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***Research Article***

# Spatial Variability and Mapping of Soil Structural Stability: The Interplay of Texture and Organic Matter at Jibia Irrigation Project, Semi-Arid Zone of Nigeria

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**ABSTRACT**
The study assessed the spatial variability and mapping of soil structural stability in relation to texture and organic matter in Sector F1 of the Jibia Irrigation Project, Katsina State, Nigeria. The area lies in a semi-arid zone with predominantly sandy soils and low organic matter, contributing to poor aggregation and low structural stability index (SI), which increases erosion risk. A total of 144 georeferenced soil samples were analyzed for texture, SOM, and aggregate stability indicators such as dry and wet mean weight diameter (MWD) and SI. Descriptive statistics showed moderate variability in sand and high variability in silt, clay, and aggregate indices. Semivariogram analysis revealed strong spatial dependence for sand, silt, clay, and dry MWD; moderate for SI; and weak for SOM and wet MWD. Clay had the widest spatial range (8.5 m), indicating stronger intrinsic control than sand (3.24 m) and silt (2.93 m). SOM showed weak spatial structure, likely influenced by land use practices. The results show that sandy soils with low organic matter content have poor aggregation and weak structural stability, making them susceptible to erosion. Fine-textured components, such as clay and silt, and OM significantly enhance SSI, while high sand content undermines it. Organic matter and fine particles were key to improving soil aggregation and stability. The study highlights the importance of managing soil texture and organic inputs to improve aggregation, moisture retention and productivity in semi-arid soils Recommendations include increasing organic inputs, reducing tillage, and adopting targeted irrigation. The exponential model best fitted most semivariograms.

**Keywords:** Aggregate stability; Organic Matter; Semi-arid Zone of Nigeria; Spatial Variability; Texture

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## INTRODUCTION

In evaluating the influence of soil texture and organic matter on soil aggregate stability in semi-arid, irrigated fields, several factors are at play. The stability of soil aggregates is a key component of soil health, influencing both fertility and resistance to erosion. Soil aggregate stability varies considerably across different soil types and environmental conditions, and it is significantly affected by soil texture and organic matter content.

Soil texture, which refers to the proportion of sand, silt, and clay, is crucial in determining water retention characteristics and aeration, both of which are vital for plant growth and soil microbial activity. In irrigated semi-arid environments, soil texture plays a pivotal role in dictating how water moves through the soil profile. Fine-textured soils (such as clay) usually have higher aggregate stability compared to coarse-textured soils (such as sand) because of their higher surface area that enhances particle cohesion (Abdulkadir *et al.*, 2025; Khosravani *et al.*, 2024; Emde *et al.*, 2021). This is especially relevant under irrigation conditions, where water management is critical to maintain soil moisture levels conducive to aggregate formation and stability.

Soil organic matter (SOM) also plays a vital role in soil structure and aggregate stability. Organic matter contributes to soil stability by binding soil particles together to form aggregates. It also improves water retention and soil aeration, which are crucial in arid and semi-arid regions where water scarcity is prevalent (Ponyane *et al.,* 2025). In these regions, increases in soil organic carbon (SOC) due to the addition of organic materials or irrigation can significantly enhance aggregate stability, as SOM improves binding and resilience against disaggregation (Noma and Sani, 2008; Xie *et al.,* 2024; Zheng *et al.*, 2023). Higher SOM content typically correlates with greater aggregate stability, as demonstrated in various studies where soil amendments and specific irrigation practices significantly increased organic matter content and subsequently enhanced soil aggregate stability (Chanlabut and Nahok, 2023; Emde *et al.*, 2021).

The study area (Sector F1) of the Jibia irrigation project Katsina State Nigeria belongs to the semi-arid climate, where soil texture and organic matter play a pivotal role in determining soil health and productivity. The combination of sandy soils, low organic matter, and continuous cultivation can lead to soil structural degradation and reduced fertility (Sani *et al* 2019). The spatial variability of these factors is a significant concern, as continuous cultivation can lead to soil degradation and reduced fertility. Sandy soils in these regions are prone to erosion, and the loss of organic matter can exacerbate this issue. Therefore, understanding the spatial variability of soil texture and organic matter, and its influence on soil aggregate and structural stability, is crucial for sustainable agricultural practices. The lack of understanding of this spatial variability hinders the development of effective management strategies for sustainable agriculture. Moreover, the spatial variability of these factors within irrigated fields influences how soil management practices should be tailored. For instance, use of GIS and machine learning models that use various environmental and soil covariates, such as topography and organic content, enhance our ability to predict spatial variations in soil aggregate stability (Khosravani *et al*., 2024). This knowledge allows for site-specific management practices that optimize water usage and improve the structural stability of soils, thus enhancing agricultural productivity and sustainability.

The importance of irrigation in the area, and the lack of research on the spatial variability of soil aggregate stability in semi-arid environments, particularly in sector F1 of the Jibia irrigation project, Northern Nigeria, make this study essential for sustainable agricultural practices. Ultimately, this study aims to determine the influence of soil texture and organic matter content and their relationship with stability of soil aggregates in the study area, which will inform the development of effective soil management strategies, that will have attendant economic benefits for farmers in the study area.

