Research Article

GIS-Based Assessment of Soil Physical Properties under Cultivated and Uncultivated Lands in Semi-Arid Conditions of Iraq

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Abstract | Understanding the spatial variability of soil physical properties is essential for sustainable land management and agricultural productivity under semi-arid conditions. This study evaluated the spatial distribution of selected soil physical properties under cultivated and uncultivated lands in Ghammas District, Al-Qadisiyah Governorate, central Iraq, using Geographic Information Systems (GIS) techniques. A total of 40 soil sampling sites were selected, including 30 cultivated and 10 uncultivated locations representing the dominant land-use systems within the study area. Soil samples were analyzed for particle-size distribution, soil texture, saturated hydraulic conductivity (Ksat), and mean weight diameter (MWD). Spatial interpolation and thematic mapping were performed using ArcGIS Desktop and the Kriging interpolation method to identify spatial variability patterns. The results revealed substantial heterogeneity in soil physical properties across the study area. Soil texture classes included clay, sandy clay, sandy clay loam, clay loam, loam, sandy loam, and sand. Sand content ranged from 21.12% to 90.40%, silt from 0.32% to 39.68%, and clay from 0.80% to 62.56%, with sandy loam identified as the dominant texture in both cultivated and uncultivated lands. Saturated hydraulic conductivity values ranged from 1.67 to 4.79 cm h^{-1}, with higher values generally associated with coarse-textured and uncultivated soils. Mean weight diameter values ranged from 0.307 to 1.409 mm, indicating considerable differences in aggregate stability and soil structural condition. Cultivated soils generally exhibited higher aggregate stability, whereas uncultivated coarse-textured soils showed comparatively higher saturated hydraulic conductivity values. The GIS-generated maps successfully identified zones with contrasting physical characteristics and demonstrated the influence of land use, soil texture, and agricultural management on soil behavior. Cultivated soils generally exhibited more diverse textural classes and relatively improved aggregate stability compared with many uncultivated sites. This study provides one of the first GIS-based assessments integrating laboratory measurements with spatial interpolation techniques to evaluate soil physical variability under cultivated and uncultivated lands in Ghammas District, thereby supporting site-specific soil and irrigation management in semi-arid regions of central Iraq.The integration of laboratory analyses with GIS spatial interpolation proved effective for evaluating soil physical variability and provided valuable information for irrigation management, soil conservation, and sustainable agricultural planning under semi-arid conditions in central Iraq.

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Introduction

Soil physical properties essentially determine water movement, aeration, root penetration and aggregate stability, thereby considerably affecting soil productivity, especially in semi-arid and arid areas where land degradation processes driven by water scarcity represent a major agricultural limitation. Soil texture, hydraulic conductivity and aggregate stability variability affect soil structure, infiltration rates, moisture retention, nutrient transport and crop performance. Thus, understanding the spatial variability of these properties is essential for sustainable soil management, agricultural planning and effective land-use practices in vulnerable ecosystems (Lal, 2020; Bünemann *et al*., 2018).

The influence of agriculture on soil physical properties depends largely on management practices. Under appropriate management, long-term cultivation can improve soil structure through organic matter accumulation and aggregate formation. In contrast, intensive tillage and inappropriate land-use practices may cause soil compaction, structural degradation, and hydraulic problems (Blanco-Canqui and Ruis, 2020). Therefore, agricultural activities may either improve or degrade soil quality depending on the type and intensity of management.

In contrast, uncultivated lands are generally less disturbed and retain some of the structural characteristics that have altered biological activity and reduced aggregate development in soils managed under agriculture-related practices depending on environmental and climatic conditions.Soil texture, an inherent soil feature that determines the sizes of soil pores holding water and air, soil moisture characteristics (which dictate how easily water infiltrates into or moves through soils) and erodibility. The proportions of sand, silt and clay affect hydraulic and mechanical properties as well as land-use factors (Hillel, 2004). Saturated hydraulic conductivity (Ksat) is the ability of soil to transport water under saturated conditions and is a key parameter governing infiltration, drainage, irrigation efficiency, and water movement through soil pores (Reynolds *et al*., 2018). Mean weight diameter (MWD), which is an important indicator of the aggregate stability that plays a large role in soil structure, aeration, root growth and can potentially reduce erosion (Hundi *et al*., 2026).

Soil properties have spatial variations along with the parent material, topography, climate, land use and cultivation and hydrology most likely in a very short span of distance. This heterogeneity is not captured by traditional point analyses. Geographic Information Systems (GIS) combines field data with lab results and spatial interpolation methods to derive soil properties maps for precision agriculture and land management purposes (McBratney *et al*., 2003).

GIS spatial analysis helps to visualize distribution of soil properties and pInG throughout an area, but allow us to identify degradation, hydraulic issues or instability in a given part of that area. GIS is also used to assess soil quality and land suitability and analyze the spatial impact of land use worldwide (Keskin *et al*., 2019; Tesfahunegn *et al*., 2021). In Iraq, GIS-based studies concerning soil physical properties under various land uses are few in a semi-arid agricultural zone. The Ghammas District, located in Al Qadisiyah Governorate, is vital agricultural land for rice, wheat, barley and more. Nevertheless, site-specific data on spatial soil physical variability and land use impacts are very limited. Under semi-arid conditions, evaluating these properties using GIS techniques may contribute to improved soil management, agricultural sustainability, and productivity.

