Research Article

Evaluating Soil Variability in District Mirpurkhas, Sindh, Pakistan through Digital Mapping

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Abstract | Understanding soil variability is highly indispensable to achieve the goals of agricultural sustainability and environmental health. Soil variability mapping of district Mirpurkhas, Sindh, Pakistan – globally known as the city of high-quality mangoes – was done for the first time. Surface (20 cm depth) soil samples were collected from 127 locations of six sub-divisions of district Mirpurkhas (locally known as *talukas*) i.e. Digri, Hussain Bux Mari, Jhuddo, Kot Ghulam Muhammad, Mirpurkhas and Sindhri. The coordinates of each sampling point were recorded with Magellan® Triton™ 200 GPS device. Efforts were made to include all agriculturally important union councils of six talukas, involving a variety of soil use and crop scenarios, viz. wheat, sugarcane, mango, brassica. Soil texture (Bouyoucos Hydrometer method), electrical conductivity and pH (1:2 soil-water extract), organic matter (Walkley-Black method), and ABDTPA (Ammonium bicarbonate diethylene triamine penta acetic acid) extractable phosphorus (P) and potassium (K) were determined using standard protocols, with no further alterations. Soil variability mapping was done using ArcGIS ver. 10.7. through IDW interpolation. The results reveled that majority (40%) of soils were clayey in texture, followed by clay loam and silty clay loam (16% each). Slightly to moderately medium-textured soils were dominant, followed by heavy clays. Majority of soils had high to excessively high salinity (56%) followed by the soils having medium salinity (38%), slightly (46%) to medium alkaline (38%) pH, high (44%) to medium (39%) organic matter content, while soils with low organic matter content was comparatively lower (only 17%). Nonetheless, spatial variability map predicted medium organic matter content in the district. Moreover, majority of soils had low (75%) to medium (16%) ABDTPA-P while only small portion (9%) of soils had adequate ABDTPA-P. Contrarily, soils having adequate ABDTPA-K were higher (62%) followed by those having marginal (36%) ABDTPA-K. The results of present study clearly highlighted that the soils of study area vary spatially. Elevated surface salinity, low P status and decreasing soil K reserves appeared to be the major constraints for sustainable agriculture in the district and must be kept in mind while taking soil fertility and fertilizer management decisions, by referring to the recently developed maps.

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Introduction

Fertile soils are important for the prosperity of any nation, in view of the current scenario of climate change and economic uncertainties. Most (~85%) of the Pakistani soils lack adequate P (Memon, 1996) and are rapidly being mined for K, mainly due to no or negligible use of K, and 30-40% soils of Pakistan are reported K-deficient (Zia-ul-Hassan *et al*., 2008).

Regular soil analysis for the determination of its nutrient status plays a key role in evaluating nutrient deficiencies, and sometimes toxicities, that may affect crop growth and reduce yield. Hence, soil analysis becomes a very helpful tool for analyzing nutritional disorders and offers practical help in crop management decisions (Rashid, 1996). The routine soil analyses and interpretation protocols are tedious, costly and requires much time and energy.

Site-specific variation in soil properties occurs at various geographical regions and agro-ecological zones, due to several reasons, e.g., differences in the nutritional requirements of plants. Hence, soil fertility evaluation becomes one of the most essential components of balanced fertilization in our quest to sustainable agriculture (Zia-ul-Hassan *et al*., 2008). There might be several factors that badly affect crop yields, most importantly poor soil fertility status and imbalanced fertilization.

The understanding of soil spatial variability is a key component in achieving the goals of sustainable soil and fertilizer management practices. Recent soil mapping and interpolation tools potentially help understand soil variability and help manage soil and water resources (Das, 2004).

Geographical information system (GIS) technique appeared to be a very promising tool to map and address soil variations effectively and provide precise fertilizer management decisions (Mousavifard *et al*., 2012). GIS practically makes it possible to handle large data sets of diverse origins through specific manipulation (Mandal and Sharma, 2010). Globally, several databases are present for their analyses and utilization in the planning and execution of soil resources. Thematic soil attribute mapping is done through GPS based soil sampling to have exact coordinates of the location under study (Mishra *et al*., 2017). This is very important for the soil variability delineation of certain geographical location.