## MATERIALS AND METHODS

### Study Area

#### Location

The study area is Sector F1 of the Jibia Irrigation Project, located in Jibia Local Government Area, Katsina State, Nigeria. It's situated between latitudes 13°04'18" N - 13°10'27" N and longitudes 7°15'06" E - 7°18'15" E (Sani *et al* 2019; 2023). The area is nearly level to gently undulating with a 0-2% slope, averaging 442 meters above sea level (FDLAR, 1990). It's within the semi-arid region, Sudan savannah zone, with a mean annual temperature of 25°C and precipitation of 600-700 mm. Rainfall is seasonal, occurring between June and September, with the peak in August. The study area falls within the Chad formation, made up of sedimentary rocks of Cretaceous origin (Shittu, 1999).

Geology, Vegetation, and Agriculture

The soil consists of mostly unconsolidated sediments, predominantly sandy, silt to sandy loam, brown or reddish brown in nature. It's formed from the deposition of eroded materials over sedimentary formation, less acidic, well-drained, and has fairly low clay content (FDLAR, 1990). The vegetation is Sudan savannah type, composed of trees scattered over an expanse of grassland. Trees like baobab, acacias, and neem are common (Sani *et al* 2019). The people in the study area are predominantly farmers growing rain-fed crops like millet, sorghum, and groundnut, and irrigated crops like wheat, cowpea, and Maize.The Jibia Irrigation Project aims to develop 3450 ha of land for irrigation purpose, with a concrete irrigation canals network, drainage channels, and service roads (KTARDA, 2010; SRRBDA, 1991; SRRBDA, 2013; Shittu, 1999).

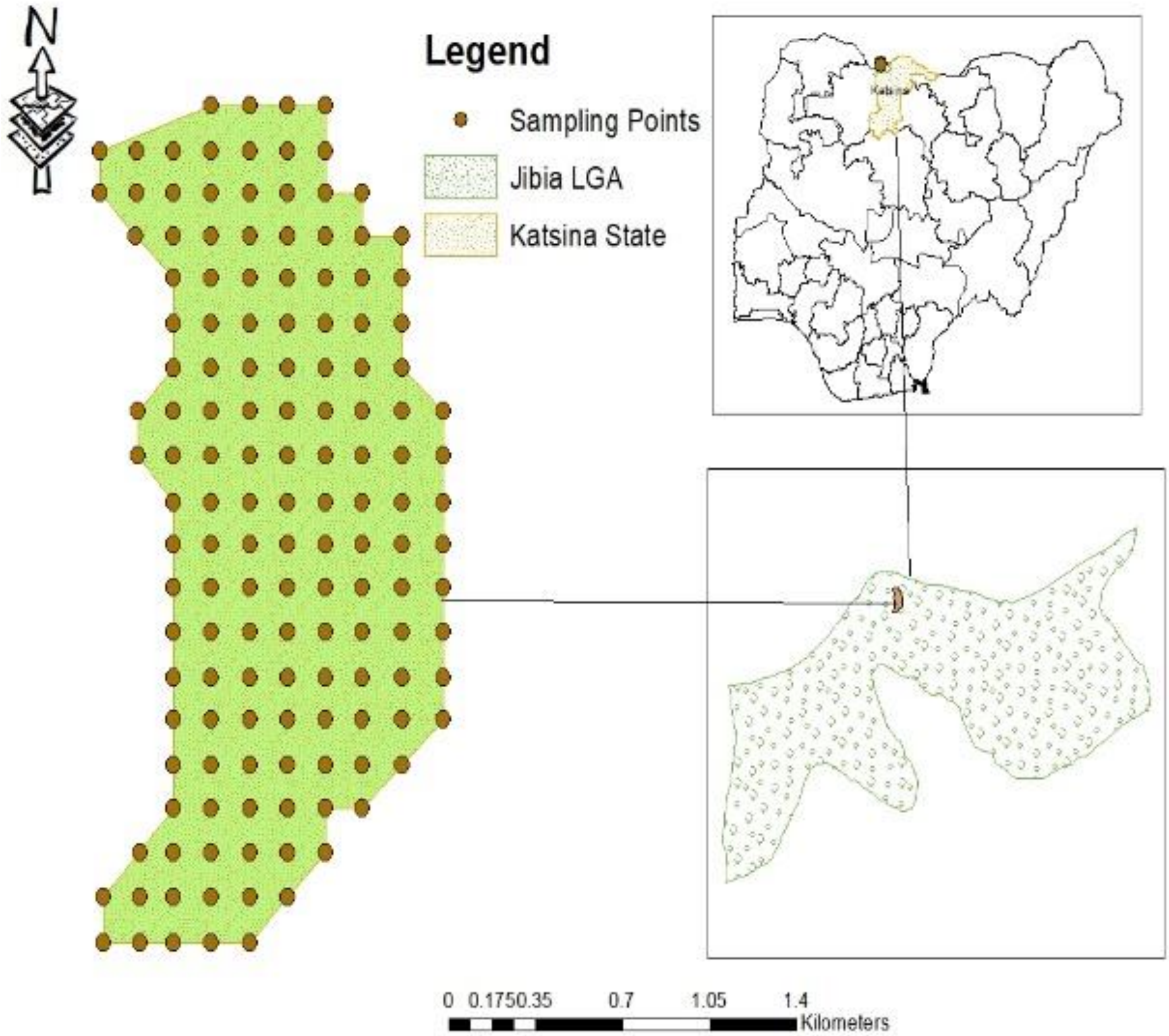


**Figure 1. Map of Katsina State showing the Study Area and Sampling Points**

**Soil Sampling**

**Reconnaissance survey**

A reconnaissance survey was conducted in the study area to establish the location and extent of the sampling area as well as to establish the sampling points