Based on the identified research gap and previous studies, this study evaluates spatial variability of soil texture, particle size, Ksat and MWD under cultivated and uncultivated lands of Ghammas using GIS. This research is designed to explore and map these properties and how land use affects the soil physical behavior in a semi-arid environment of central Iraq.

Materials and Methods

Study area

The study area is Ghammas District, located in Al-Qadisiyah Governorate, central Iraq, where rice, wheat, barley, and other crops are cultivated. The region is characterized by a semi-arid climate. The area experiences high summer temperatures, limited rainfall, and high evaporation rates, which significantly influence soil properties and agricultural productivity (Allen *et al*., 1998). A total of 40 soil sampling sites were selected across the district, including 30 cultivated and 10 uncultivated locations. Adequate spatial coverage was obtained from sites identified by GIS and georeferenced by GPS (Burrough and McDonnell, 1998). Coordinates varied from 44.497724° to 44.774895° E and 31.624375° to 31.843889° N. The locations of Iraq, Al-Qadisiyah,

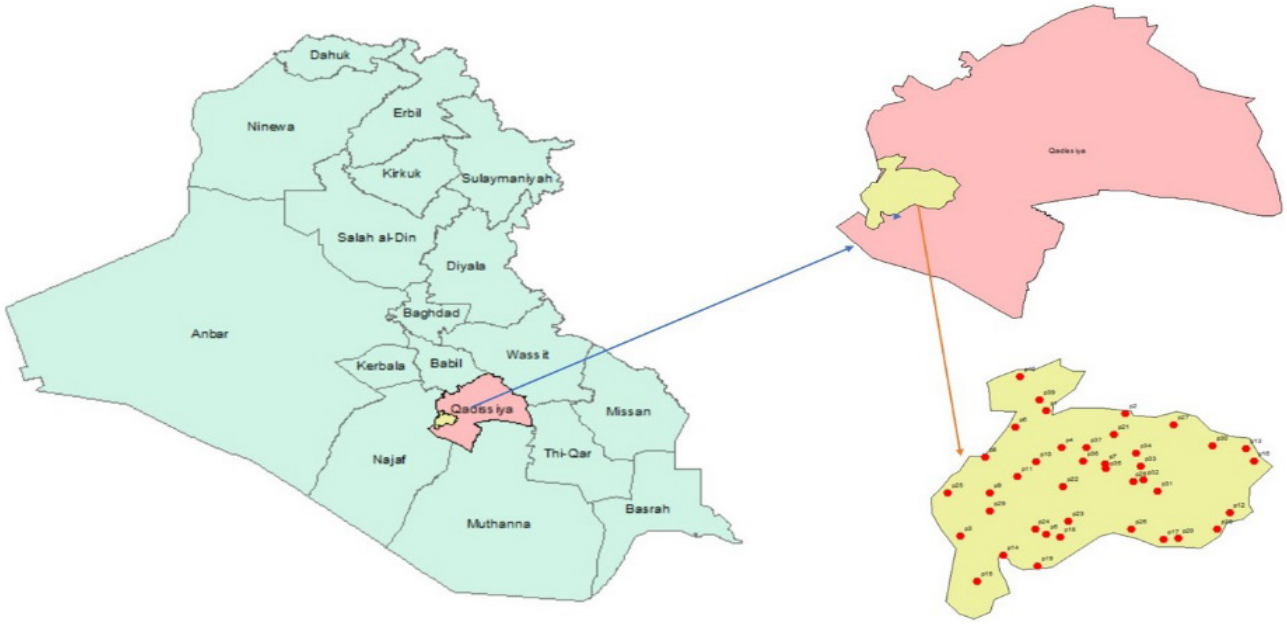

Figure 1: *Map indicating the Ghammas District In Al-Qadisiyah Governorate, Iraq and the positions of 40 soil sampling sites used for this study.*

Ghammas Districts and the sampling sites are presented in Figure 1.

The geographic coordinates of all sampling locations used in the present study are presented in Table 1.

Table 1: *Geographic coordinates of the soil sampling sites in Ghammas District, Al-Qadisiyah Governorate, Iraq.*

ID	Longi-tude_X	Lati-tude_Y	ID	Longi-tude_X	Lati-tude_Y
p1	44.586944	31.807500	p21	44.647994	31.781734
p2	44.658574	31.804612	p22	44.602243	31.725984
p3	44.509148	31.673086	p23	44.606667	31.689167
p4	44.600556	31.767778	p24	44.577261	31.680278
p5	44.586745	31.675213	p25	44.497724	31.719348
p6	44.558844	31.789729	p26	44.664154	31.680285
p7	44.640278	31.750000	p27	44.702196	31.792099
p8	44.531310	31.757579	p28	44.665556	31.731667
p9	44.535799	31.719368	p29	44.535576	31.699647
p10	44.577778	31.752778	p30	44.737588	31.769892
p11	44.560833	31.736667	p31	44.687500	31.721389
p12	44.752935	31.698258	p32	44.674722	31.733056
p13	44.767730	31.766832	p33	44.672500	31.747778
p14	44.547911	31.652494	p34	44.668333	31.761944
p15	44.524288	31.624375	p35	44.641111	31.745556
p16	44.774895	31.753216	p36	44.620278	31.753611
p17	44.692946	31.669702	p37	44.623056	31.768056
p18	44.599777	31.671986	p38	44.741746	31.680152
p19	44.578900	31.641105	p39	44.580833	31.818889
p20	44.706397	31.670569	p40	44.563333	31.843889

