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Spatial Variability Mapping of Selected Soil Properties of District Tando Allahyar, Sindh, Pakistan

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Abstract:

Identifying soil spatial differences and their mapping appeared to be one of the most crucial steps for the better management of soil resources, site-specific fertilization, and environmental health. This study aimed at spatial variability mapping of selected soil properties of district Tando Allahyar using GIS and kriging interpolation. Soil samples were collected (20 cm depth) from all agriculturally important union councils of three talukas of district Tando Allahyar, viz. Jhando Mari, Tando Allahyar, and Chamber, involving important cropping systems. Most soil textures (10 of 12) were present in the district. Loamy medium-textured (slightly or moderately) soil types were dominant followed by fine clayey heavy-textured soils and sandy or coarse-textured soils. The soils were mostly low (46%) to medium (45%) saline; strongly (38%) to slightly (24%) or medium (22%) alkaline, with some slightly acidic (13%) or neutral (3%) areas; low (84%) to medium (12.5%) or high (5%) organic matter content; low (55%) to high (31%) or medium (14%) phosphorus (P) content, and high (62%) to medium (28%) or low (11%) potassium (K) content. Spatial variability maps revealed the dominance of silty clay (fine/clayey), clay loam, sandy clay loam, loam (medium) and sandy loam (light/sandy) soil textures, with the dominance of low to high salinity areas, slightly to medium alkaline soils, low organic matter content, medium to adequate P content and adequate K content. The study concluded that the soils of district Tando Allahyar vary spatially and require site-specific fertilization and management practices for various soil properties.

Keywords: *GIS, Kriging, spatial variability mapping, Tando Allahyar, soil properties*

Introduction

Fertile soils are one of the most precious natural resources and are directly related to the affluence and economic strength of any nation. Therefore, wise management of soil resources is an indispensable activity for sustainable agriculture. Interestingly, soils differ spatially, and this variation mainly governs soil management and fertilizer recommendation for site specific nutrient management (Rajesh *et al*., 2023). Hence, the soils should be regularly monitored using standard protocols for maintaining their fertility to keep the fertilizer input cost at the bare minimum level (Rashid, 1996; Hou, 2023). Predicting the differences among various soil traits is a procedure used to delineate the deficiencies of plant nutrients (Leena *et al*., 2021). The GIS technique has been established as an authentic tool to identify and map the spatial differences for wise management of soil resources (Mousavifard *et al.*, 2012). It has remained the very subject of many recently published research studies (Rajesh *et al*., 2023). The GIS mapping effectively addresses soil variations, based on logical sampling techniques (Lawrence *et al.*, 2020), involving the collection, management, analysis, and dissemination of results of large sets required to achieve the goals of low-input sustainable agriculture (LISA) and healthy ecosystem and environment (Mousavifard *et al*., 2012). District Tando Allahyar is one of the top revenue generating districts of Pakistan, mainly because of its contribution in agricultural production. It plays vital role in provincial and national economy due to its suitability for the climates of variable extremes, to grow a variety of important cash crops such as sugarcane, cotton, wheat, banana, gram, etc. (FAO, 2017). The soils of district Tando Allahyar are characterized by the parent material having mixed alluvial deposit and widely variable properties, with dominant soil series including Jaccobabad, Nabipur,

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Shahdara and Pacca which greatly differ in their properties (FAO, 2017). The district spreads on an area of 173,000 hectares with almost 70% of cultivated area. However, the net sown cultivated area is about 75000 hectares while the left over (43,000 hectares) area includes fallow lands (GoS, 2021). Despite its being agriculturally important district of Sindh, the farmers of district Tando Allahyar surprisingly pay negligible attention in getting the soils of their farms analyzed and it has been reported that only 10% of the farmers utilize soil testing services (FAO, 2017). It is, therefore, very alarming in view of rapidly deteriorating status of Pakistan soils. It has been reported that N is deficient in almost all soils and P in almost 85% soils (Memon, 1996) while almost one-third soils are facing K scarcity (Zia-ul-Hassan *et al.*, 2008). Keeping in mind the significance of essential nutrients for plants, especially P and K, it looks extremely worthwhile to map the soil variations in one of the most agriculturally important districts of Sindh **-** Tando Allahyar **-** to manage them wisely in view of sustainable development goals (SDGs). The GIS mapping of soil variations has become very popular since the last decade and has remained the subject of many research studies (Ihsan, 2018). Nonetheless, there is no pertinent research study available in the literature focusing on soil spatial variability mapping. With these facts under consideration, we planned this first-ever study to map the soil differences in the agricultural fields of district Tando Allahyar to manage them in a befitting manner for better agriculture and environment.

Materials and Methods

Development of GIS maps of district Tando Allahyar: The latest demarcation proposed by the government of Pakistan was considered in this study. Accordingly, district Tando Allahyar has three talukas, viz. Jhando Mari, Tando Allahyar and Chamber. Based up on this document, and by utilizing the knowledge of the local people and administrative staff (*Tapedaar*) of the district government about the geographical boundaries of district Tando Allahyar, GIS map of district Tando Allahyar was developed using ArcGIS 10.6 ® (http://www.esri.com) and Google earth®.

Soil sampling methodology: Soils were sampled from different locations and cropping systems of district Tando Allahyar, as proposed by Ryan *et al.* (2001). The GPS locations were properly recorded for each sampling site using Magellan® Triton™ 200 (Map 1).

Soil analyses: The soil samples were collected at the depth of 20 cm, following standard methods outlined by Ryan *et al.* (2001), i.e. soil texture by Bouyoucos Hydrometer, EC, and pH (1:2 soil-water) by respective meters, organic matter by Walkley-Black procedure, and P and K by ABDTPA extractant.