**Sampling area demarcation & soil collection**

Google Earth satellite imagery was used to pinpoint the exact sampling area, ground-truthed it with a GPS device, and georeferenced the area using ArcGIS 10.3.1 GIS software. We employed the grid sampling technique, drawing grids at 150-meter intervals, which resulted in collecting 144 soil samples at grid intersection points identified using a handheld GPS device. At each sampling point, we collected both disturbed and undisturbed soil samples. After collection, we air-dried the samples, gently crushed them, and sieved through a 2mm mesh size. The fine earth separates were then properly labeled and stored for laboratory analysis .

**2.2 SOIL LABORATORY ANALYSES**

Particle size analysis was determined using Bouyoucos hydrometer method (Bouyoucos, 1951) Percent sand, silt and clay were determined and textural classes obtained using the USDA soil textural triangle. Soil organic carbon content was determined by the dichromate oxidation method (Nelson and Sommers 1982) and organic matter was obtained by multiplying organic carbon content with 1.724. Aggregate Stability was determined by dry and wet sieving procedures described by Kemper and Chepil (1965). Mean weight diameter (MWD) of aggregates was calculated by summing the product of mean diameter of aggregates and proportion of soil in each aggregate-size class). (Kemper and Rosenau, 1986. The results were used to define the stability of the soil aggregates.

$$MWD = \sum_{i=1}^{n} X_i W_i$$

Where;
$X_i = Proportional\ by\ weight\ of\ sand\ free\ aggregate$
$W_i = Mean\ diameter\ of\ the\ proceeding\ and\ preceding\ sieve$

Structural Stability Index which is an index for assessing the risk of structural degradation in cultivated soils (Pieri, 1992). It is calculated by using the equation;

SI (%) = $\frac{1.724\ x\ OC}{Silt\ +\ Clay}$ x 100

Where;
$OC\ (wt.\%) is\ soil\ organic\ carbon\ content$
$Silt + Clay\ (wt.\%) is\ the\ Soil's\ combined\ silt\ and\ clay\ content.$

**Data Analyses**

Data analyses were performed using descriptive statistics, Geostatistical and correlation analyses.The Measured variables were analyzed to obtain Mean, Median, Range, Maximum, Minimum, Variance, Skewness, Kurtosis and Coefficient of variation. Pearson Correlation analysis was performed to show the relationships among the soil properties measured.

2.4 Geospatial analysis

We used geostatistical methods, like Kriging and Semivariogram analysis, to figure out how much each soil property varied across the area. First, we checked if the data was normally distributed using the Shapiro-Wilk test (Shapiro and Wilk, 1965). If the data was skewed, we transformed it using natural logarithms to make it more normal. Then, we used experimental semivariograms to visualize the spatial variation. This helped us understand how different the soil properties were at different distances apart, basically showing us how similar or dissimilar the soil was from one spot to another (Webster and Oliver, 2007).

Semivariogram can be expressed mathematically as:

$$\gamma(h) = \frac{1}{2N(h)} \left[ \sum_{i=1}^{N(h)} [Z(x_i + h) - Z(x_i)]^2 \right]$$

Where;
($h$) is the semi-variance for interval class $h$,
$N$ ($h$) is the number of pairs separated by a lag distance (separation distance between sample positions.
$Z(x_i)$ is a measured variable at spatial location i.
$Z(x_i + h)$ is a measured variable at spatial location $i + h$.

Variable spatial dependency was calculated by the Nugget to sill ratio, which is the ratio of nugget variance to total variance (sill) multiplied by 100.

$$Spatial\ dependency = \frac{C_o}{C_o + C}\ x\ 100$$

Where;
$C_o = Nugget$
$C_o + C = Sill$

## RESULTS AND DISCUSSION

**Particle Size Distribution**

The soils examined in the study area are predominantly sandy, with an average sand content of 84%, while silt and clay average 11% and 5%, respectively. These values indicate a coarse-textured soil environment that is typically associated with low natural aggregation, high permeability, and poor nutrient retention (Salako, 2003; Sani 2019). Such characteristics are common in semi-arid environments and often result in fragile soil structure, especially under irrigation conditions. This is likely because the soils of the study area were formed from granitic sandstone and aeolian deposits. The findings match those of Malgwi *et al*. (2000) and Voncir *et al*. (2008), who said that Northern Nigerian soils have a lot of sand due to clay eluviation and wind erosion. Top soils usually have more sand than sub soils (Nartey *et al*., 1997; Usowicz *et al*., 2004). Using Ogunkunle's (1993) classification, we found that sand has medium variability (CV= 15.72%), while silt and clay have high variability (CV = 74.10% and 109%). This variability is likely due to different land use systems, like how farmers use different tools to till the land, which affects how silt and clay move through the soil profile. The results match those of Okon and Babalola (2006), Oku *et al*. (2010), Phil-Eze (2010), and Obalum *et al*. (2012), who also found high variability for silt and clay contents