Soil sampling and laboratory analyses

Soil physical properties in cultivated and uncultivated lands were assessed in terms of their spatial variability, for which soil samples were collected from selected sites. Disturbed soil samples were collected for the determination of soil texture, particle-size distribution, and aggregate stability, whereas undisturbed soil samples were collected for saturated hydraulic conductivity measurements. Samples were dried in the open air, crushed with a wooden pestle and hand sieve (2 mm) prior to analysis according to standard protocols developed by Klute (1986).

Soil texture and particle-size distribution

Soil texture and particle-size distribution were determined to quantify the relative proportions of sand, silt, and clay fractions within the investigated soils. The hydrometer method was employed after dispersing soil particles using an appropriate dispersing solution according to the procedure described by Gee and Bauder (1986). Soil textural classes were subsequently identified according to the USDA textural triangle system based on the measured percentages of sand, silt, and clay (Soil Survey Staff, 2014). The obtained results were later integrated into the GIS environment to evaluate the spatial distribution of soil texture classes and particle-size fractions across the study area.

Saturated hydraulic conductivity (Ks)

Saturated hydraulic conductivity (Ksat) was determined to evaluate the ability of soil to transmit

water under saturated conditions. Measurements were conducted using the constant-head method according to standard soil physics procedures described by Reynolds *et al.* (2002). Hydraulic conductivity values were calculated based on Darcy's law using the following equation:

$$KS = \frac{V}{At} \times \frac{L}{\Delta H}$$

- KS = Soil saturation Hydraulic conductivity (cm. min^{-1})
- V = the volume of water passing through the soil column (cm^3)
- L = Soil column length (cm)
- A = the cross-sectional area of the soil column (cm^2)
- T = Time (minute)
- ΔH = L+ Height of the water above the soil column (cm)

Mean weight diameter (MWD).

Soil aggregate stability was evaluated using the mean weight diameter (MWD) index, which is considered one of the important indicators of soil structural stability and resistance to degradation. Aggregate distribution was determined using the wet sieving method through a series of sieves with different mesh diameters following the procedure described by Kemper and Rosenau (1986). The MWD values were calculated using the following equation:

$$MWD = \Sigma^{n}_{i=1} Xiwi$$

- MWD = Mean weight diameter (mm)
- Xi = Diameter rating for any size range of separated assemblies (mm)
- Wi = The weight of the remaining aggregates within one size range as a ratio to the total dry weight of the soil sample (g)
- The calculated MWD values were used to assess aggregate stability and soil structural behavior under different land-use systems.

GIS Spatial analysis

The soil spatial distribution maps of different soil properties studied were generated in the GIS environment using ArcGIS Desktop (ArcMap) software. The geographic coordinates of the field sampling sites were recorded and mapped, structured as well as integrated spatially within the GIS wide information system database to allow for thematic mapping (Chang, 2018). Continuous distribution maps were generated to represent the spatial variability of the investigated soil physical properties, These maps were produced using spatial interpolation techniques. Among the available interpolation methods, Kriging is widely recognized for its ability to provide reliable spatial predictions of soil variables (Webster and Oliver, 2007), we adopted the Kriging interpolation method. The optimal interpolation model was selected based on statistical accuracy criteria and prediction performance. Afterwards, the classification and visualization were carried out to produce the final thematic maps of soil texture fractions, saturated hydraulic conductivity and mean weight diameter. Subsequently, these maps were used to identify spatial distribution patterns and evaluate the impacts of cultivated and uncultivated land-use systems on soil physical properties in semi-arid environments.

Results and Discussion

Spatial variability of soil texture and particle-size distribution

Particle-size distribution characteristics varied considerably by soil texture in the Ghammas District of cultivated and uncultivated lands as well as spatially (Table 2). Soils were characterized with proximal to distal proportioning of sand, silt and clay yielding classes such as clay, sandy clay, sandy clay loam, clay loam, loam,sandy loam and sand. This variability can be attributed to the parent material, sediment delivery, land-use practices including irrigation and hydrological conditions. In semi-arid alluvial settings, the differences in texture vary with unique cycles sediment transportation, particle redistribution from irrigation and soil development.

The investigated soils exhibited wide variation in particle-size fractions, with sand ranging from 21.12% to 90.40%, silt from 0.32% to 39.68%, and clay from 0.80% to 62.56%. The clay content was highest at Site P3 (forage maize) (62.56%) which also classified it as clay (< 25% fine sand; Gee and Or., 2002), followed closely by Sites P1 and P8 with equally high levels of clay % at 53.60% and 46.72%, respectively. The dominance of clay in cultivated sites reflects the accumulation and stabilization of fine sediments through irrigation and agriculture, allowing soils with higher water-retention capacities and greater nutrient retention abilities to take hold over time.

