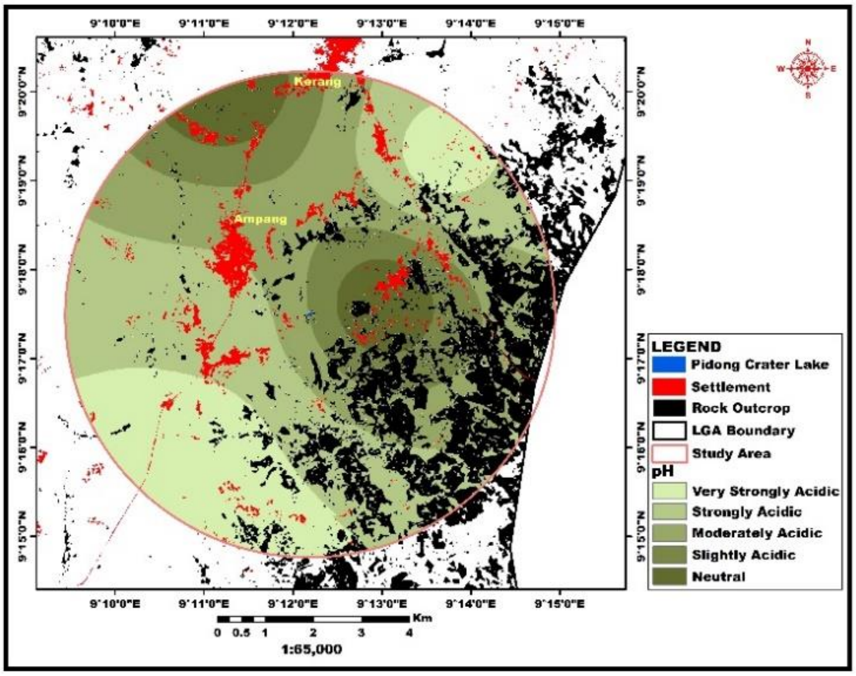

Figure 2: Map of pH Levels Around Ampidong Crater Lake

Soil acidity (pH) significantly impacts the production of crops, including Irish potatoes, as it influences nutrient availability, microbial activity, and root growth. Plants typically thrive at pH levels greater than 5.5. Soil pH of 6.5 is usually considered optimum for nutrient availability. Lower pH increases the solubility of aluminum (Al), manganese (Mn), and iron (Fe), which are toxic to plants in excess. A major consequence of excessive soluble Al is the inhibition or cessation of root growth. Additionally, low pH decreases the availability of both micro and macro nutrients to the plant. High pH reduces the availability of most micronutrients. Extreme pH values decrease the availability of most nutrients and reduce or change microbial activity. Very strongly acidic, strongly acidic and moderately acidic soils predominate the research area, as indicated in figure 2 and table 1.

The portions of the soil that are strongly acidic (Figure 2) will likely struggle to support most crops and will require liming to raise the pH and improve condition for plant growth, because soils that are strongly acidic often limit availability of essential nutrients like phosphorus, calcium, and magnesium. Toxic levels of aluminum and manganese may also be present, which can inhibit root growth and overall plant health, thereby reduce potato yields. Moderately acidic soil (pH between 5.0-5.5) coverage can still limit nutrient availability in the study area but is generally more manageable than strongly acidic soil. Potatoes can tolerate moderate acidity better than many other crops, but there could still be reduced growth and tuber size if pH correction measures (like lime application) are not taken. 19% of the map (Figure 2) that is very slightly acidic soils (pH between 6.0-6.5) are generally ideal for Irish potatoes. This pH range is optimal for nutrient availability and supports healthy root growth, leading to better yield and quality. On the other hand, neutral soils (pH 6.5-7.0) are good for potatoes, though they tend to prefer slightly acidic conditions. This part of the soil will likely perform well in supporting potato production.

The occurrence of volcanic and intrusive rocks around the study area contributes in generating acidic soils found in those areas around Kerang in Mangu LGA. These volcanics often weather to form ferruginous soils especially at the heights of the Jos Plateau. The soils in the high altitudes and higher slopes had low pH values probably suggesting the leaching out of basic cations. Mushere and Toff in Bokkos, Chakfem and Mangun in Mangu LGA are examples of this phenomenon. The Continuous application of UREA and NPK of different rates (15:15:15, 20:10:10, 0:10:10 etc.) on the same piece of land as a main source of nitrogen, phosphorus and potassium might further accelerate formation of strong acidity in soils of the study area. Although soil acidity is naturally occurring in some areas, human activity can change the pH of a soil too; cropping system or cultural practices might accelerate the process of soil acidification.