**Dry and wet Mean Weight Diameter of Soil Aggregate**

The dry mean weight diameter of soil aggregate had a mean value of 0.56 mm. The minimum and maximum values were found to be 0.14 mm and 2.41 mm respectively. High coefficient of variation (CV) of 87.5% was observed. The Skewness and Kurtosis values were both positive as 2.05 and 3.78 respectively. The data did not pass the normality test. The mean weight diameter of water stable aggregates was found to be 0.49 mm. The minimum and maximum values were found to be 0.16 mm and 1.31 mm respectively. The data has high coefficient of variation (CV) of 42.9%. The Skewness and Kurtosis values were both positive as 1.12 and 1.63 values respectively. The variables did not pass normality test. The results make aligns with previous studies conducted in sandy dominated soils with low organic matter, as low organic matter means less aggregation, sandy soils are more susceptible to erosion, and are less stable, all of which can lead to low minimum weight diameter as found in the study area (Salako 2003) The mean coefficients of variation of the dry and wet mean weight diameter were 87.5 and 42.9% indicating high variability in the study area. Similar results have been found by Ramzan, (2016) who observed high CV (> 35 %) of MWD in both studied layers. The higher CV of the mean weight diameter in studied soils could be the consequence of agricultural practices such as soil tillage, fertilization, vertical eluviation of finer materials, and the changes of soil water balance (Ramzan, 2016).

**Soil Organic Carbon (SOC) and Soil Organic Matter (SOM)**

The soil organic carbon (SOC) content in the study area ranged from very low (0.08%) to moderate (2.35%), with a mean of 0.89%. The low to moderate organic carbon content is likely due to intensive continuous cultivation and the nature of the soil parent materials. This low organic carbon content leads to low water holding capacity, low aggregation, and high infiltration rate, which is consistent with the findings of Salako (2003), Noma and Sani (2008), and Shehu *et al*. (2015). Additionally, the seasonal character of the savannah climate (Jones and Wild, 1975) and the risk of bush fires a common practice by farmers in the study area, which destroys leaf litter (Sani *et al* 2019; Shehu *et al*., 2015), also contribute to the low level of organic carbon in the study area.

**Correlation Analysis**

Table 2 shows the correlation analysis between the soil properties of the study area. Sand content exhibited a significant negative correlation with key soil physical properties including silt (r = –0.90**), clay (r = –0.84**), wet mean weight diameter (MWDwet; r = –0.49**), dry mean weight diameter (MWDdry; r = –0.46**), and structural stability index (SI; r = –0.83**). It also negatively correlated with organic matter (OM) and porosity. Conversely, both silt and clay showed strong positive correlations with OM, indicating that organic matter tends to accumulate in finer-textured soils while sandy soils are more prone to depletion due to leaching and accelerated decomposition. These findings align with those reported by Gulser *et al*. (2016), Gulser and Candemir (2014), and Abu and Malgwi (2012), who also observed lower organic matter content in coarse-textured soils.

The correlation analysis supports the role of OM in enhancing soil aggregation and stability. OM was positively correlated with both MWDdry and MWDwet, as well as with SI, highlighting its contribution to forming stable macro-aggregates and improving soil resistance to erosion and structural breakdown, particularly under irrigation. Sand, on the other hand, negatively impacted structural indicators, emphasizing the vulnerability of coarse soils to degradation. The lower MWDwet (0.49 mm) compared to MWDdry (0.56 mm) suggests increased susceptibility to structural failure when soils are saturated, a common problem in sandy, OM-poor soils, a pattern also reported by Salako (2003).

Further, both MWDdry and MWDwet showed significant positive relationships with clay and OM, but negative correlations with sand. The relatively stronger association of MWD with OM ($r^2 = 0.50$**) suggests that organic matter not only supports aggregate formation but also helps protect soil organic carbon (SOC) from decomposition. This agrees with findings by Zhang *et al*. (2016), who emphasized that increasing organic inputs and reducing soil disturbance can enhance the formation of macro-aggregates and thus improve structural stability. Earlier studies by Hartge and Horn (1984), Horn and Dexter (1989), and Horn *et al*. (1995) also confirm that higher clay and OM levels favor aggregation, while sand has a dis aggregating effect.

Regarding the structural stability index (SI), the strongest correlation was observed with clay (r = 0.99, $p < 0.01$), underscoring clay's essential role in structural integrity due to its surface properties and bonding capacity with OM. OM and silt also contributed positively to SI (r = 0.56 and r = 0.52, respectively), while sand showed a negative relationship (r = –0.83), further reinforcing the destabilizing effect of coarse textures. SI was positively linked to both MWDdry and MWDwet, suggesting that larger aggregates contribute to more stable soil structures under varying moisture conditions (Mirzaee *et al* 2016)

The results highlight the central role of clay and organic matter in improving soil structure and stability, while high sand content undermines it. These relationships emphasize the importance of managing soil texture and organic inputs to enhance aggregation, improve moisture retention, and promote long-term productivity in irrigated semi-arid soils.