The lowest clay content (0.80%) was recorded at Site P10 (cowpea, okra, pumpkin), resulting in sandy

Table 2: *Particle-size distribution and soil texture classes of cultivated and uncultivated lands.*

Land use / Crop type	Site No.	Sand (%)	Silt (%)	Clay (%)	Soil texture
Wheat	P1	30.24	16.16	53.60	Clay
Wheat + Rice	P2	45.60	20.32	34.08	Sandy Clay Loam
Forage Maize	P3	21.28	16.16	62.56	Clay
Wheat	P4	53.12	0.32	46.56	Sandy Clay
Fallow	P5	56.32	19.84	23.84	Sandy Clay Loam
Wheat	P6	40.96	28.64	30.40	Clay Loam
Wheat	P7	44.80	36.64	18.56	Loam
Alfalfa + Barley	P8	21.12	32.16	46.72	Clay
Fallow	P9	42.24	20.48	37.28	Clay Loam
Cowpea + Okra + Pumpkin	P10	87.52	11.68	0.80	Sand
Barley	P11	68.96	16.80	14.24	Sandy Loam
Barley	P12	39.52	39.68	20.80	Loam
Alfalfa	P13	70.40	20.96	8.64	Sandy Loam
Wheat	P14	86.40	8.48	5.12	Sand
Fallow	P15	53.28	4.48	42.24	Sandy Clay
Fallow	P16	76.32	7.84	15.84	Sandy Loam
Fallow	P17	64.48	3.68	31.84	Sandy Clay Loam
Fallow	P18	72.64	19.52	7.84	Sandy Loam
Barley	P19	55.68	35.68	8.64	Sandy Loam
Wheat	P20	73.12	12.48	14.40	Sandy Loam
Barley	P21	69.28	13.60	17.12	Sandy Loam
Sesame	P22	90.40	4.32	5.28	Sand
Alfalfa	P23	77.44	8.16	14.40	Sandy Loam
Clover	P24	42.24	28.32	29.44	Clay Loam
Fallow	P25	68.48	23.68	7.84	Sandy Loam
Barley	P26	52.00	35.36	12.64	Sandy Loam
Barley	P27	55.36	27.36	17.28	Sandy Loam
Okra	P28	35.68	31.52	32.80	Clay Loam
Okra	P29	54.40	28.32	17.28	Sandy Loam
Eggplant	P30	58.24	28.32	13.44	Sandy Loam
Local Cucumber + Cowpea	P31	63.20	19.84	16.96	Sandy Loam
Barley	P32	76.48	11.68	11.84	Sandy Loam
Alfalfa	P33	74.40	16.32	9.28	Sandy Loam
Forage Maize	P34	43.52	23.52	32.96	Clay Loam
Sesbania (Forage)	P35	59.84	20.00	20.16	Sandy Clay Loam
Cowpea	P36	70.40	12.32	17.28	Sandy Loam
Cowpea	P37	43.52	23.52	32.96	Clay Loam
Fallow	P38	76.48	11.68	11.84	Sandy Loam
Fallow	P39	64.32	19.84	15.84	Sandy Loam
Fallow	P40	72.48	15.68	11.84	Sandy Loam

soil; similar sandy textures are also observed at P14 and P22 with sand 86%. The soil's properties affect various physical processes in the soil, such as"course" soils have rapid infiltration rates, weak cohesion to retain water and nutrients.Therefore it can stimulate drought stress in semi-arid climatesand usebetter management practices of irrigation and fertilization.

Sandy loam was the most common texture class, especially at the sites disposed in P11, P13, P16,

P18, P20, P21, P23, P25-P27 and 29-33 and further supports as coarse alluvial deposits that lead to balanced features of the soils such as permeability, aeration and root penetration making them suitable for cultivated agriculture with proper irrigation (Brady and Weil 2017).

Localized finer sediment zones of lower drainage (dominated by clay and clay loam) were mainly common in cultivated lands, indicating long-term farming practices and irrigation if this is the case redistribute and stabilize fine particles. Clay movement is influenced by tillage, crop residues, irrigation flow and sediment deposition within fields.

The uncultivated sites mainly fallow, such as P16, P18, P25 and P38-P40 had sandier textures (sandy loam, sandy clay loam, sandy clay) suggesting lower aggregate stability and increased risk of erosion. Erosion is exacerbated with a lack of vegetation and organic matter by the selective removal of silt and clay, causing the accumulation of coarser particles (Borrelli *et al.*, 2017). Soils were more heterogeneous in cultivated lands due to the interaction of agricultural management with natural deposition resulting in a higher range of textures (clay, clay loam, loam, sandy clay loam and sandy loam). Soil particle-size distribution and structure are important ecological conditions in semi-arid agricultural areas (Bunemann *et al.*, 2018) Land-use is one of the most key factors impacting on soil characteristics, especially particle size and structure.

The findings revealed clear heterogeneity of soil texture in the study region (Figure 2) represented by GIS spatial distribution map. Sandy/ sandy loam soils dominated in the eastern and southeastern areas, whereas clay/ clay loam interpreted in the western and northwestern regions. The pattern is linked to how sediments are delivered, buried and transported horizontally because of elevation differences and irrigation water. Regions deeply saturated by finer sediments transported via irrigation or rapid deposition will typically build up more clay and silt compared to higher mesophytic elevations or regions prone to erosion.