Table 1: Soil pH Variation Within the Study Area

CLASS	AREA (Km^2)	pH Level	AREA (%)
Neutral	4.57	5.678 - 7.059	7.33
Slightly Acidic	8.58	5.360 - 5.678	13.77
Moderately Acidic	15.43	5.065 - 5.360	24.76
Strongly Acidic	19.91	4.793 - 5.065	31.95
Very Strongly Acidic	13.83	4.050 - 4.793	22.19
Total	**62.32**		**100**

Soil Texture

The study area is characterized by clay, clay loam soils (Figure 3). Clay loam is the dominant soil textural class, covering approximately 86% of the total land area. These soil textures are generally well suited for agricultural production, particularly for crops such as potatoes and maize, owing to their favorable balance of drainage, aeration, and water-holding capacity.

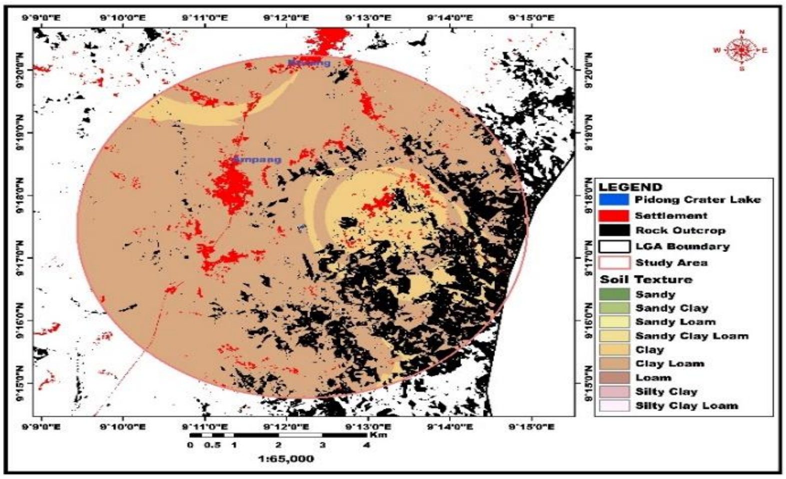

Figure 3: Soil Texture Map of the Study Area

The research area is made up of two textural classifications, the majority of which are clay loam soils (Figure 3). Clay loam accounts for 86.06% of the whole area, while clay accounts for the remaining percentage. Both soils appear suitable for agricultural crops, particularly potato and maize. The clay soils in the study area are located in an area roughly encircling the caldera of the volcano, which may be due to volcanic ash and other fine-grained ejecta that may have come to rest closer to the vent.

From study within the surrounding areas, the textural preference for Irish potato indicates that the crop does well in sandy clay, sandy clay loam, clay loam, loam textured soils. There is a notable exclusion of purely sandy soils from the vicinity of the study area. This may indicate that extremely well drained soils may not be able to host Irish potato properly. As a matter of course, soils within this area, due to parent rock influence, contain ready amounts of clay generated from the breakdown of various feldspars and other clay forming minerals contained within the various granites and vocanic rocks. This fine grained extrusive and volcanic rocks (most especially around the volcanic activities in and around Kerang, particularly around the Pidong crater lake) contribute to enriching the silt content of the soils in this location and leads to greater yield of potato per unit of hectare. Another contributing factor is the presence of volcanic ash from previous volcanic activities around Kerang, Ampang West in Mangu local government area. The soils derived from the basaltic rocks and volcanic ashes in parts of Mangu (Kerang, Ampang and Mangun) and Bokkos are extensively used for food crop productions like potatoes and maize than their granitic equivalents.

The reddish basaltic soils occur over a wide range of altitudes of about 1600m to 3000m above sea level around Kerang in Mangu LGA, (Olowolafe, 2002). Such soils are highly prolific for the production of agricultural activities in this region. This volcanic ash and other pyroclastic materials are rich in nutrient minerals in their native states. This concentration of mineral nutrients is also encouraged by the juvenile nature of soils in this area, particularly closer to the sites of the previously mentioned volcanic activities and magmatic intrusions, which still remain close to the parent rocks and still contain much of the original mineral nutrients that they did before weathering.

Table 2: Soil Texture Classes and Statistics

CLASS	**AREA (Km^2)**	**AREA (%)**
Clay	8.7	13.96
Clay Loam	53.62	86.03
Total	**62.32**	**100**

Total Nitrogen

The spatial distribution of soil nitrogen (N) in the study area ranged from very low to very high. The spatial distribution map (Figure 4) shows that soils with very low and low nitrogen levels covered 23.37% and 43.8% of the total area, respectively (Table 3). Areas with very low nitrogen concentrations were predominantly concentrated in the southwestern part of the study area, with additional occurrences in the northern part. In contrast, moderate to very high nitrogen concentrations were mainly observed in the northeastern part of the study area.

The observed spatial variability in soil nitrogen is likely associated with differences in land use, cropping intensity, organic matter content, and soil management practices across the study area. Areas with higher nitrogen concentrations may reflect greater organic matter accumulation and improved nutrient management, whereas the widespread occurrence of low nitrogen levels suggests nutrient depletion resulting from continuous cultivation, crop residue removal, and insufficient nutrient replenishment.