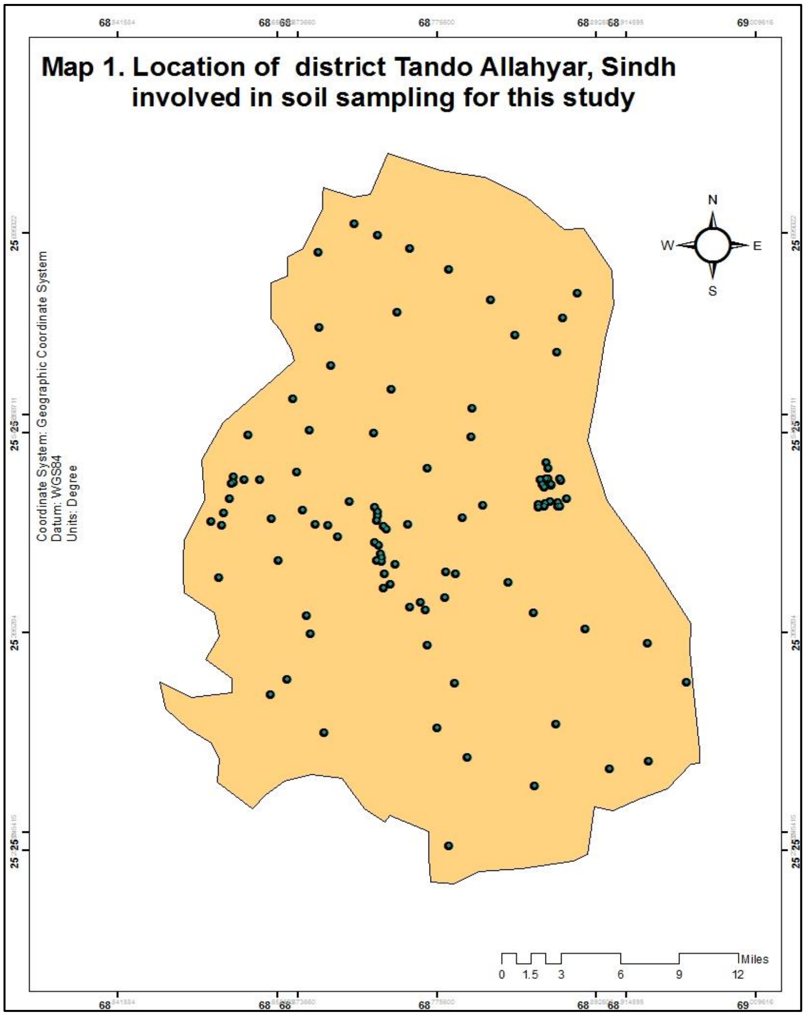
Quality Assurance: The validation of various soil analyses results was done by employing the standard laboratory protocols using reference material. Each soil sample was analyzed by running at least two replications and where necessary more repeats were also involved to obtain reliable and reproducible results.

Developing soil maps and spatial interpolation / geostatistical prediction: The delineation of spatial differences through interpolation and mapping of soils was achieved through ArcGIS 10.6® in addition to Google earth®. According to Zhu et al. (2020), "spatial interpolation is method of predicting the unknown value from known given values. Spatial interpolation is a traditional geostatistical process of predicting the attribute values of unobserved locations given a sample of data defined on point supports". Kriging is believed to be the best spatial interpolation technique. According to Wu *et al*. (2019), "Kriging is a type of geostatistical interpolation method with abundant variants",

Descriptive statistics: The primary data were processed through MS-Excel® (Microsoft, 2010) to compute basic statistics, viz. range, average, mode, standard deviation, and Coefficient of variability.

Results

Soil texture: Interestingly, the soil textures were very well distributed in the soil textural triangle. Out of twelve textural classes, eleven were found to be present in the district (Figure 1). The results further revealed (Table 1) that majority of soils (35.6%) had loamy slightly medium-textured type, including with the dominance (30.8%) of silt loam, followed by clayey, fine-textured heavy soil type (27.9%), including clay (18.3%), silty clay (6.7%) and sandy clay (2.9%). Soils with sandy, coarse-textured light type were 20.2%, including sandy loam (16.3), loamy sand (1.9%) and sand (1.9%). Loamy, moderately medium textured soils (16.3%) included clay loam (9.6%) and sandy clay loam (6.7%). Silty clay loam was absent (Table 1).



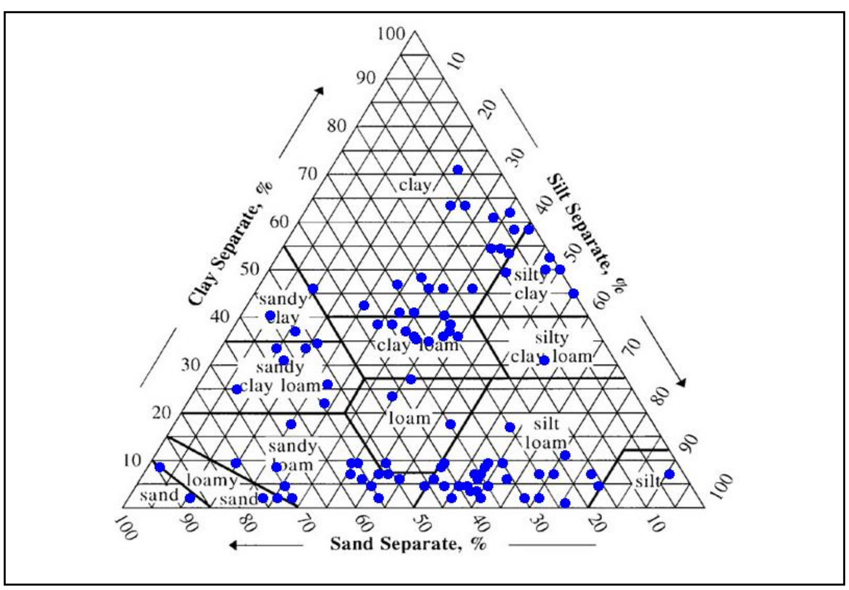


Figure 1. Soil textures present in district Tando Allahyar, Sindh

Table 1. Percent distribution of various soil textures and soil types found in district Tando Allahyar, Sindh