GIS efficacy was confirmed by the interpolation results used in mapping soil variability and comparing physical characteristics. Soil texture affects irrigation, nutrient retention, root growth and crop yields leading to the necessity of managing spatial heterogeneity for agriculture. They provide for the characterization of management zones and land-use planning in semi-arid systems. (Tesfahunegn *et al.*, 2022) Similar trends in soil texture were documented and published in 2022 by Recha *et al.* (2022) was focused on how GIS (geographic information system) is useful in soil assessment and precision management. Cultivated areas dominated by sandy loam and sandy clay loam textures generally provide favorable conditions for crop growth due to adequate aeration, permeability, and water movement. Sandy soils with little clay in semi-arid areas are then susceptible to rapid moisture loss and inability to retain nutrients. Among the topics is evidence that clay soils can suffer as a result of excessive agricultural practices and machinery use including compaction, low infiltration rates and drainage problems as well as poor aeration (Dexter, 2004). The spatial distribution of soil textures in Ghammas District appears to be influenced by land-use practices, sediment deposition processes, irrigation activities, and inherent soil-forming factors, resulting in a wide range of texture classes from coarse- to fine-textured

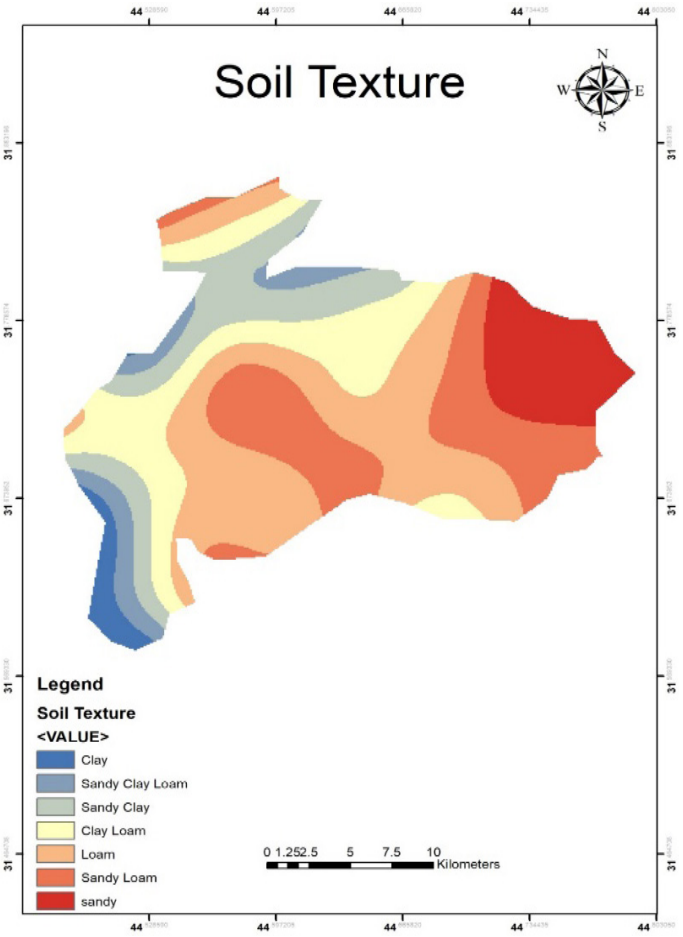

Figure 2: *Spatial distribution map of soil texture classes in ghammas district generated using GIS spatial interpolation techniques.*

soils. In conclusionsThe method described in this article for blending lab evaluations and GIS based interpolation for identifying soil zones is a useful step toward directing sustainable soil management practices and agricultural planning across semi-arid central Iraq.

Spatial variability of saturated hydraulic conductivity

Saturated hydraulic conductivity (Ksat) revealed high variability across cultivated and uncultivated lands at the Ghammas District, which was described by the characteristics of soil structure or water flow as shown in (Table 3 and Figure 3). The Ksat fell between 1.6679 and 4.7915 cm h -1, showing a rather heterogeneous soil conditions across the semi-arid area (Jarvis *et al*., 2013). The lowest Ksat values at site P24 (clover) and site P1 (wheat) were, most likely, attributed to their relatively fine-textured soils (fine textured soils with little pore continuity or water movement). Cultivation and machinery traffic also contribute to compaction leading to reduction in macroporosity and Ksat (Jarvis *et al*., 2017). Sites P5 and P25 (uncultivated) had highest Ksat values as well as others (P18, P17, or P38 above 3.80 cm h^{1-}). These were however coarse-textured soils (sandy loam, sandy clay loam) which would favour larger pores and quicker water movement. Conserving Pore Structures Improves Conductivity Tillage reduces natural pore structures and creates new structure, whereas lack of tillage preserves them as well.

Ksat is driven by soil texture; sandy soils so had moderate to high Ksat across the profile because of many macropores in layers at 10–30 cm and 50–80 cm, whereas clay-rich soils exhibited lower Ksat due to restricted pore continuity. Guo *et al*. (2020) They reported in semi arid conditions greater permeability of coarse soils (2020). Ksat for cropland was intermediate, being moderate depending on crop species present and management practices of irrigation and tillage, which affect the structural form of macropores through compaction. Higher Ksat at uncultivated sites generally reflected lesser disturbance at these sites with coarser particles from erosion and sediment redistribution. But land use only partly explains hydraulic conductivity, which is also influenced by inherent soil texture, sediment history and local conditions.