Keeping the above facts in mind, this first-ever study was conducted to delineate soil variability of one of the most agriculturally important districts of Pakistan– district Mirpurkhas, the world-renowned hub of high-quality mangoes through digital soil mapping.

Materials and Methods

Area under study

Mirpurkhas is an agriculturally important district of Sindh, Pakistan, located between 25°33′02″N 069°00′11″E. It covers an area of 331,655.11 ha, comprising six sub-divisions (locally known as *talukas*), viz. Digri (59799.68 ha), Hussain Bux Mari (30858.57 ha), Jhuddo (55084.70 ha), Kot Ghulam Muhammad (78383.92 ha), Mirpurkhas (49773.98 ha) and Sindhri (57754.26 ha).

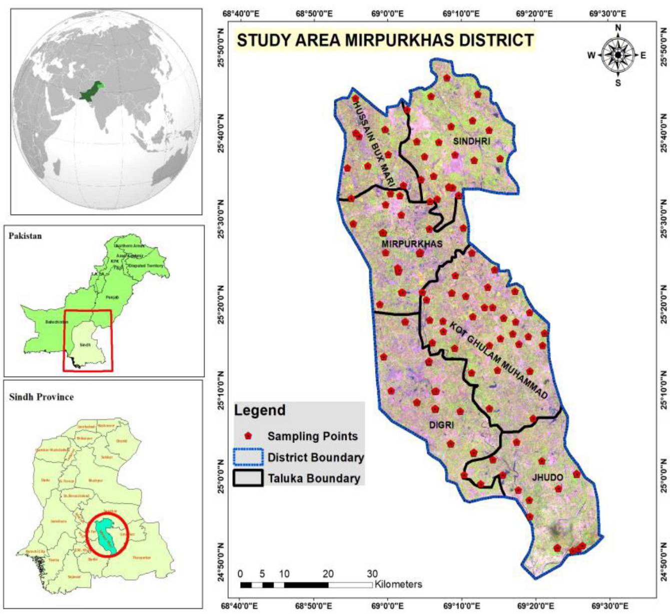

Figure 1: *Location of farms of district Mirpurkhas, Sindh, Pakistan involved in this study.*

Soil sampling philosophy and crop diversity

In this study, efforts were made to include all agriculturally important union councils of six talukas, involving a variety of soil use and crop scenarios. We selected each district through Sampling point technique, by employing IDW method, which possess the potential to cover the whole area of all talukas/district. Surface soils (0-20 cm depth) were sampled during winter (starting from 25-11-2018 to 09-12-2018), following Ryan *et al*. (2001), from 127 farms of six talukas of district Mirpurkhas, Sindh, Pakistan, as depicted in Figure 1. Five homogenous pieces of one-acre land were selected from each farm at random. Composite soil samples were collected from each piece, involving eight cores, and mixed well to have one representative sample. The samples were properly processed, stored, and used for soil analyses as recommended earlier (Ryan *et al*., 2001). The location of each farm was recorded with Magellan® Triton™ 200 GPS device (Megellan, MiTAC International Corporation, San Dimas, Santa Carla, California, CA, United States). Majority of farms selected for this study had wheat, sugarcane, mango and brassica, as previous or current crop, at the time of soil sampling, while some farms had other crops like onion, tomato, chillies, soonf, sweet potato, banana, and other miscellaneous crops (Table 1).

Table 1: *Crop diversity at various farms of district Mirpurkhas Sindh, Pakistan involved in this study.*

Name of crop	Farms sampled (%)
Wheat	21.3
Sugarcane	17.3
Mango	14.2
Brassica	13.4
Onion	7.9
Tomato	6.3
Chillies	5.5
Soonf and Sweet Potato (3.1% each)	6.2
Banana	1.5
Ber, Carrot, Chiku, Cotton, Ispangol, Maize, Papayya and Sunflower (0.8% each)	6.4

Analysis of soil properties

Soil texture (Bouyoucos Hydrometer method), electrical conductivity and pH (1:2 soil-water extract), organic matter (Walkley-Black method), and ABDTPA (Ammonium bicarbonate diethylene triamine penta acetic acid) extractable P and K were determined using standard protocols (Ryan *et al*., 2001) with no alterations.