**Table 1. Descriptive Statistics of the Soil Properties**

| Variable | Mean | Minimum | Maximum | SD | CV (%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| SAND (%) | 84 | 37 | 93 | 13.01 | 15.72 | -1.70 | 2.74 |
| SILT (%) | 11 | 2 | 38 | 8.31 | 74.10 | 1.50 | 2.10 |
| CLAY (%) | 5 | 1 | 25 | 6.54 | 109.00 | 3.35 | 15.68 |
| SOM (%) | 0.88 | 0.14 | 2.6 | 0.98 | 63.64 | 0.73 | 0.20 |
| MWD dry | 0.56 | 0.14 | 2.41 | 0.49 | 87.50 | 2.05 | 3.78 |
| MWD wet | 0.49 | 0.16 | 1.31 | 0.21 | 42.90 | 1.12 | 1.63 |

SD = Standard deviation; CV = Coefficient of variations; SOM = Soil Organic Matter, $MWD_{dry}$ = Dry Mean weight diameter, $MWD_{wet}$ = Wet Mean weight diameter

**Table 3. Pearson Correlation Matrix of Soil Hydro-physical Properties**

| Variables | OM | Sand | Silt | Clay | MWDw | MWDd | SI |
|---|---|---|---|---|---|---|---|
| OM | 1 | | | | | | |
| Sand | -.66** | 1 | | | | | |
| Silt | .60** | -.90** | 1 | | | | |
| Clay | .55** | -.84** | .53** | 1 | | | |
| MWDw | .50** | -.49** | .41** | .44** | 1 | | |
| MWDd | .45** | -.46** | .38** | .45** | .41** | 1 | |
| SI | 0.56** | -0.83** | 0.52** | 0.99** | 0.44** | 0.45** | 1 |

OM= ORGANIC MATTER MWDw= WET MEAN WEIGHT DIAMETER; MWDd = DRY MEAN WEIGHT DIAMETER; SI= STRUCTURAL STABILITY INDEX

**Geostatistical Analysis**

**Spatial structure analysis**

Semivariograms was used to identify the spatial structure of different soil properties, and found the best-fitting models (like rational, quadratic, stable, K-Bessel, and exponential) for each parameter, as shown in Tables 3. The nugget (Co) represents estimation error due to sampling errors, while the sill (Co+C) represents spatially independent variance. We noted the nugget effect, sill, and range of influence (in meters) for each parameter. The spatial dependencies (Nugget/Sill ratio were classified as strongly spatially dependent (<0.25), moderately spatially dependent (0.25-0.75%), or weakly spatially dependent (>0.75%) (Cambardella *et al.*,1994)

**Table 3. Semivariogram model parameters of soil properties**

| Soil Properties | Statistical model | Nugget (Co) | Sill (Co+C) | Range (m) | Nugget/sill C/(Co+C) | SDC | $R^2$ | Interpolation techniques |
|---|---|---|---|---|---|---|---|---|
| % OC | Exponential | 0.4073 | 0.5113 | 9.3 | 79.7 | Weak | 0.36 | Ordinary |
| %SAND | Stable | 0.00 | 0.984 | 3.24 | 0.00 | Strong | 1 | Simple |
| % SILT | Exponential | 0.00 | 0.5652 | 2.93 | 0.00 | Strong | 1 | Ordinary |
| % CLAY | K-Bessel | 0.000102 | 0.7392 | 8.5 | 0.14 | Strong | 1 | Universal |
| MWD dry | Exponential | 0.00 | 0.478 | 0.342 | 0.00 | Strong | 1 | Ordinary |
| MWD wet | J-Bessel | 0.118 | 0.149 | 2.86 | 79.2 | Weak | 0.84 | Universal |
| SI | Exponential | 0.22 | 0.595 | 4.53 | 36.9 | Moderate | 1 | Simple |
| % O.M | Exponential | 0.407 | 0.511 | 9.3 | 79.6 | Weak | 0.36 | Ordinary |

SD=Standard deviation; CV= Coefficient of variations; BD= Bulk density; SOC=Soil Organic Carbon; MWD dry = Dry Mean weight diameter, MWD Wet = Wet mean weight diameter, PD = Particle Density, % OC = percentage organic carbon, SDC = Spatial dependency clay

**Soil Texture**

The particle size distribution sand, silt, and clay exhibited strong spatial dependency across the study area, with nugget-to-sill ratios below 0.25. According to Cambardella *et al*. (1999) and Bo *et al*. (2003), such a ratio indicates strong spatial dependence, which typically results from intrinsic soil characteristics like parent material, texture, and mineralogy. In contrast, weak spatial dependence is usually due to random extrinsic factors such as tillage, fertilization, and other human-induced management practices (Zheng *et al.,* 2009). The strong spatial dependence observed in this study likely stems from the parent material that formed the soils. Semivariogram analysis showed varying spatial ranges for different soil texture components: 8.5 m for clay, 2.93 m for silt, and 3.24 m for sand. The wider range for clay suggests it is influenced by natural variations in mineralogy and soil-forming processes (Abu & Malgwi, 2011). While these values are smaller than those reported in the Kadawa Irrigation Scheme where clay had a range of up to 594.5 m, this variation emphasizes how natural and anthropogenic influences, such as topography and land use, contribute to spatial differences (Lopez-Granados *et al*., 2002; Ayoubi *et al*., 2007).

**Soil Organic Matter (SOM)**

The semivariogram for organic matter showed it was best modeled by an exponential function, with a low nugget (0.407) and sill (0.511), indicating weak spatial dependency (79.7%) based on the nugget/sill ratio exceeding 0.75. The spatial range was 9.3 m, similar to the 10.6 m observed by Reza *et al*. (2010). The low spatial dependence suggests that SOM distribution is primarily governed by external management activities rather than inherent soil characteristics. Higher organic matter concentrations observed in the northeastern and southern parts of the field may be attributed to their location along stream valleys, where dense vegetation growth—particularly grasses and shrubs—contributes organic inputs as they decompose (Pullan, 1961).