Clayey or Fine-textured or Heavy Soils	**27.9**
Clay	18.3
Silty Clay	6.7
Sandy Clay	2.9
Loamy moderately medium-textured soils	**16.3**
Clay Loam	9.6
Silty Clay Loam	0
Sandy Clay Loam	6.7
Loamy slightly medium-textured soils	**35.6**
Loam	3.8
Silt Loam	30.8
Silt	1.0
Sandy or Coarse-Textured or Light Soils	**20.2**
Sandy Loam	16.3
Loamy Sand	1.9
Sand	1.9

Soil salinity (EC dS m^{-1}): Soil salinity ranged from very low (0.14 dS m^{-1}) to low (4.44 dS m^{-1}). It was medium on an average basis (0.69 dS m^{-1}). However, most frequently found soils of the district had low salinity (mode: 0.42 dS m^{-1}). The data in Table 2 highlight that the soils of the district vary widely (CV: 94.2%). The categorization of soils (Sonon *et al*., 2015) revealed that most (91%) of the soils had negligible to moderate salinity (Figure 2).

Soil alkalinity (pH): The soils of district Tando Allahyar ranged from slightly (6.2) to medium alkaline (8.6) and medium alkaline on average basis (7.7). Most frequently, the soils of the district were strongly alkaline (mode: 8.3). Very low variation (CV: 8.4%) was found in the soils of the district for their alkalinity (Table 2). The categorization of soils for their alkalinity (Ankerman and Richard, 1989) revealed that majority (84%) of soils were alkaline in nature having slight to strong alkalinity (Figure 2).

Table 2. Descriptive statistics of various soil properties of district Tando Allahyar, Sindh

	EC (dS m^{-1})	pH	Organic matter (%)	ABDTPA-P (mg kg^{-1})	ABDTPA-K (mg kg^{-1})
Minimum	0.14	6.2	0.10	1.2	31
Maximum	4.44	8.6	1.60	18.8	376
Mean	0.69	7.7	0.64	5.38	154
Mode	0.42	8.3	0.17	2.40	230
Standard Deviation	0.65	0.65	0.32	4.26	81
CV %	94.2	8.4	51.0	79.2	52.8

Soil organic matter content (%): The soils of district Tando Allahyar had very low (0.10%) to high (1.6%) organic matter content, however, it was low on an average (0.64%) basis. Most of the soils had low (0.17%) organic matter content, and considerable variation (CV: 51%) was noted among soils for the organic matter content (Table 2). Further categorization of soils for their organic matter content (Cottenie, 1980) highlighted that most (84%) of the soils were low in their organic matter content (Figure 3).

ABDTPA-P content (mg kg^{-1}): The soils of district Tando Allahyar had low (1.2 mg kg^{-1}) to high (18.8 mg kg^{-1}) P content which was medium (5.38 mg kg^{-1}) on average basis. However, wide variation (CV: 79%) was noted among the soils of district for their P content with soils having low P content (2.4 mg kg^{-1}) found frequently (Table 2). The ranking of soil P (Soltanpour and Schwab, 1977) suggested that 55% of soils were low, 14% medium and 31% high in their P content (Figure 4).

ABDTPA-K content (mg kg^{-1}): The soils of district Tando Allahyar had low (31 mg kg^{-1}) to high (376 mg kg^{-1}) K content, which was high (154 mg kg^{-1}) on average basis. Interestingly, considerable variation (CV: 53%) was noted in soils for their K content and soils with high K content (230 mg kg^{-1}) were found frequently (Table 2). The ranking of soil K (Soltanpour and Schwab, 1977) suggested that 62% soils had adequate, 28% soils had medium, and 11% soils had low K content (Figure 5).

Geostatistical processing and mapping for spatial variation among soil properties: All soil textures were found present in district Tando Allahyar, ranging from heavy clays to light sands and slightly to medium-textured loams. Notably, loam, sandy clay loam, sandy loam, silty clay, and clay loam were dominant soil textures. Silt, silt loam, clay and sandy clay textures were negligible (Map 2). Majority of areas of the district had medium salinity followed by low and high salinity areas (Map 3). Slightly to medium alkaline soils were dominant in the district, however, considerable strongly alkaline areas were also found (Map 4). Moreover, the soils of district were identified to have low organic matter content, with some pockets having high organic matter (Map 5), frequently available soils with medium to adequate soil P, with a few instances of low P soils (Map 6) and the dominance of soils with adequate K (Map 7).