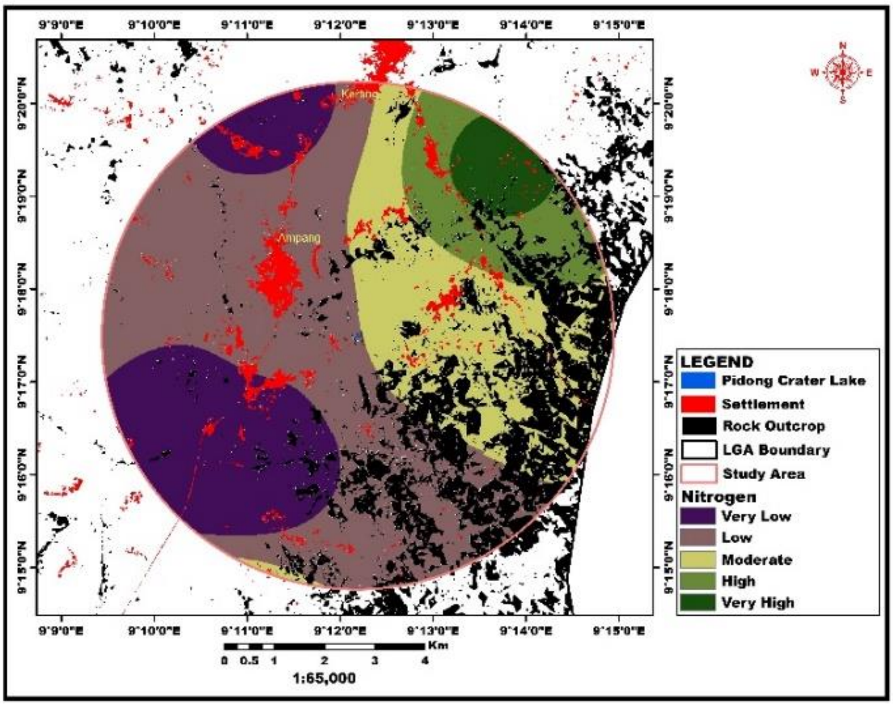

Figure 4: Map Showing Variation of Total Nitrogen (N)

Nitrogen is a critical nutrient for Irish potato production as it directly impacts vegetative growth, tuber size, and yield. The distribution of available nitrogen in the soil will significantly influence the health and productivity of potato crop. It was observed from the study that more than 65% of the total area studied is very low or low in nitrogen content. The implication is that such soil will severely limit potato growth. Several studies have shown that Nitrogen is essential for foliage development, and insufficient nitrogen can result in stunted plants with poor leaf growth, leading to reduced photosynthesis and, consequently, smaller, and fewer tubers. In these soils, potato yields will be significantly lower unless nitrogen is supplemented through fertilization.

Table 3: Variation of Total Nitrogen Levels

CLASS	**AREA (Km^2)**	**AREA (%)**
Very Low	14.56	23.37
Low	27.3	43.8
Moderate	12.36	19.84
High	5.39	8.64
Very High	2.71	4.35
Total	**62.32**	**100**

Available Phosphorus

The study revealed that the available phosphorus (P) content of the soils in the study area ranged from 3.68 to 23.24 mg kg^{-1} and was classified as very low to very high (Figure 5; Table 4). The spatial distribution map of available phosphorus (Figure 5) shows that soils with very high and high phosphorus levels predominate throughout the study area, with with moderate to very low concentrations restricted to the northern parts. In contrast, high and very high levels of available phosphorus were predominantly concentrated in the central part of the study area.

This distribution pattern reflects the relatively high availability of phosphorus in the location, which may be associated with favourable soil properties, organic matter accumulation, fertilizer application, and weathering of the parent materials. Conversely, the lower phosphorus concentrations observed in the northern part of the study area may be attributed to continuous crop uptake, phosphorus fixation, erosion, and limited nutrient replenishment.

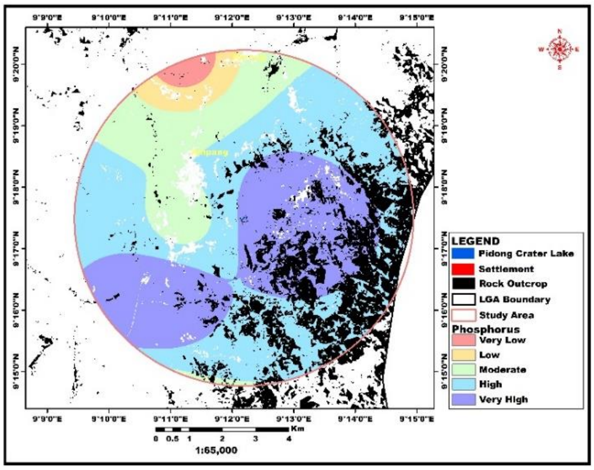

Figure 5: Map of Spatial Concentrations of Available Phosphorus (P)

Table 4: Statistics of Available Phosphorus

CLASS	AREA (Km^2)	AREA (%)
Very Low	1.07	1.71
Low	2.35	3.77
Moderate	12.02	19.29
High	27.72	44.47
Very High	19.16	30.75
Total	**62.32**	**100**