The GIS-based spatial distribution map of saturated hydraulic conductivity highlighted clear spatial patterns over the study area (Figure 3). Moderate conductivity classes were the most common, primarily in the central and eastern regions of the District (between 2.5 and 3.0 cm h^{-1}). In contrast, lower conductivity was limited to several northern regions with finer-textured soils whereas elevated electrical conductivity classes greater than 3.25 cm h^{-1} were largely restricted to western and south-western sectors linked to coarser soil textures.

Table 3: *Spatial variability of saturated hydraulic conductivity (Ksat) in cultivated and uncultivated lands of Ghammas District, Al-Qadisiyah Governorate, Iraq.*

No.p	Value	No.p	Value
p1	1.7286	p21	2.2138
p2	1.9308	p22	2.7698
p3	2.881	p23	1.8701
p4	2.3958	p24	1.6679
p5	4.7915	p25	4.6702
p6	2.2037	p26	2.4766
p7	2.5575	p27	2.3048
p8	2.1607	p28	2.4337
p9	4.4579	p29	2.8709
p10	2.8911	p30	2.1936
p11	2.2947	p31	2.699
p12	2.0015	p32	2.3533
p13	2.2517	p33	2.5878
p14	2.8608	p34	2.1607
p15	2.5069	p35	2.4463
p16	3.4723	p36	2.5959
p17	3.9121	p37	2.2684
p18	4.6096	p38	3.8413
p19	2.7293	p39	3.2348
p20	2.5878	P40	2.9315

Differences in Ksat distribution among the various segments of the alluvial plain at this site may be attributed to differences in depositional environment, irrigation water movement regime, sediment accumulation rates and soil structural development across the study area. Hydraulic conductivity variability is significant in semi arid agricultural systems because it governs infiltration rate, irrigation efficiency, drainage performance and salt and water movement and its availability under root zone. Arguably even if a blatant usage of it during watering, sites that have extremely low conductivity could be susceptible to surface overland movement, elongated inundation and deplorable aeration which leads to

strongly diminished returns on irrigation.

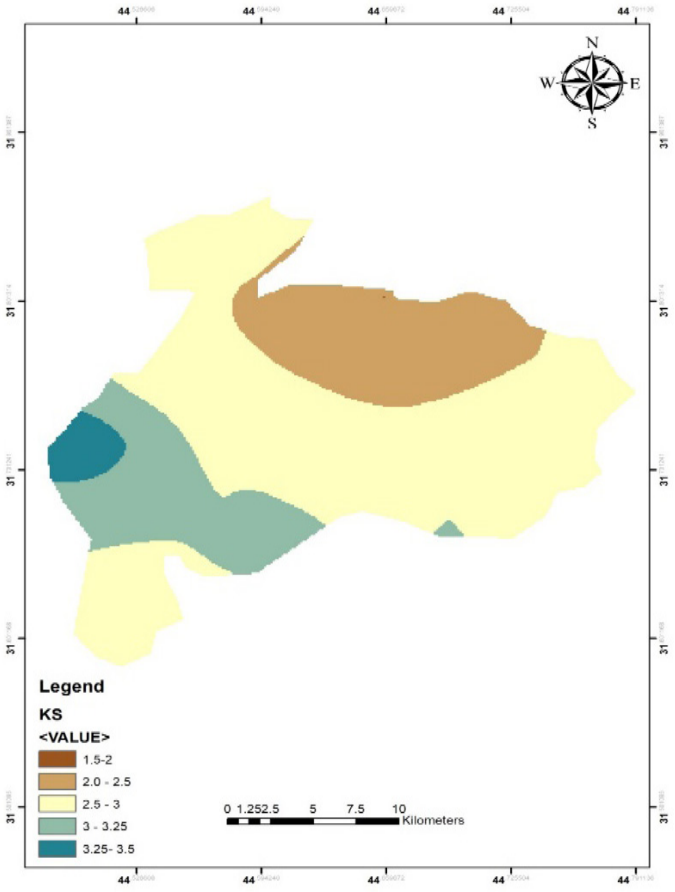

Figure 3: *Spatial distribution map of saturated hydraulic conductivity (Ksat) in Ghammas District generated using GIS interpolation techniques.*

The results demonstrated the effectiveness of GIS techniques for mapping areas with contrasting hydraulic response and for visualising spatial heterogeneity of soil water transmission properties. Such spatial information may provide the perfect starting point for site specific irrigation management, soil conservation planning and sustainable agricultural development in semi-arid areas. This exact finding has been gotten in similarl studies done by Neshat *et al*., 2021; However, GIS-based spatial interpolation greatly improves soil hydraulic properties analysis in heterogeneous systems and has been applied successfully to aid precision agriculture (Neshat *et al*., 2021).

Overall, The findings confirm high influence of soil texture, land use, pore distribution and environmental conditions on the variability of saturated hydraulic conductivity across Ghammas District. The integration of field measurements with GIS spatial analysis distinguished spatial zones characterized by variable hydraulic behavior and provided insights aimed at optimizing irrigation management and soil sustainability under semi-arid conditions in central Iraq.