**Mean Weight Diameter (MWD) and Structural Stability:**

Mean weight diameter, a measure of soil aggregate stability, showed contrasting spatial behaviors under dry and wet conditions. MWD under dry conditions (MWDdry) had strong spatial dependency with a nugget-to-sill ratio of 0%, indicating that its variation is controlled by inherent factors such as soil texture, clay mineralogy, and humus composition (Tobergte & Curtis, 2013). The spatial range for MWDdry was 0.342 m. Conversely, wet mean weight diameter (MWDwet) demonstrated weak spatial dependency (nugget/sill = 79.2%) with a range of 2.86 m. This weak dependency is attributed to the influence of both natural soil properties and external disturbances like tillage and continuous cropping. Practices such as overgrazing, residue removal, and land clearing expose the soil to erosion, disrupt aggregate formation, and limit SOM buildup—thereby reducing soil stability (Salako, 2003; Arshad & Lowery, 1996).

**Spatial Mapping of Soil Particles**

Spatial distribution maps revealed notable patterns in particle size distribution. Sand content was highest (65–98%) in the central, northeastern, and western parts of the field, while lower sand content (34–52%) was found along the northwestern, eastern, and southern boundaries. Silt content reached its peak (24–41.3%) in the southeastern and northwestern areas, with smaller patches (0.56–24%) scattered across the eastern and central regions. Clay was most concentrated (20–51%) in small patches in the southeastern section, while lower clay levels (0.72–20%) dominated the central and northern zones, covering a majority of the study area. These spatial variations in particle size reflect the complex interactions between landscape position, soil formation processes, and land management across the field.

Figure 2 shows that sand is unevenly distributed across the field, with higher concentrations located in the central, northeastern, and western parts. The spatial continuity of sand over relatively short distances suggests a strong spatial dependency, which is also reflected in its low nugget-to-sill ratio from the statistical model. The observed spatial pattern is likely influenced by parent material and sediment deposition patterns (Noma and Sani, 2008). These zones of high sand content correlate with areas likely to have poorer structure, lower water retention, and reduced fertility, thus requiring more targeted soil management, such as organic matter addition or mulching (Salako, 2003).

The distribution of silt appears more fragmented, with higher silt content in the southeastern and northwestern sections. These areas are likely to exhibit better moisture retention and higher organic matter accumulation, given the positive correlation between silt and SOM (Sani *et al* 2019; 2023. The pattern suggests influence from runoff, deposition, and possibly vegetation cover. These silt-rich patches may respond better to irrigation and could be managed as zones for intensive cultivation or organic matter accumulation