Exchangeable Potassium

The spatial distribution of available potassium (K) in the study area lies between the low and moderate concentration classes, as shown in Figure 6. Areas with moderate levels of available potassium covered 6.02 km² (9.65%) of the study area, while areas with low potassium levels occupied 56.3 km² (90.34%). This observed spatial variation in available potassium is likely influenced by differences in parent material, soil mineralogy, weathering intensity, and land management practices. Areas with moderate potassium concentrations in this area are located around the crater lake, suggesting some enrichment from the mineral rich ejecta and volcanic ash that characterize the area. Though the general results indicate that the continuous cropping of the area has led to a measure of depletion in the concentration of potassium.

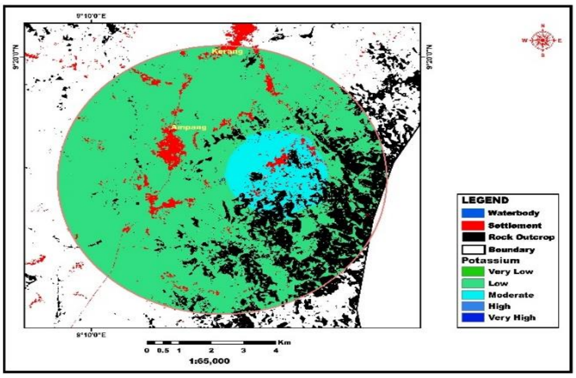

Figure 6: Spatial Variation of Exchangeable Potassium (K)

Potassium is an important nutrient for Irish potato production, affecting tuber development, water regulation, disease resistance, and overall plant health. Potatoes have relatively high potassium requirements, and the distribution of available potassium in the soil will have a direct impact on the crop's yield and quality. The spatial variation of soil potassium concentrations in the area showed that low and moderate concentrations are the only two classes in the area with the moderate potassium concentration surrounding the vicinity of the crater lake. The soil within this area may drastically reduce potato yields unless potassium is added.

Table 5: Statistics of Exchangeable Potassium

CLASS	AREA (Km^2)	AREA (%)
Low	56.3	90.34
Moderate	6.02	9.65
Total	**62.32**	**100**

Organic Carbon

The Inverse Distance Weighted (IDW) interpolation map of soil organic carbon reveals distinct spatial variability across the study area. Soil organic matter levels ranged from very low to high, with areas classified as very low, low, and moderate covering 4.34 km² (6.97%), 17.35 km² (27.84%), and 24.60 km² (39.47%) of the total study area, respectively (Figure 7; Table 6). These results indicate that low to moderate soil organic matter levels dominate much of the study area. The spatial distribution suggests that areas with relatively higher soil organic matter are likely to exhibit improved soil fertility due to enhanced nutrient retention, increased cation exchange capacity, improved soil structure, and greater water-holding capacity. Conversely, areas with low organic matter may be more susceptible to nutrient depletion and declining soil productivity, emphasizing the importance of organic matter management for sustainable agricultural production in the study area.

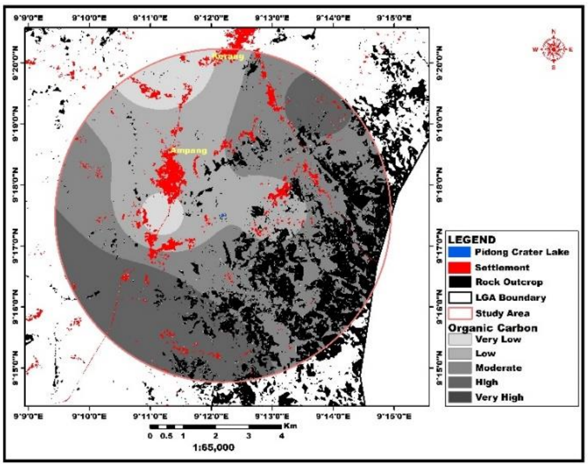

Figure 7: Map Showing Organic Carbon concentrations (C)

The distribution of organic matter in soil is essential for Irish potato production because organic matter enhances soil structure, water retention, nutrient availability, and microbial activity, all of which directly affect potato growth and yield. One of the major stresses on the soil resources is the decline of organic carbon content. The spatial distribution maps for organic matter (Figure 7) revealed that soils with very low organic matter (less than 1-2%) content with almost 7% of the total area coverage and low organic carbon (around 2-3%) content with 27.84% of the total area coverage (Table 6) are lower nutrient availability or poor in nutrient content, water-holding capacity, and soil structure. Potatoes grown in these soils are likely to exhibit poor or stunted growth, weak root systems, smaller tubers, and reduced yields. due to lower nutrient availability. Such soils may also be more prone to erosion and compaction, which can further reduce productivity. Soils with moderate organic carbon content occupy almost 40%, of the total land area. Also, areas with high organic matter soils in Kerang and Ampang (typically above 20%) content and very high organic matter soils, are highly conducive to potato production. These soils offer excellent nutrient availability, improved water retention, and a healthier microbial environment, promote robust plant health, large tuber formation, and high yields, these soils are generally highly productive.