Spatial variability of mean weight diameter (MWD). The analysis of mean weight diameter (MWD) indicated a high spatial variability in soil aggregate stability between the cultivated and uncultivated lands in Ghammas District (Table 4 and Figure 4). This variation in soil structure stability, aggregate cohesion and degradation resistance to the soils studied was reflected in MWD values that ranged from 0.3069 to 1.409 mm. The variability is linked to the interaction of texture, farming system adopted, methods of cultivation, available moisture (both organic and irrigation) as well as prevailing ecosystem services played by climate change in a semi-arid region.

Table 4: *Spatial variability of mean weight diameter (MWD) in cultivated and uncultivated lands of Ghammas District, Al-Qadisiyah Governorate, Iraq.*

No.p	Value	No.p	Value
p1	1.2018	p21	0.9149
p2	1.085	p22	0.478
p3	1.164	p23	1.003
p4	1.0068	p24	0.7773
p5	0.37478	p25	0.3315
p6	1.0116	p26	0.609
p7	1.0095	p27	0.9432
p8	1.205	p28	0.8252
p9	1.409	p29	0.697
p10	0.5174	p30	0.6706
p11	0.637	p31	0.5676
p12	0.7781	p32	0.665
p13	0.6886	p33	0.8508
p14	0.794	p34	1.0147
p15	0.9197	p35	0.706
p16	0.3069	p36	0.7479
p17	0.438	p37	1.1532
p18	0.3326	p38	0.544
p19	0.7047	p39	0.382
p20	0.624	P40	0.3207

In the Hansen values, mean weight diameter at site P9 was 1.409 mm on fallow land and it is a value greater than that of other sites MWD in the same manner as before sites; P6> P5>P4>P3>P2>P1 compared to their analysis and findings. In sites P1, P3, P8 and P37 the values were also high (i.e., > 1.15

mm). Higher values of MWD indicate a more stable aggregation associated with high binding strength between soil particles. Thus stabilization aggregates can enhance physical properties of soils by increasing pore continuity and consequently infiltration, aeration and more resistance erosion factors. Through stronger structural development, the organic binding agents together with biological interactions can also be interpreted as an improved connection between clay and aggregates resulting in increased aggregate stability (Totsche *et al.*, 2018).

The high MWD values recorded in some cultivated sites (P1, P3, P8 and P37) can be explained by stabilization of the landscape cover and nutrient cycling as a result of continuous root growth and organic matter input from cultivation systems. Microbial turnover and leaching of adhesins from decaying organic detritus and fleshy roots are crucial to soil aggregate stabilization because making aggregates larger with microbes increases their stability. Furthermore, we may have clay-rich soils previously identified in these regions facilitating the states of aggregates with stronger attachment due to higher surface contact.

On the other hand, the lower MWD values were recorded for sites P16, P40 as well as P25 and P18 where the values decreased to 0.3069; 0.3207; 0.3315 and 0.3326 mm in respectively Most of these sites were place into Managed Non-Cultivated or Coarse-Textured Systems dominated sandy loam textures. Low mineralogical and organic-matter contents are limiting factors that inhibit binding forces within coarse-textured soils capable of cementing particles to create stable aggregates; thus, aggregate stability was impaired due to the low capacity for particle bonding in soils such as Sandy land fields (probably observed by rapid rains or irrigation) Similar results were obtained in the study by Rabot *et al.* (2018) Under dryland conditions, even the use of cover crops on sandy soils typically resulted in low aggregate stability due to weak particle cohesion and limited organic binding materials (Blanco- Canqui and Ruis, 2020).

In many uncultivated sites, the MWD values of cultivated lands showed moderate to relatively high levels. This trend may indicate the positive effect of plant roots, organic residue incorporation and seasonal wetting–drying cycles associated with irrigation on aggregate formation and stabilization. Root exudates and a shift towards greater biological activity leading to aggregate stability may have been most pronounced within wheat, forage maize, alfalfa and legumes in agricultural systems. However, excessive tillage intensity may hinder soil aggregation through disruption of stable structural units and organic matter degradation due to mechanical disturbance. Therefore, the co-variability observed in cultivated sites can be explained by differences in crop type, management intensity and soil texture regimes. The fallow soils, on the other hand, showed different behavior. Although P9 was one of the fallow sites with high MWD values, others such as P16, P18, P25, P39 and P40 had weak stability against disaggregating forces. This variation implies that aggregate stability in non-cultivated lands is very much determined by soil characteristics, mainly texture and clay, but also erosion processes and natural cover. Also, sites with higher clay contents tended to develop stable aggregates in the absence of cultivation, while coarse-textured sandy loam soils displayed weak structural coherence and a lower MWD.

The GIS-based spatial interpolation map of mean weight diameter (MWD) revealed clear spatial patterns of aggregate stability across the study area (Figure 4). Top soil mean weight diameter (MWD) classes ranged from 1.25 to 1.75 mm, and higher MWD areas were centered in the central and northwestern portions of the district, while lower MWD classes dominated areas along the southern and eastern regions that were characterized by coarser soil textures In the vast transitional regions of the study area, moderate aggregate stability classes (0.75–1.25 mm) occupied medium to high proportions of cover.