Soil spatial variability mapping and interpolation method

Soil variability mapping was done using ArcGIS ver. 10.7 (Environmental Systems Research Institute (ESRI), 380 New York Street, Redlands, CA, USA) through Inverse Distance Weighted (IDW) interpolation, which is known to be the most applied technique, where more weight/importance is assigned to close points as against their distant counterparts (Robinson and Metternicht, 2006).

Categorization of soil properties

The soil properties, determined in this pedometric mapping study, were categorized as recommended earlier (Ryan *et al*., 2001; Zia-ul-Hassan *et al*., 2008).

Descriptive statistics

The descriptive statistics were performed using spreadsheet software program Microsoft Excel (Microsoft 365® for enterprise, Microsoft Corporation, WA, US).

Results and Discussion

Soil texture

The soils of district Mirpurkhas were dominated by the heavy clays and loams (Figure 2). Clayey or fine-textured soil type (clay, silty clay, sandy clay) was the dominant at various locations followed by loamy moderately medium-textured soils (clay loam, sandy clay loam, silty clay loam). A small portion of soils had loamy slightly medium-textured soils (loam, silt loam, silt). Light sandy soil type did not exist at all.

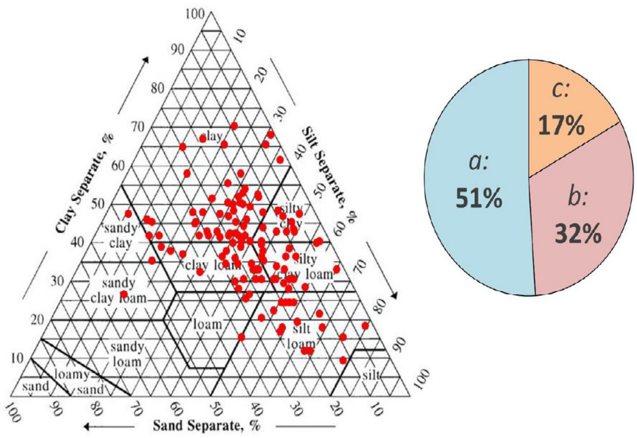

Figure 2: *Occurrence of different soil textures in district Mirpurkhas, Sindh, Pakistan (as depicted in the textural triangle) and presence of various soil types (as illustrated in pie-chart, a: Clayey or fine-textured soils, i.e., Clay, Silty Clay, Sandy Clay; b: Loamy moderately medium-textured soils, i.e., Clay Loam, Sandy Clay Loam, Silty Clay Loam; c: Loamy slightly medium-textured soils, i.e., Loam, Silt Loam, Silt).*

The soil spatial variability map predicted the presence of eight soil texture in district Mirpurkhas, Sindh, Pakistan (Figure 3), with the dominance of slightly to moderately medium-textured soils followed by heavy clays, while did not predict light, sandy, coarse-textured soil type in the district.