Table 6: Organic Carbon Statistics for the Area

CLASS	AREA (Km^2)	AREA (%)
Very Low	4.34	6.97
Low	17.35	27.84
Moderate	24.6	39.47
High	16.03	25.71
Total	**62.32**	**100**

Fertility Indices

Carbon/Nitrogen Ratio

This index ranges from Low to very high in the area of interest. Areas with low ratios account for more than half the spatial extent of the area at 36.84 km^2 (59.11%). Moderate, high and very high ratios present in 13.88 The carbon/nitrogen (C/N) fertility index is an important indicator of soil nutrient cycling and nitrogen availability in Irish potato (*Solanum tuberosum* L.) production systems. It reflects the balance between soil organic carbon and nitrogen, which determines the rate of organic matter decomposition, microbial activity, and the release of plant-available nitrogen. Therefore, the C/N ratio provides useful information for assessing whether soil nitrogen will be readily available for crop uptake or temporarily immobilized by soil microorganisms.

A high C/N ratio indicates that carbon-rich organic materials dominate the soil system, causing microorganisms to utilize available nitrogen during decomposition. This process, known as nitrogen immobilization, can reduce the amount of nitrogen available to potato plants, resulting in poor early growth, reduced leaf development, and lower tuber yield potential. Conversely, a lower or balanced C/N ratio promotes faster mineralization of organic matter and more efficient release of nitrogen for plant uptake, supporting healthy crop establishment and canopy development.

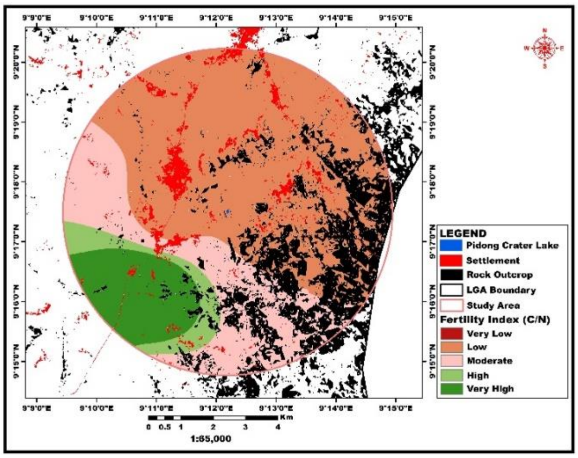

Figure 8: Map of Carbon/Nitrogen Ratio (C/N)

In potato production, the interpretation of the C/N fertility index is particularly important because potatoes require adequate nitrogen during early growth stages to support canopy formation but require moderated nitrogen availability during tuber bulking to ensure proper partitioning of carbohydrates into tubers. A soil with high organic carbon but an imbalanced C/N ratio may contain substantial carbon reserves while still limiting nitrogen availability to the crop.

Overall, the carbon–nitrogen index provides valuable insight into the biological fertility of soils and should be considered alongside soil nutrient analyses when developing fertilizer recommendations for Irish potato production. Maintaining a balanced C/N ratio enhances nutrient availability, improves soil health, increases nitrogen use efficiency, and supports sustainable potato yield and tuber quality.

In the study area, very low and low carbon/nitrogen ratios cover more than 80% of the area (59.11% and 22.26%, respectively). This balance indicates that these soils are healthy soils with good carbon and nitrogen circling and will be especially good for potato cultivation and production. The other areas (moderate and high) may need careful interventions which may include better management of nitrogen fertilization.

Table 7: Carbon/Nitrogen fertility Index Variation

CLASS	**AREA (Km^2)**	**AREA (%)**
Low	36.84	59.11
Moderate	13.88	22.26
High	3.56	5.71
Very High	8.04	12.91
Total	**62.32**	**100**

Magnesium/Potassium Ratio

The magnesium–potassium (Mg/K) fertility index has important implications for Irish potato (*Solanum tuberosum* L.) production because both nutrients play complementary roles in crop growth, tuber yield, and quality. Potassium (K) is the primary nutrient responsible for maximizing tuber yield, size, dry matter accumulation, and processing quality, while magnesium (Mg) is essential for chlorophyll formation, photosynthesis, and carbohydrate production that support tuber bulking. Consequently, adequate availability and a balanced relationship between these nutrients are essential for optimum potato productivity.

A low potassium fertility index indicates inadequate potassium availability, which can limit tuber development, reduce tuber size, lower marketable yield, and adversely affect quality traits such as dry matter content and storage performance. Conversely, a high potassium fertility index generally supports improved yield potential but may create nutrient imbalances if magnesium availability is insufficient. From figure 9 and table 8, 2.81 km^2 (4.51%) of the study area displays very low Mg/K ratio, while 22.62 km^2 (36.30%), 34.48 Km^2 (55.34%) and 2.40 km^2 (3.85%) are low, moderate and high, respectively.