Such spatial patterns can also be closely associated with textual differences, covariance related to land–use systems or irrigation impacting soil properties and/or sedimentation events or processes. The implication was that clay and clay loam soils previously recognised as well were more kerbside tolerant of increased aggregate cohesion and fine-particle interaction, leading to relatively larger values for MWD. In contrast, sandy and sandy loam areas in these layers were characterized by lower aggregate stability apparently due to the decrease of clay and higher number of weak mechanism interparticle contacts. Qingli Zhang *et al* reported such relationships between

texture and soil aggregate stability. a novel observation of, fine-textured soils tend to show relative resistance to physical degradation in comparison to coarse-textured soils over semi-arid agricultural space.

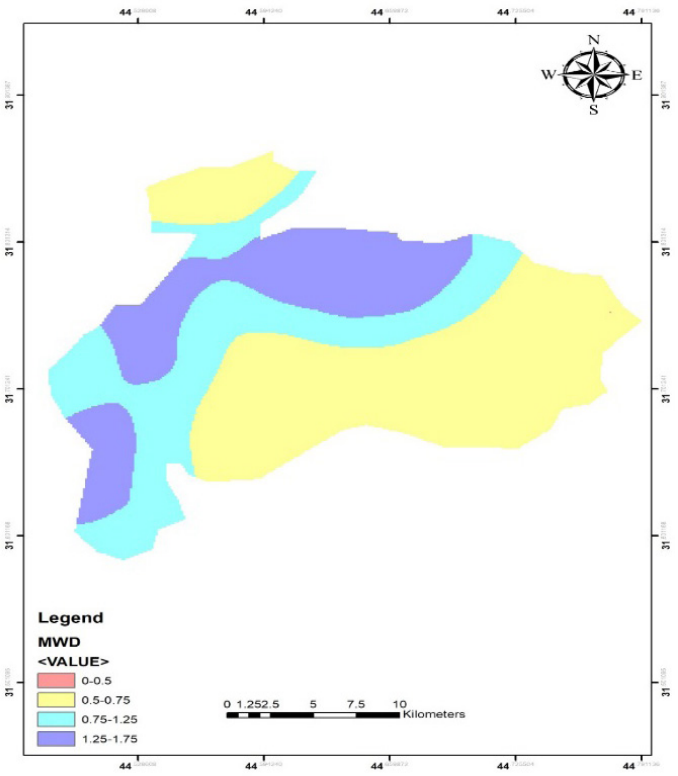

Figure 4: *Spatial distribution map of mean weight diameter (MWD) in Ghammas District generated using GIS interpolation techniques.*

Spatial analysis techniques to determine areas high risk of failure and erosion were validated using GIS-based interpolation results. Aggregate stability looks to us to be critical, as it is regarded as one of the most important soil physical quality indicators, and is an essential controlling factor that affects important processes like infiltration capacity (how fast water moves into the soil), resistance against surface sealing, root penetration and water retention behavior . There are underlying for soil with a exceptional skill to combination result in the process of crust formation and run-off generation extra susceptible in semi-arid climatic regions when drying events had low return intervals (Le Bissonnais, 2016).

Moreover, the previous assessment of soil texture and hydraulic conductivity characteristics combined with MWD spatial analysis will provide insight into soil physical process in this region. The high MWD sites were typically classified as being more organized structurally and functionally hydrologically balanced with the low-MWD soils characterized by weak aggregate structure indicating lower resistance to physical perturbation.

In summary, the results show that mean weight diameter in Ghammas District was strongly influenced by land use and texture in soil as well as environmental condition and aggregate cohesion. A successful case study ascertained that a GIS-based spatial interpolation analysis of the laboratory results provided useful information for sustainable soil management, erosion control, and agricultural planning under comparable semi-arid conditions in central Iraq.

Conclusion and Recommendations

This study demonstrated considerable spatial variability in soil physical properties of cultivated and uncultivated lands in Ghammas District, semi-arid region at the central Iraq. The mean weight diameter, saturated hydraulic conductivity and soil texture all had clearly significant differences among the sampling sites due to land use, soil texture, irrigation practices and environmental conditions. Results showed that sandy loam was the most common soil texture across most sites, while clays were found to have lower hydraulic conductivity compared with coarse-textured soils and larger aggregate stability. The zones identified by the GIS-based spatial analysis successfully exhibited contrasting physical properties and were effective in evaluating variability of soils for land management. This study provides one of the first GIS-based assessments of soil physical properties under cultivated and uncultivated lands in Ghammas District, contributing valuable baseline information for sustainable land management in semi-arid regions of Iraq. Despite the diversity of virgin sites showing poor structural stability, soils subjected to cultivation generally had relatively stable aggregates due to vegetation cover and agricultural management practices. The study suggests site-specific soil and irrigation management practices based on the spatial variability of soil leg characteristics. Conservation practices including reduced tillage, retention of crop residues and addition of organic matter to soils are also recommended for improving soil structure, increasing the water-use efficiency and sustaining agricultural production under semi-arid conditions in central Iraq.

Novelty Statement

This study presents one of the first GIS-based evaluations of soil physical properties under cultivated and uncultivated lands in Ghammas District, central Iraq.

Author's Contribution

All authors conceived and designed the study, performed field sampling, laboratory and GIS analyses, interpreted the data, wrote the manuscript, and approved the final version of the manuscript.

Generative AI and AI-assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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