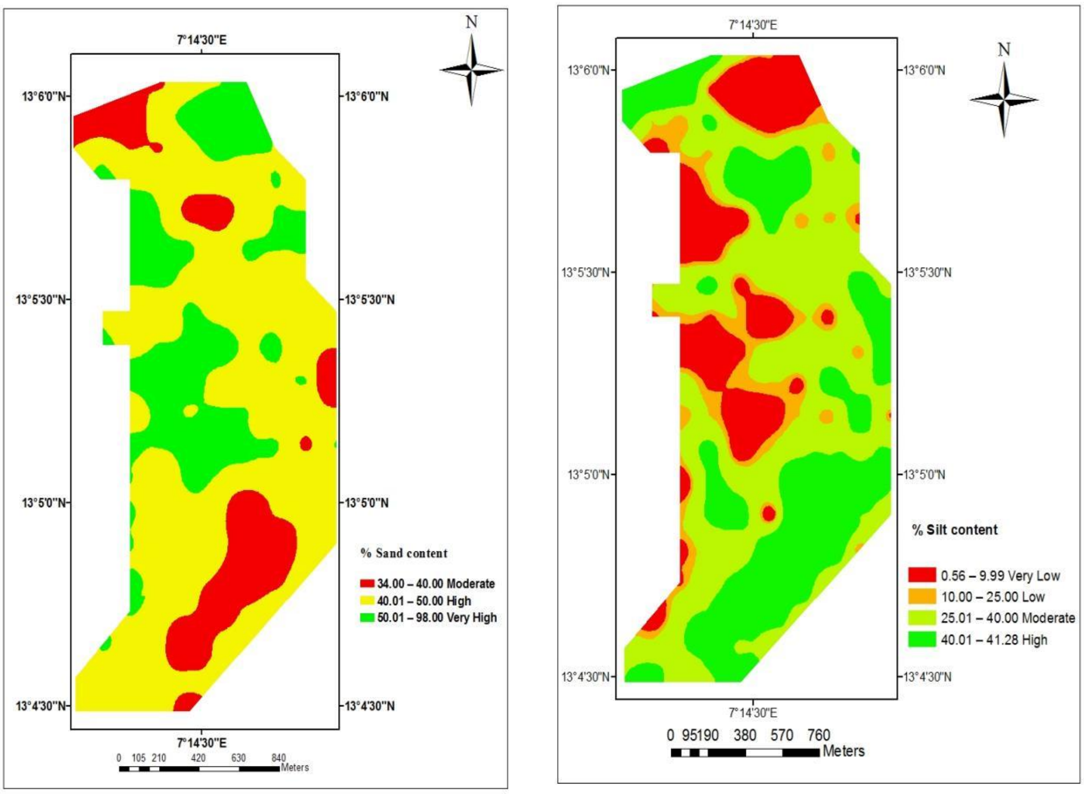


**Figure 2: Semivariogram map for percent Sand and silt content**

Clay shows a broader and more structured distribution, particularly concentrated in small patches in the southeastern part of the field (Figure 3). This map reflects a longer spatial correlation range, consistent with clay's strong spatial dependence and relatively immobile nature in soil profiles. The accumulation of clay in lower-lying areas may indicate zones affected by topographic flow or fine particle deposition, resulting in higher aggregation potential and greater structural stability (Obalum *et al*. 2012). The dry mean weight diameter map reveals localized zones with higher aggregate stability, corresponding spatially with clay- and OM-rich areas. MWD dry exhibited strong spatial dependence, indicating that its variability is largely driven by intrinsic factors, such as clay content, mineral composition, and soil organic matter. These regions are less affected by tillage or external disturbances, suggesting they have better soil resilience and are less prone to erosion under dry conditions.

Unlike MWD dry, the wet aggregate stability exhibits weak spatial dependence, as shown by the patchy and inconsistent distribution (Figure 4). This indicates high susceptibility to external influences like tillage, compaction, and residue removal. The limited range of spatial correlation reflects rapid changes in stability across short distances, requiring more site-specific management to improve aggregate resistance under irrigation or rainfall (Safadoust *et al.,* 2015).

The spatial variability of SOM and SI across the field. High values were observed in the northeastern and southern regions, likely due to proximity to stream valleys or natural vegetation zones, which contribute organic residues. OM shows weak spatial dependence, implying its variability is shaped more by land use and management practices than by inherent soil characteristics (Reza *et al.,* 2010).

The SI map (Figure 5) indicates zones of greater structural integrity aligning with higher clay and OM contents, reinforcing the interdependence of these properties. Areas with low SI may benefit from management practices such as compost application, cover cropping, or reduced tillage to improve structure and resilience (Zeraatpisheh *et al.*,2019)

The semivariogram maps collectively reveal a highly variable spatial landscape, where texture (sand, silt, clay), organic matter, and structural properties interact differently across the field. While texture shows strong inherent spatial control, properties like SOM and MWDwet are more affected by human-induced management and surface processes. These insights highlight the importance of site-specific soil management strategies to optimize productivity, especially in semi-arid irrigated systems where resource efficiency and sustainability are crucial.