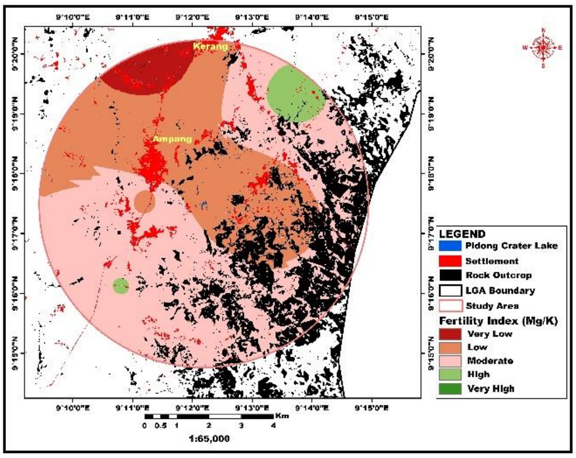

Figure 9: Map Showing Variation of Magnesium/Potassium Ratio (Mg/K)

One of the most important agronomic implications of the Mg/K fertility index is the antagonistic relationship between potassium (K^+) and magnesium (Mg^{2+}). Excessive potassium concentrations in the soil can suppress magnesium uptake by potato plants, resulting in magnesium deficiency even when soil magnesium levels are considered adequate. Under such conditions, plants may exhibit interveinal chlorosis on older leaves, reduced photosynthetic efficiency, impaired carbohydrate transport, and lower tuber yield and quality.

In the study area, the largest area is covered by moderate values of Mg/K ratios (34.48 km^2 or 55.34%). These areas may require more application of potassium which could have been depleted due to continuous cropping and other negative farming practices. As such, the balance of these two nutrients must be carefully monitored in these areas. Locations in the northwest of the study area and spreading towards the lands surrounding the crater lake, made up of 22.62 km^2 and 2.81 km^2 of low and very low ratios respectively, need little or no interventions. The negligible portion of land that have a high range of Mg/K ratios may need more fertilization and necessary monitoring to perform optimally for potato production.

From a fertilizer management perspective, potassium application should be guided by soil test recommendations and adjusted according to the soil fertility index. Where magnesium levels are low, magnesium fertilizers such as magnesium sulphate or magnesium limestone should be applied to correct deficiencies, particularly in fields receiving high potassium fertilizer rates. This integrated approach minimizes nutrient antagonism, improves nutrient use efficiency, and enhances potato yield, tuber quality, and long-term soil fertility.

Table 8: Magnesium/Potassium (Mg/K) Fertility Index Statistics

CLASS	**AREA (Km^2)**	**AREA (%)**
Very Low	2.81	4.51
Low	22.62	36.3
Moderate	34.48	55.34
High	2.4	3.85
Total	**62.32**	**100**

Calcium/Magnesium Ratio

The calcium/magnesium (Ca/Mg) fertility index is an important indicator of nutrient balance in Irish potato (*Solanum tuberosum* L.) production because calcium (Ca) and magnesium (Mg) are essential secondary macronutrients involved in plant growth, tuber development, and quality formation. The index provides insight into the relative availability of these nutrients and helps identify potential nutrient imbalances that may affect crop performance.

Calcium plays a major role in maintaining cell wall strength, membrane stability, and tuber structural integrity. Inadequate calcium availability can weaken tuber tissues, increase susceptibility to physiological disorders such as internal browning and hollow heart, reduce skin quality, and negatively affect storage performance. Adequate calcium nutrition, therefore, contributes to firmer tubers, improved resistance to mechanical damage, and enhanced marketability. The distribution of Ca/Mg ratios indicate that low, moderate and high dominate, covering 14.57 km^2 (23.38%), 23.57 km^2 (37.83%) and 18.66 km^2 (29.94%), respectively. The very low and very high ratios cover almost 10% (4.51% and 4.34%, respectively) of the study area.

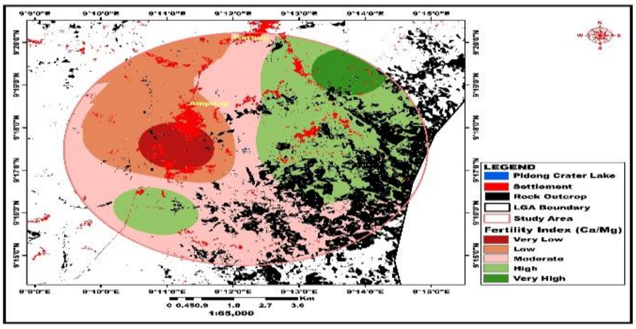

Figure 10: Map Showing Variation of Calcium/Magnesium Ratio (Ca/Mg)

An imbalance between calcium and magnesium can negatively influence nutrient uptake because these cations compete for exchange sites in the soil and absorption sites in plant roots. Therefore, a soil with adequate levels of one nutrient but insufficient levels of the other may still result in reduced potato productivity. Excessive calcium availability, for example, can restrict magnesium uptake, while insufficient calcium can compromise tuber quality even when magnesium levels are adequate.