Links Researchers

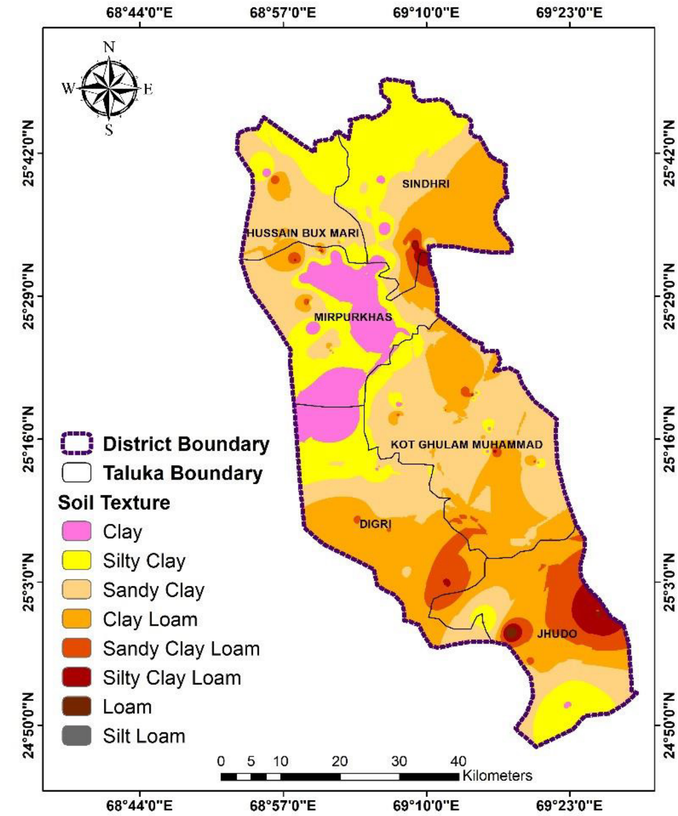

Figure 3: *Spatial distribution of soil texture in district Mirpurkhas, Sindh, Pakistan.*

Table 2: *Soil EC, pH, organic matter and ABDTPA P and K content at various locations of district Mirpurkhas, Sindh, Pakistan.*

	EC (dS m^{-1})	pH	Organic matter (%)	ABDT-PA-P (mg kg^{-1})	ABDT-PA-K (mg kg^{-1})
Minimum	0.25	6.5	0.38	1.25	37
Maximum	15.88	8.3	1.93	13.04	434
Mean	2.38	7.4	1.18	3.59	177
Mode	1.08	7.0	0.84	2.50	70
STDEV	2.36	0.4	0.29	2.30	93
CV (%)	98.86	4.7	24.90	63.91	53

Soil electrical conductivity (EC, dS m^{-1})

The EC values ranged from 0.25 to 15.9 dS m^{-1}, with a mean and mode values of 2.38 and 1.08 dS m^{-1}, respectively. The coefficient of variability among the EC was 99%, which indicated perfect variation among all farms for salinity in district Mirpurkhas, Sindh (Table 2). The data for electrical conductivity values were utilized for the categorization of district Mirpurkhas, Sindh soils for soil salinity (Sonon *et al*., 2015), as presented in Figure 4. It is evident from the data that majority of soils had high to excessively high salinity status (56%) or medium salinity (38%), while a small portion of soils had low salinity (7%). The spatial variability map predicted the soils of district Mirpurkhas to have medium to excessively high salinity (Figure 5).