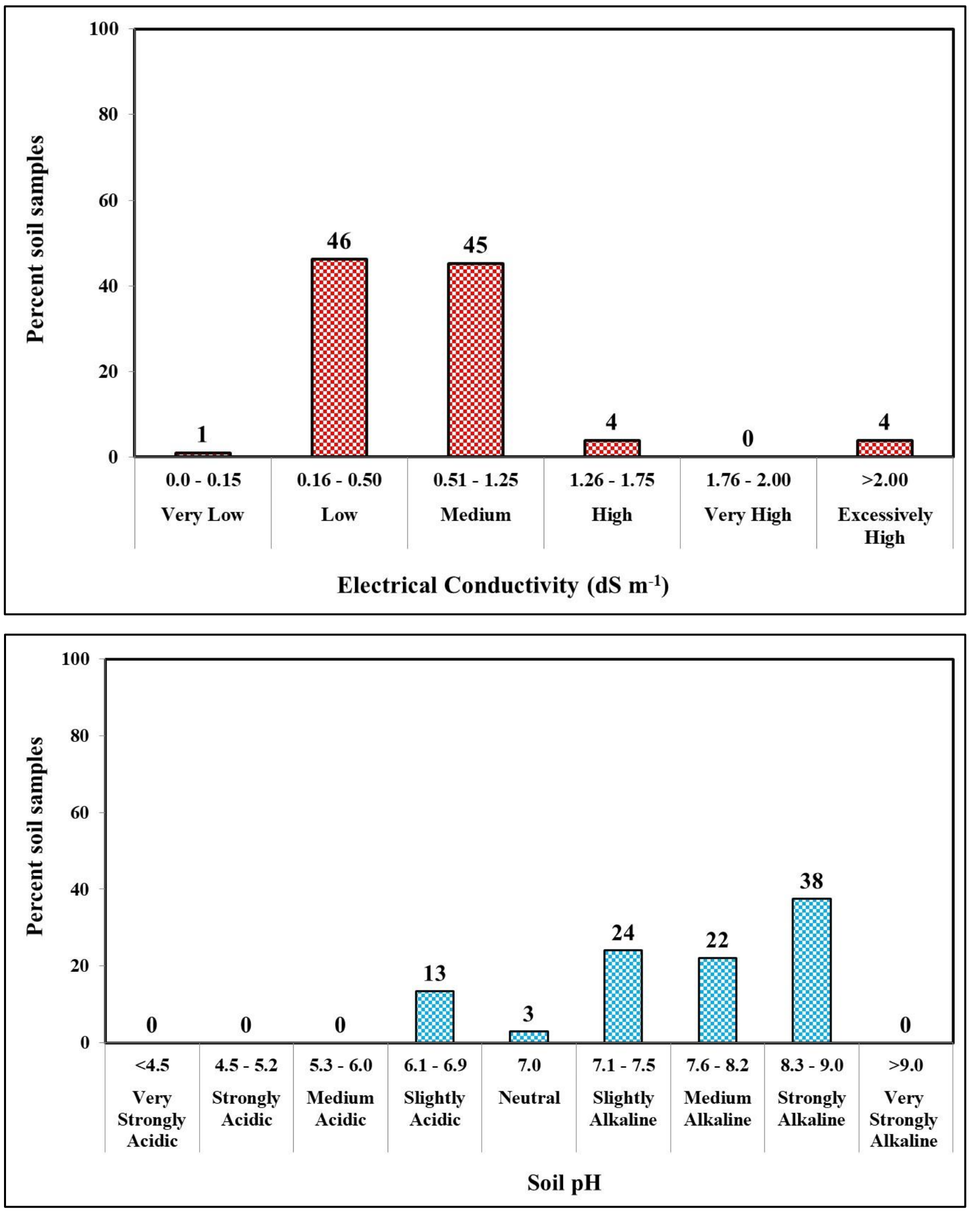


Figure 2. Categorization of soils of district Tando Allahyar, Sindh based on electrical conductivity (Sonon *et al*., 2015) **and pH** (Ankerman and Richard, 1989)

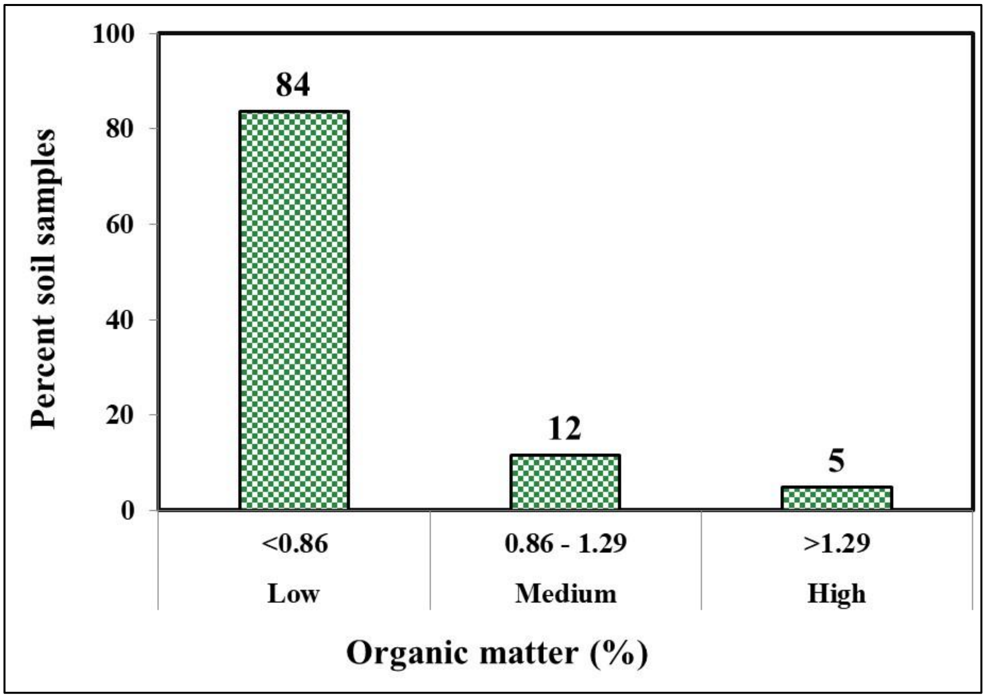


Figure 3. Categorization of soils of district Tando Allahyar, Sindh based on organic matter content (Cottenie, 1980)