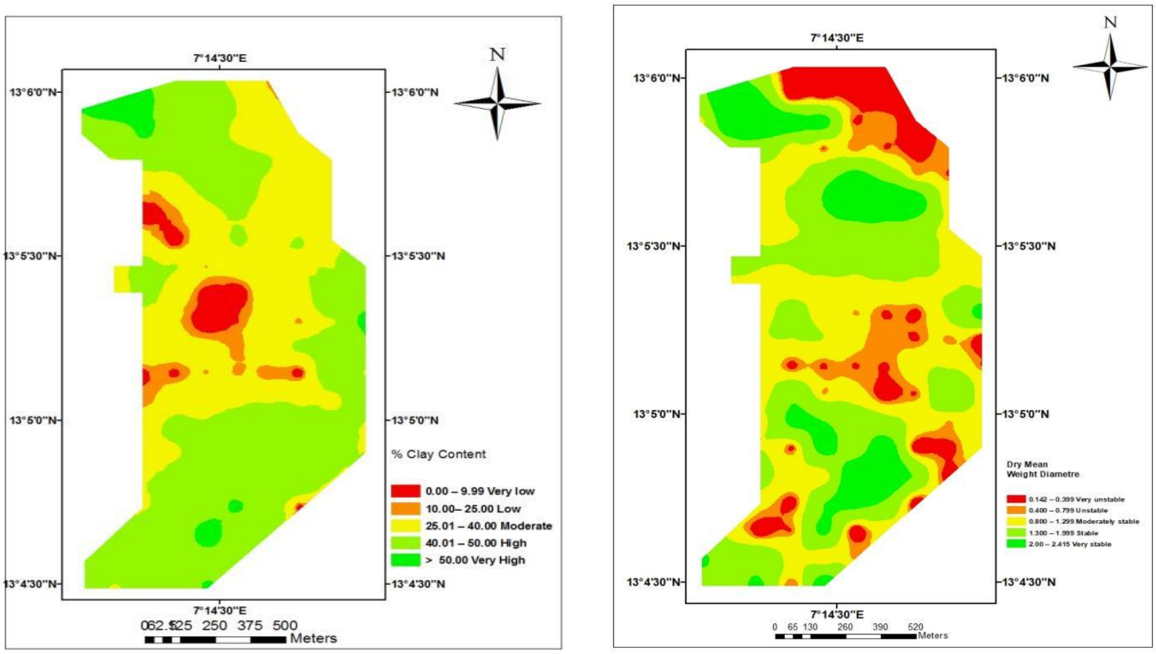


**Figure 3. Semivariogram map of clay and Dry mean weight diameter**

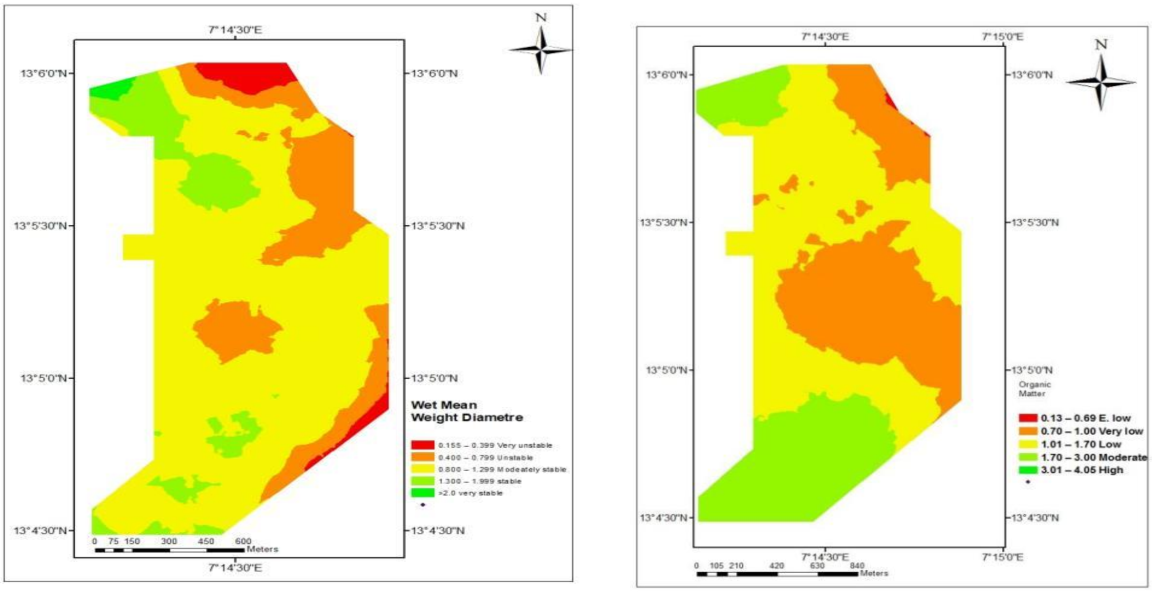


**Figure 4. Semivariogram map of wet mean weight diameter and OM**

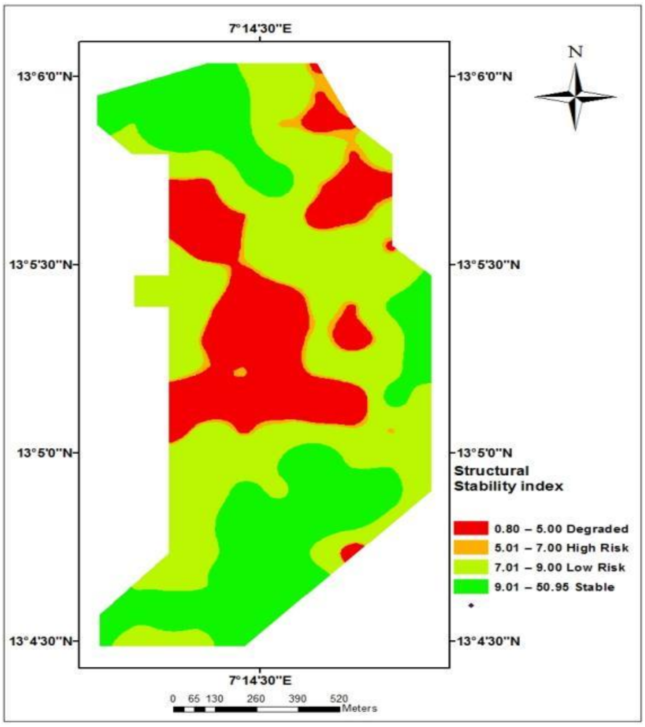


**Figure 5. Semivariogram Map of Structural Stability Index (SI)**

## CONCLUSION

This study highlighted the critical influence of soil texture and organic matter on aggregate stability and structural resilience in the semi-arid, irrigated fields of the Jibia Irrigation Project, Katsina State. The predominance of sandy soils, coupled with low organic matter content, has contributed to poor aggregation, weak structural stability, and increased susceptibility to erosion across much of the study area. Spatial and statistical analyses revealed that fine-textured components (clay and silt) and organic matter significantly enhance soil structural integrity, as evidenced by their strong positive correlations with mean weight diameter and structural stability index. Geostatistical modeling showed strong spatial dependence for soil texture and dry aggregate stability, suggesting that these properties are governed primarily by inherent soil characteristics such as parent material and mineral composition. In contrast, organic matter and wet aggregate stability exhibited weak spatial structure, indicating a stronger influence from land use, vegetation cover, and soil management practices. These findings underscore the importance of adopting site-specific soil management strategies that account for spatial variability to optimize soil health and productivity.

To improve soil structural stability in this region, we recommend increasing organic matter inputs through the use of compost, green manures, or residue retention, along with reduced tillage and careful irrigation management. The use of geostatistical tools such as kriging and semivariograms proved effective for identifying variability patterns and should be integrated into precision agriculture and land-use planning in similar environments. Ultimately, improving soil structure and resilience in semi-arid irrigated systems will enhance sustainable crop production and long-term land productivity.

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