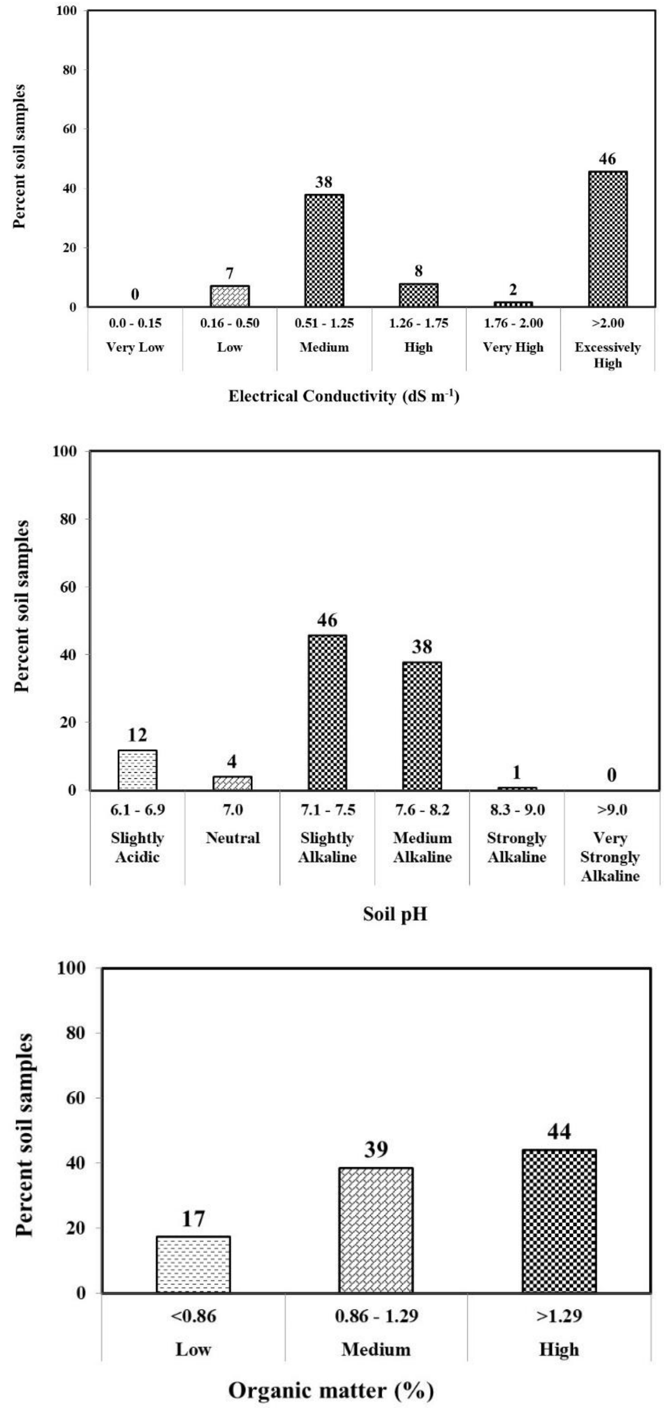

Figure 4: *Categorization of soils of district Mirpurkhas, Sindh, Pakistan based on their status of salinity (ranked after Sonon et al., 2015), alkalinity (ranked after Ankerman and Richard, 1989) and organic matter (ranked after Rashid and Ahmad, 1994).*

Soil pH

Soil pH ranged from 6.5 to 8.3, with mean and mode values of 7.4 and 7.0, respectively. The coefficient of variability among pH values was only 4.7%, which indicated negligible variation for soil pH in district Mirpurkhas, Sindh (Table 2). Soil pH data were

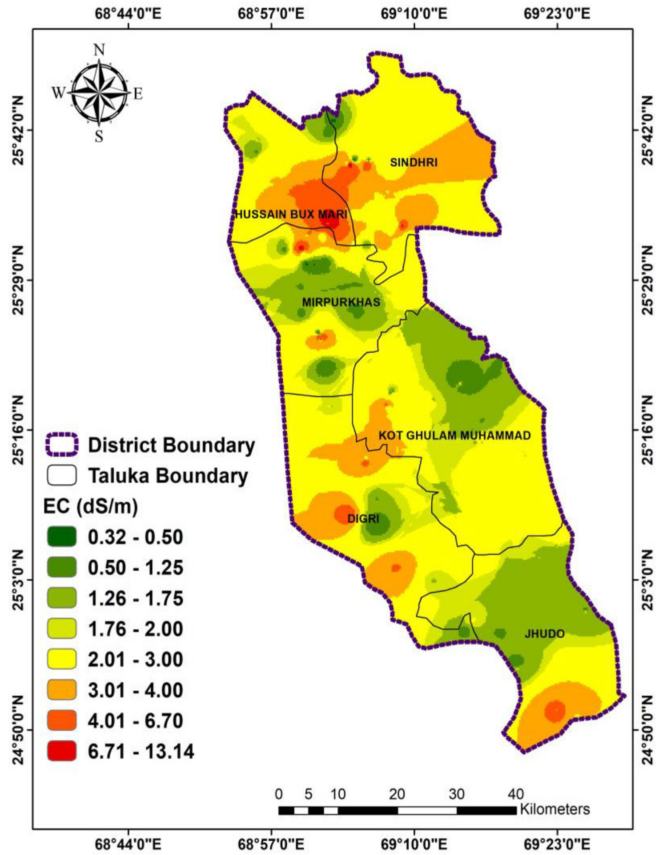

Figure 5: *Spatial distribution of soil electrical conductivity in district Mirpurkhas, Sindh, Pakistan.*