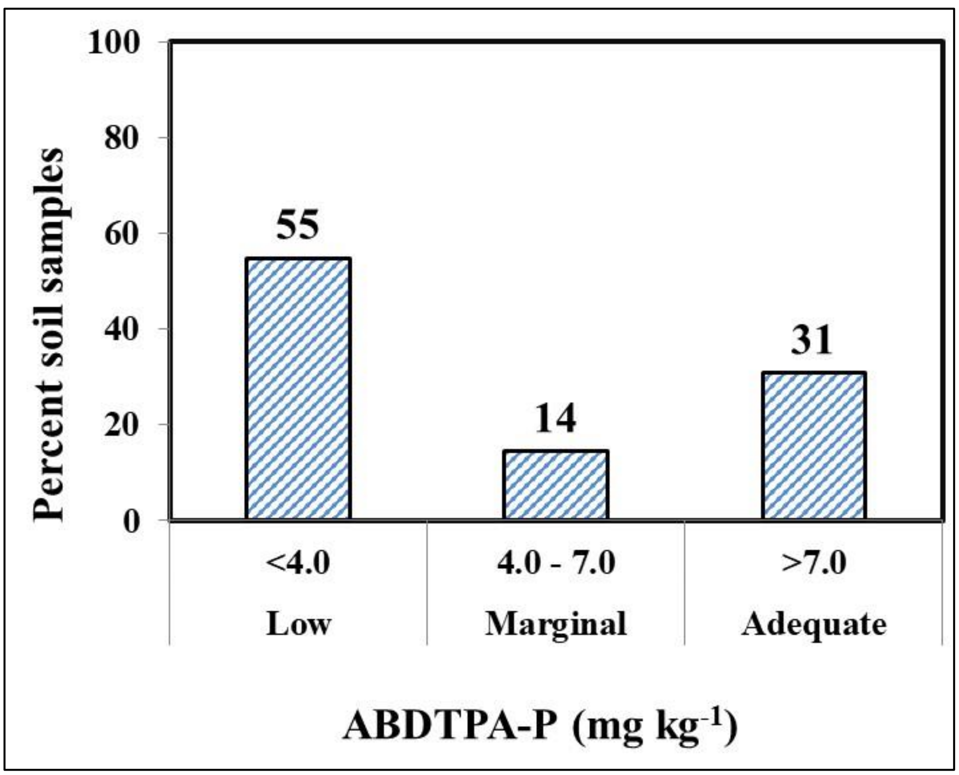


Figure 4. Categorization of soils of district Tando Allahyar, Sindh based on ABDTPA-P content (Soltanpour and Schwab, 1977)