From a soil fertility management perspective, the Ca/Mg fertility index should be interpreted as a measure of nutrient balance rather than a requirement to maximize either nutrient individually. Soil testing is essential for identifying limiting nutrients and guiding appropriate corrective measures. Where calcium is deficient, lime or calcium-containing fertilizers may be applied, while magnesium deficiencies can be addressed using magnesium-containing amendments such as dolomitic limestone or magnesium sulphate.

Table 9: Calcium/Magnesium (Ca/Mg) Fertility Index Variation

CLASS	AREA (Km^2)	AREA (%)
Very Low	2.81	4.51
Low	14.57	23.38
Moderate	23.57	37.83
High	18.66	29.94
Very High	2.71	4.34
Total	**62.32**	**100**

Water Quality and Irrigation Sustainability

Water quality is a major determinant of irrigation sustainability. Parameters commonly evaluated include pH, electrical conductivity (EC), sodium adsorption ratio (SAR), total dissolved solids (TDS), residual sodium carbonate (RSC), chloride, sulphate, bicarbonate, nitrate, and heavy metal concentrations (Ayers & Westcot, 1985).

Poor-quality irrigation water can induce soil salinization, sodicity, nutrient imbalance, toxicity, and reduced crop productivity. Conversely, water that satisfies international irrigation standards promotes long-term soil health and sustainable crop production. Results obtained from Longpia et al (2021) indicates that the water contained in Ampidong lake is quite suitable for irrigation purposes and will not result in any negative consequences. The quantity of water (with a surface area of 6219 m^2, a depth reported at between 6 m to several kilometers and, thus, a volume which should exceed 37314 m^3) also signals the sustainability of regular irrigation across the 62 km^2 area within the buffer zone and even beyond.

Findings show that, within the immediate proximity of the Ampidong crater lake, only about 13% of the land is being used regularly for dry season irrigation farming and most of this is around Bwompe, to the west of the crater and the immediate vicinity of the crater. The natural seepage of water from the lake (through layers of sands, volcanic ash and other fine-grained ejecta sandwiched between layers of lava flow and intrusions) supplies the year-round water demands for this highly productive area. With emplacement of necessary irrigation infrastructure, the whole of the study area can benefit from the abundant resources of the Ampidong crater lake.

Table 10: Key Water Quality Indicators

ASPECT	FINDINGS
Water origin	The lake water is predominantly meteoric, meaning it originates mainly from precipitation that infiltrates and replenishes the lake.
Age of water	Radiocarbon analysis estimated the water age at approximately 230 ± 30 years

	before present, indicating relatively young water and continuing recharge.
Water-colour changes	The lake experiences intermittent changes in water colour, associated with fluctuations in its chemical conditions and the occurrence of floating "mat" vegetation.
pH variation	During observed colour-change episodes, pH declined from approximately 7.39 to 6.71 in November 2014, 7.15 to 6.83 in October 2015, and 7.18 to 6.20 in September 2016.
Carbon dioxide influence	Increased CO_2 in the lake water was linked to greater acidity and changes in dissolved chemical constituents.
Iron concentration	Iron concentration increased from about 335 ppb to 429 ppb, and this increase was associated with the sporadic colour changes in the lake.
Acidity	The lake shifted from near-neutral conditions, around pH 7.35, to more acidic conditions of below pH 6.71 during some episodes.
Recharge	The relatively young water age and meteoric origin suggest that the lake is continually replenished by rainfall and percolating groundwater.
Main interpretation	The colour changes are interpreted as a consequence of changing CO_2, pH, iron availability, and related hydrochemical processes rather than evidence that the lake is an ancient, isolated water body.

Source: Longpia, Cedric Bernard and Lar, Uriah Alexander (2021)

Table 11: Water Quality Parameters and their Variations between 2014 and 2016

PARAMETER	VALUE / RANGE OBSERVED	KEY ENVIRONMENTAL NOTES
pH	6.20 – 7.7	• Dry Season (March–June): More acidic (< 7)
		• Oct–Dec Period: Rises to alkaline (> 7)
		• Drops below 6.71 when PCO_2 prompts iron surges
Water Temperature	20°C – 30°C	• March–April: Peeks at highest levels (27°C–30°C)
		• December: Gradually drops to seasonal lows (~20°C)
Electrical Conductivity (EC)	340 – 390 µs/cm	• Closely correlates with high temperature peaks in March/April
Total Dissolved Solids (TDS)	150 – 170 mg/l	• Peaks concurrently with the highest EC and temperature windows
Predominant Water Type	Mg-Ca-HCO_3	• Demonstrates solute acquisition derived from water-rock interaction/hydrolysis with the basaltic host aquifer
Minor Water Types	Na-K-HCO_3, Na-K-Cl, Na-K-SO_4	• Accounts for ≤ 20% of total sample distribution
Iron Concentration (Fe)	335 ppb – 429 ppb	• Fluctuations are triggered by PCO_2 shifts; manifests visibly as intermittent water colour changes from natural blue to brown-yellowish
Stable Isotopes ($\delta^{18}O$ & δ^2H)	Meteoric Origin	• Confirms water source is heavily supplied by regional rainfall
Water Apparent Age (^{14}C)	230 ± 30 years before present	• Indicates a relatively modern geological water retention age