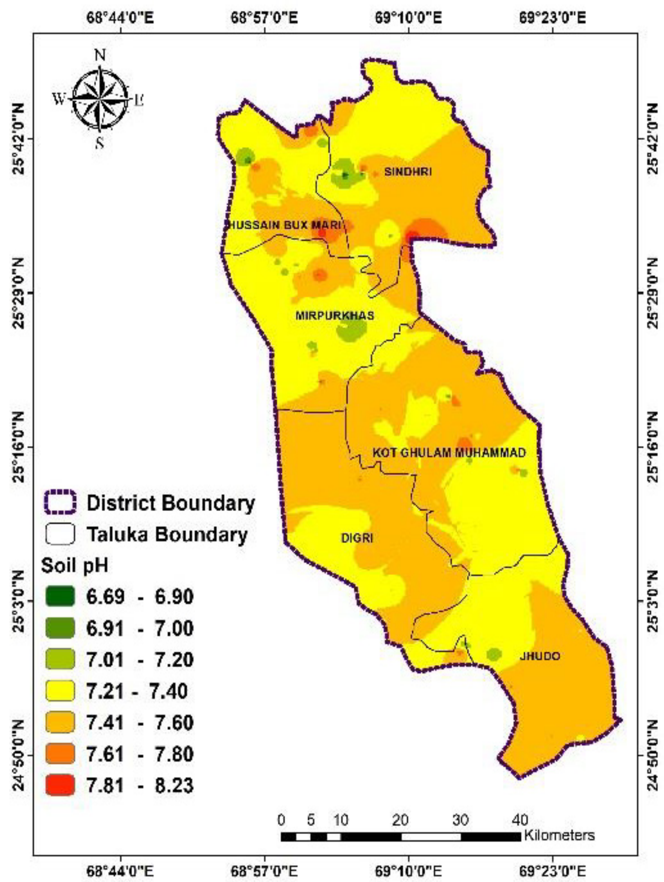

Figure 6: *Spatial distribution of soil pH in district Mirpurkhas, Sindh, Pakistan.*

distributed among various categories (Figure 4) according to the criteria proposed by Ankerman and Richard (1989). Majority (84%) soils had slightly to medium alkaline pH. Interestingly, soils with slightly acidic pH also existed in small proportion (12%). However, IDW interpolation only predicted slightly to medium alkaline soils in the district and ruled out the possibility of the existence of slightly acidic or neutral soils (Figure 6).

Soil organic matter content (%)

Soil organic matter content ranged from 0.38% to 1.93% with mean and mode values of 1.18% and 0.84%, respectively. The coefficient of variability (24.9%) exhibited considerable variation for soil organic matter in district Mirpurkhas, Sindh (Table 2). Soil organic matter content was categorized using the standard criteria (Rashid and Ahmad, 1994). Interestingly, majority of soils had high (44%) or medium (39%) organic matter content, while organic matter deficient soils were only 17% (Figure 4). Contrarily, the IDW interpolation predicted most of the study area having medium organic matter content (Figure 7).

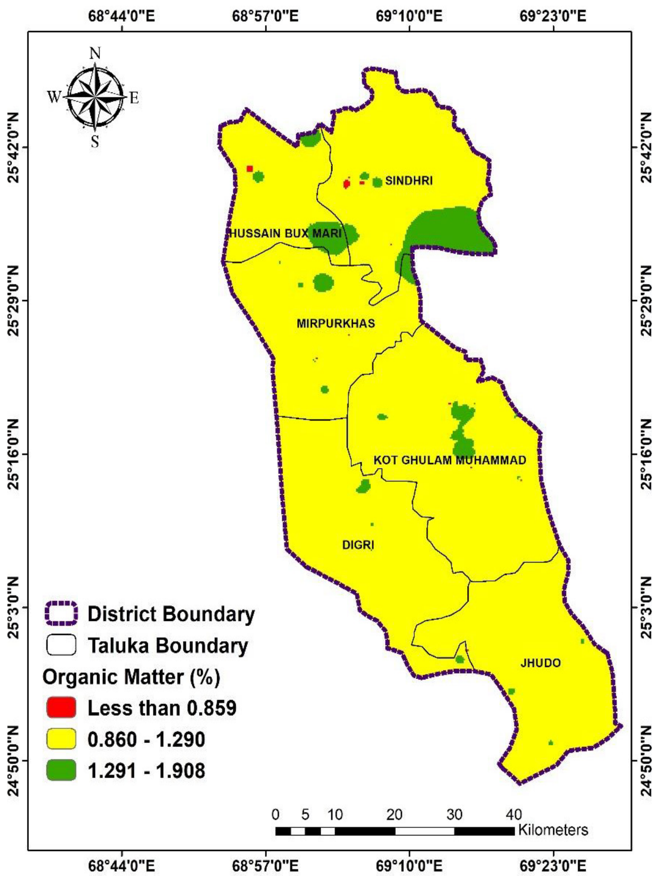

Figure 7: *Spatial distribution of soil organic matter in district Mirpurkhas, Sindh, Pakistan.*