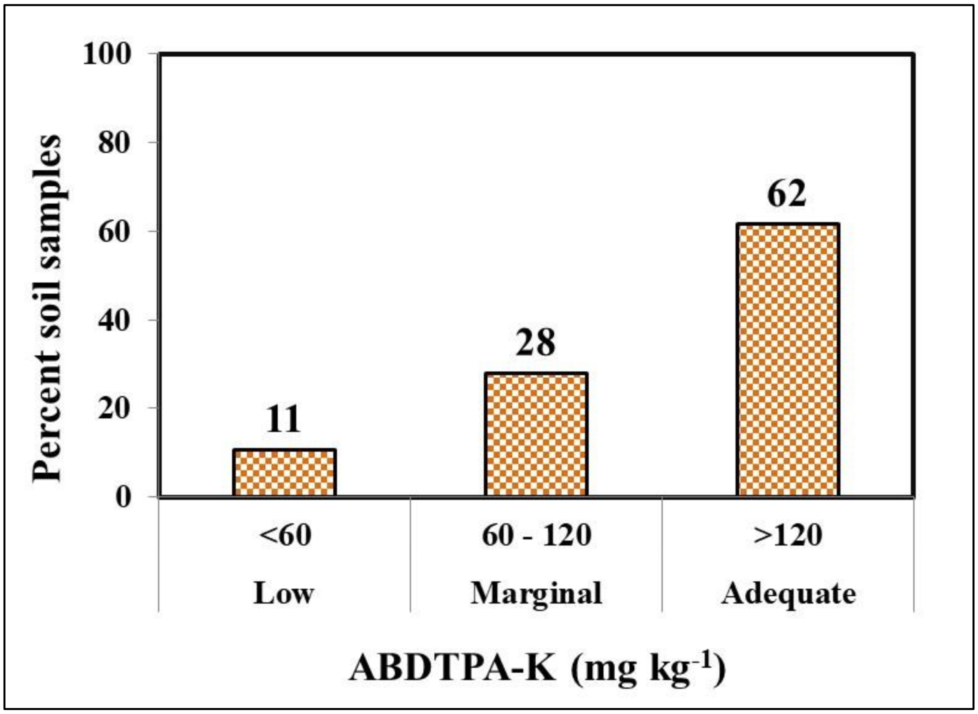
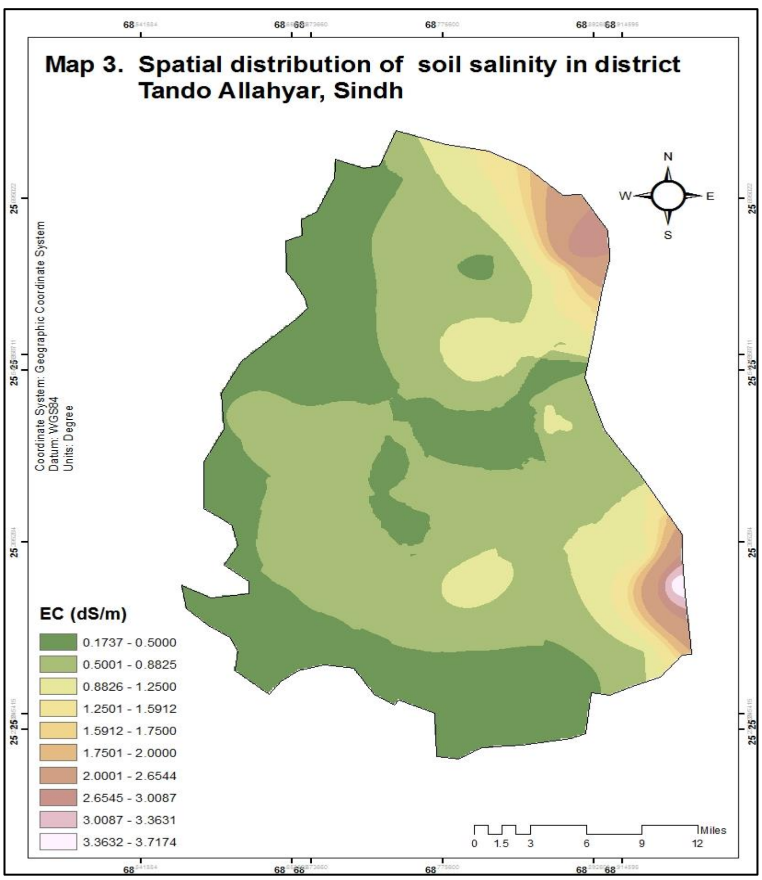
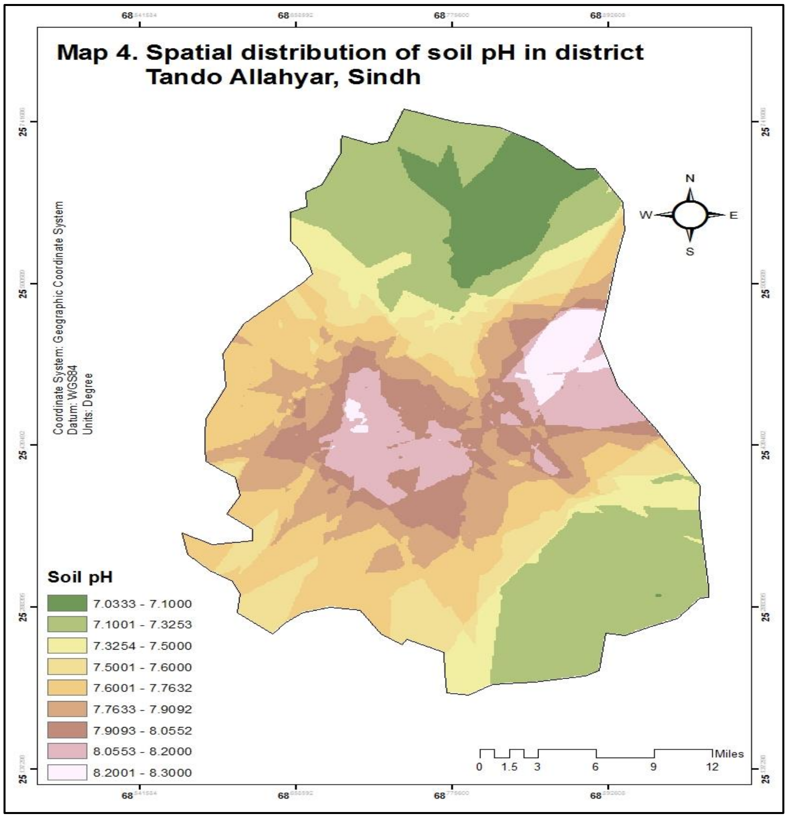
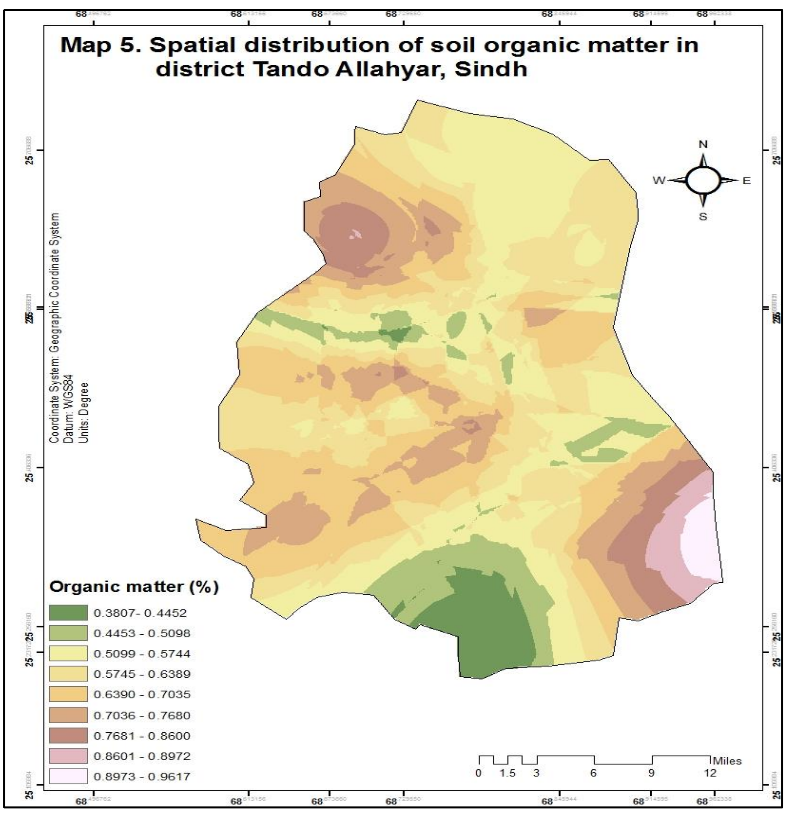
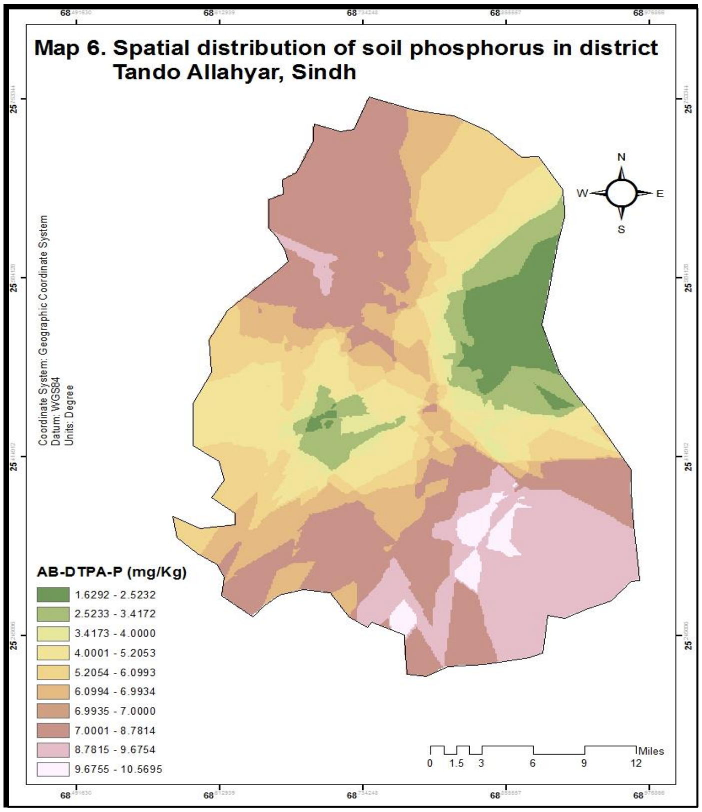