Source: Longpia, Cedric Bernard and Lar, Uriah Alexander (2021)


Plates 1 and 2: Irish Potato Farmlands Within the Vicinity of the Volcanic Hill (left) Kerang Volcano Leaches Macro and Micro Nutrients into Surrounding Soils (right)

Potato Value Chain, Yield Breakdown and Potential

The average potato yield on the Jos Plateau ranges between 310 and 380 metric tonnes per square kilometre. Agricultural data for the region is typically recorded in tonnes per hectare. On average, smallholder farmers on the Jos Plateau achieve a yield of 3.1 to 3.8 tonnes per hectare. While the regional average sits under 400 tonnes per square kilometre, output varies significantly depending on farming practices. The current average of 310 – 380 tonnes/km² is driven by traditional smallholder practices and negatively affected by limited access to certified seeds. Some optimized commercial farms generate up to 700 tonnes/km² achieved by utilizing basic mechanization and improved local techniques. the Plateau State Government and Sahel Consulting have a target potential of 2,000 tonnes/km². This is an achievable milestone being targeted by through seed multiplication and modern farming methods.

Several factors play key roles in the limited production of potatoes within the area and on the Jos Plateau in general. They include, among others, seed quality, crop diseases, lack of mechanization and absence of irrigation infrastructure.

RECOMMENDATIONS

The results and findings from this study has given rise to the following recommendations:

- Much of the 62.32 km^2 land in the study area could be used for mechanized year-round irrigated Irish Potato production given the proximity to the Ampidong Crater Lake and that the soils are generally conducive for potato farming.
- Irrigation infrastructure such as mechanical water pumps, piping and canals extending throughout the study area and beyond would be a great advantage in boosting potato production. With such investments, the annual production of the area could rise to over 120,000 metric tonnes.
- Better soil management through regular soil testing and fertility interventions are a necessity to obtain the maximum value from soils in the location.
- The establishment of processing and storage facilities at or close to the location will reduce post-harvest waste and increase the transportability and international reach of potatoes produced in the area.
- These other recommendations paired with improved, disease resistant seeds and adequate farm inputs will improve potato production across the region.

LIMITATIONS OF THE STUDY

In the interest of transparency, and in line with feedback received during peer review, the following limitations of the current study are acknowledged:

1. Secondary hydrological and bathymetric data. The lake water-quality parameters (Tables 10 and 11) and the depth/storage-capacity figures used in this study are secondary data drawn principally from Longpia and Lar (2021) and Patterson (1986), with field measurements spanning 2014–2016 and, in the case of Patterson (1986), several decades earlier. These data have not been independently re-verified against present-day conditions, and the reported lake surface area (6,219 m^2) appears small relative to the 62.32 km^2 area of interest; a fresh bathymetric and water-quality survey is recommended before the storage and water-supply figures are used for infrastructure investment decisions.

2. Soil-sampling density and reporting. The number and spatial distribution of soil sampling points, exact sampling dates, GPS equipment and positional accuracy, and the precise acquisition dates of the satellite imagery used for the lake surface-area/perimeter measurement have not been fully reported in this version of the manuscript; these details are necessary for another researcher to reproduce the soil and lake-boundary maps and are being compiled for the revised submission.

3. Descriptive rather than inferential statistics. The relationships described between soil properties, irrigation conditions, and potato productivity are, at this stage, based on spatial (GIS zonal) and descriptive comparison of mapped classes rather than on formal inferential statistics (e.g., correlation or ANOVA) linking point-level soil data to plot-level yield. This is identified as a priority for the next phase of the research (see Statistical Analysis).

4. Yield-potential projection. The estimate of over 120,000 metric tonnes of annual potato production is a planning-level projection based on total mapped area and a regional yield-potential target, not a measured or field-validated yield; it further assumes that irrigation water demand across the full 62.32 km^2 can be met, an assumption not yet verified against confirmed lake storage and recharge data (see Irrigation Water-Demand and Yield-Potential Estimation).

CONCLUSION

The results of this research have shown, by providing scientific evidence, that it will be beneficial for development partners, non-governmental organizations, and private investors to invest in irrigation infrastructure, soil fertility improvement, agricultural extension services, and potato value chain development around Ampidong crater lake. Furthermore, the study has enriched the existing body of knowledge in hydrology, soil science, irrigation engineering, agricultural geography, and value chain analysis. Also, by promoting sustainable utilization of water and soil resources, the study has the potential to improve food security, create employment opportunities, reduce rural poverty, and contribute to the achievement of several Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land).

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