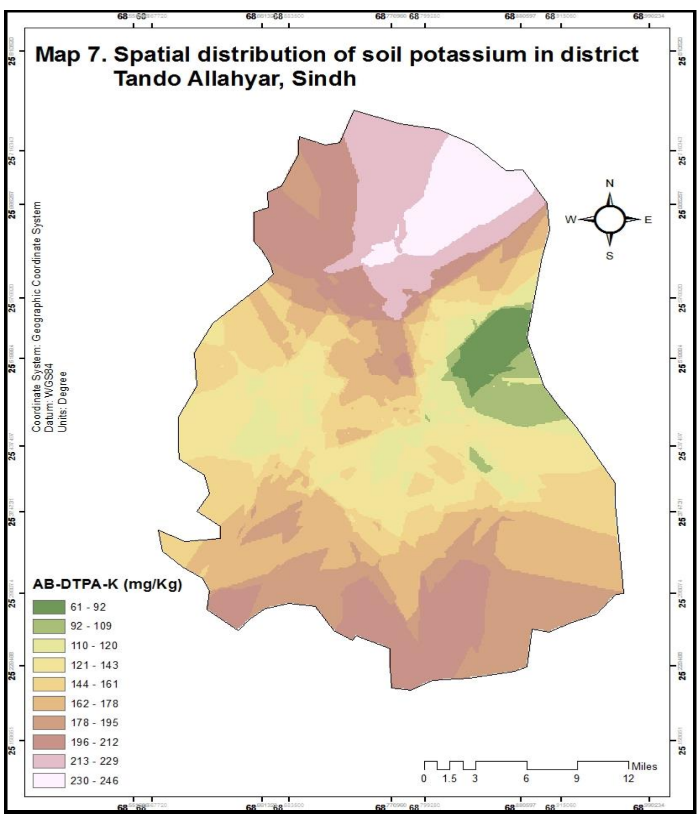
Figure 5. Categorization of soils of district Tando Allahyar, Sindh based on ABDTPA-K content (Soltanpour and Schwab, 1977)




Map 4. Spatial distribution of soil pH in district Tando Allahyar, Sindh
Coordinate System: Geographic Coordinate System
Datum: WGS84
Units: Degree
N
W
E
S
Soil pH
7.0333 - 7.1000
7.1001 - 7.3253
7.3254 - 7.5000
7.5001 - 7.6000
7.6001 - 7.7632
7.7633 - 7.9092
7.9093 - 8.0552
8.0553 - 8.2000
8.2001 - 8.3000
0 1.5 3 6 9 12 Miles


Map 5. Spatial distribution of soil organic matter in district Tando Allahyar, Sindh
Coordinate System: Geographic Coordinate System
Datum: WGS84
Units: Degree
N
W
E
S
Organic matter (%)
0.3807- 0.4452
0.4453 - 0.5098
0.5099 - 0.5744
0.5745 - 0.6389
0.6390 - 0.7035
0.7036 - 0.7680
0.7681 - 0.8600
0.8601 - 0.8972
0.8973 - 0.9617
0 1.5 3 6 9 12 Miles


Map 6. Spatial distribution of soil phosphorus in district Tando Allahyar, Sindh
Coordinate System: Geographic Coordinate System
Datum: WGS84
Units: Degree
N
W
E
S
AB-DTPA-P (mg/Kg)
1.6292 - 2.5232
2.5233 - 3.4172
3.4173 - 4.0000
4.0001 - 5.2053
5.2054 - 6.0993
6.0994 - 6.9934
6.9935 - 7.0000
7.0001 - 8.7814
8.7815 - 9.6754
9.6755 - 10.5695
0 1.5 3 6 9 12
Miles


Map 7. Spatial distribution of soil potassium in district Tando Allahyar, Sindh
Coordinate System: Geographic Coordinate System
Datum: WGS84
Units: Degree
N
W
E
S
AB-DTPA-K (mg/Kg)
61 - 92
92 - 109
110 - 120
121 - 143
144 - 161
162 - 178
178 - 195
196 - 212
213 - 229
230 - 246
0 1.5 3 6 9 12
Miles

Discussion

Fertile soils are precious natural resource for any country. Interestingly, soils differ spatially, and this variation mainly governs soil management and fertilizer recommendation for site specific nutrient management (Rajesh *et al*., 2023). Hence, the soils should be regularly monitored using standard protocols for maintaining their fertility to keep the fertilizer input cost at the bare minimum level (Rashid, 1996; Hou, 2023). In this regard, soil spatial variability mapping play a pivotal role in understanding and managing soil variations for their sustainable use. It has remained the subject of many recently published research studies (Rajesh *et al*., 2023). This study reports the soil variability of district Tando Allahyar, by developing GIS maps, for their sustainable management.

According to the most recent study published by FAO (2017), soil pH of district Tando Allahyar ranged from 7.1 to 9.9 (avg. 8.24), EC (dS m^{-1}) was in between 0.11-40.3 (avg. 1.36), organic matter (%) was in between 0.1-1.99 (avg. 0.82), available P (mg kg^{-1}) within 1.0-36 (avg. 3.86) and extractable K (mg kg^{-1}) within 30-400 (avg. 200). Our results revealed that most of the soils of district Tando Allahyar had either loamy slightly medium-textured type or clayey, fine-textured heavy type, followed by sandy, coarse-textured light type and loamy, moderately medium-textured type, low to medium salinity, slightly, medium or strongly alkaline pH, deficient in organic matter, low or adequate P, and adequate to marginal K (Figure 1 to 5, Map 2 to 7).

Very limited research studies are available highlighting soil traits and their differences in various districts of Sindh involving a variety of cropping systems. Khatri (1997) highlighted that paddy areas of Maatli taluka had texture ranging from clayey to clay loam, with very little to strong salinity, alkaline pH and organic matter deficiency. Menghwar (1997) reported that almost all (97%) paddy areas of deh Barasar of Maatli had heavy texture, either free from salinity or strongly saline, with neutral to medium alkaline pH and poor organic matter content. Junejo (1997) found the soils of K.N. Shah taluka heavy in texture, with alkaline pH, no salinity, and low to adequate organic matter.

Moreover, Talpur (2002) reported that majority (70%) of topsoil in Kunri taluka had low organic matter. For two dehs (Badaleah and Delawarpur) of district Jaccobabad, Siddiqui (2003) reported heavy texture, low to medium pH, no to strong salinity, and low to medium organic matter content. Talpur and Rajpar (2006) reported that the soil of district Mirpurkhas were generally heavy in texture, medium alkaline in reaction and low in organic matter. The paddy rice and cotton fields of Surgo deh, Pano Akil taluka, had heavy texture, alkaline pH, no to low salinity, medium to strong calcareousness and low organic matter Chachar (2007).

In a recent study, the Chilli fields of Kunri taluka were found to have heavy texture, no to strong salinity, alkaline pH, low to strong calcareousness, and low to medium organic matter (Talpur *et al*., 2016). Moreover, in Khairpur taluka the date palm field were reported P deficient in two separate studies (Jabbar, 2016; Talpur, 2016).

Soil K was reported adequate in district Thatta (Qureshi, 1996), Latif Experimental Farm, Tandojam (Deho, 1997), taluka Khairpur Nathan Shah (Junejo, 1997), taluka Umerkot, and taluka Kamber (Buriro, 1998). Same results were reported by Harijan (1998) for Tando Muhammad Khan taluka. Likewise, Menghwar (1997) found that that the rice soils of deh barasar, taluka Matli were adequate in AB-DTPA extractable K (218 to 780 mg K kg^{-1}). Buriro (1998) observed that the soils of taluka Kamber were medium in extractable K. Kashmiri (2001) showed that soils of Tando Allahyar were medium in AB-DTPA extractable K. The soils of district Larkana were reported adequate in exchangeable K (Samo, 2002). Similar results were tabled for the soils of district Badin and Thatta (Soomro, 2003). In contrast to these results, Siddiqui (2003) found that the paddy fields of two dehs of district Jacobabad (Badaleah and Delawarpur) were deficient in extractable K. Siddiqui (2003) reported that most of the soils of Jaccobabad district were deficient in extractable K. Soomro (2003) noted that the soil K of Badin and Thatta districts was adequate.

Keerio (2004) highlighted that the soil exchangeable K content of Hyderabad district was medium to adequate. Shahmir *et al.* (2004) reported that banana soils of district Thatta were medium to high in exchangeable K. Talpur and Rajpar (2006) and reported that, the soil of district Mirpurkhas were adequate in available K. Recently, Talpur *et al*. (2016) reported that chilli growing fields of Kunri taluka had adequate ABDTPA-K.

In a recent GIS mapping study, Sabir (2017) reported low to very high ABDTPA-K in guava growing fields of district Larkana. The GIS mapping further revealed that out of a total of 27 union councils of district, 10 were medium while the leftover 17 were adequate. Recently Ihsan (2018) reported that ABDTPA-K content of 23% banana growing areas of district Naushahro Feroze were low, 32% farms was medium while 45% farms was adequate. Panhwar (2018) reported that 92% rice farms of 11 union councils of taluka Dokri were adequate and 8% were medium in their ABDTPA-K content.

Conclusion

The study concludes that the soils of district Tando Allahyar vary spatially and require site-specific fertilization and management practices for various soil properties.

Competing Interests Disclaimer

We declare no competing interests affecting the work reported in this study.

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