Soil ABDTPA-P content (mg kg^{-1})

Soil ABDTPA-P ranged from 1.25 to 13.04 mg kg^{-1}, with mean and mode values of 3.59 and 2.5 mg kg^{-1}, respectively. Soil ABDTPA-P content at various locations of district Mirpurkhas vary widely (CV 63.9%) (Table 2). Soil ABDTPA-P was categorized following Soltanpour and Schwab (1977), as depicted in Figure 8. Accordingly, 75% soils were found low in ABDTPA-P while 16% soils were found medium, and only 9.0% soils were found adequate. The spatial variability map also predicted most of the soils to have low ABDTPA-P (Figure 9).

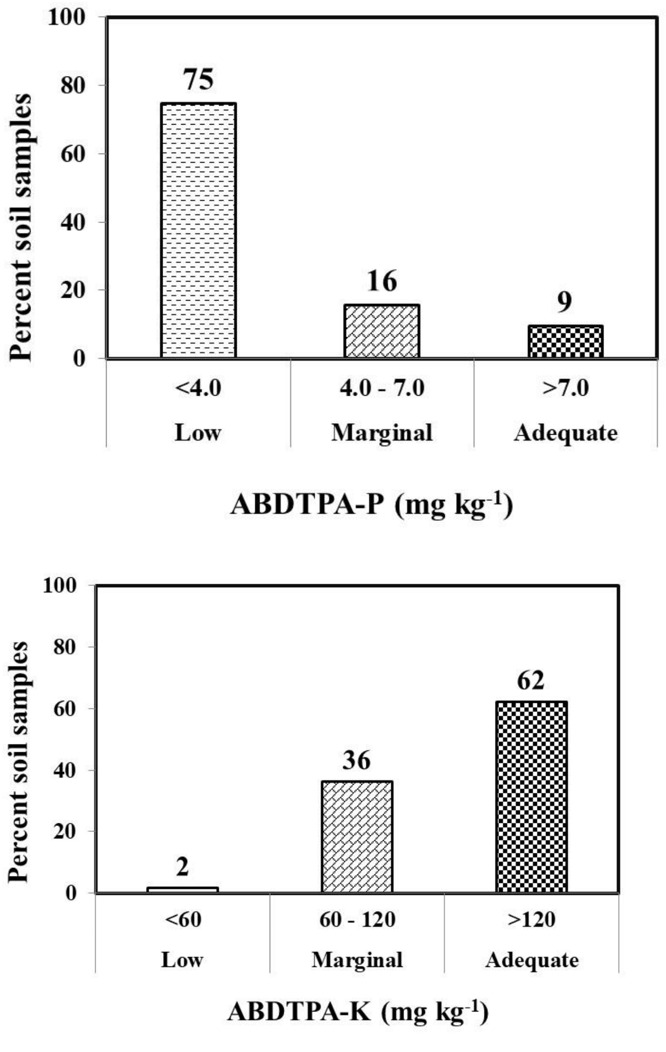

Figure 8: *Categorization of soils of district Mirpurkhas, Sindh, Pakistan based on ABDTPA-P and ABDTPA-K content (Soltanpour and Schwab, 1977).*

Soil ABDTPA-K content (mg kg^{-1})

Soil ABDTPA-K ranged from 37 to 434 mgkg^{-1}, with mean and mode values of 177 and 70 mg kg^{-1}, respectively. The coefficient of variability among soils for ABDTPA-K was 53%, which showed a wide variation for soil ABDTPA-K content at various locations of district Mirpurkhas (Table 2). Soil ABDTPA-K was categorized according to criteria proposed by Soltanpour and Schwab (1977). Accordingly, majority (62%) of soils were found adequate in ABDTPA-K while 36% soils were found marginal and only 2.0% soils low (Figure 8). The IDW map predicted only small area of district Mirpurkhas, Sindh with marginal content of soil ABDTPA-K while negligible soils with low ABDTPA-K content. Most of the soils of district Mirpurkhas, Sindh were predicted to have adequate ABDTPA-K (Figure 10).

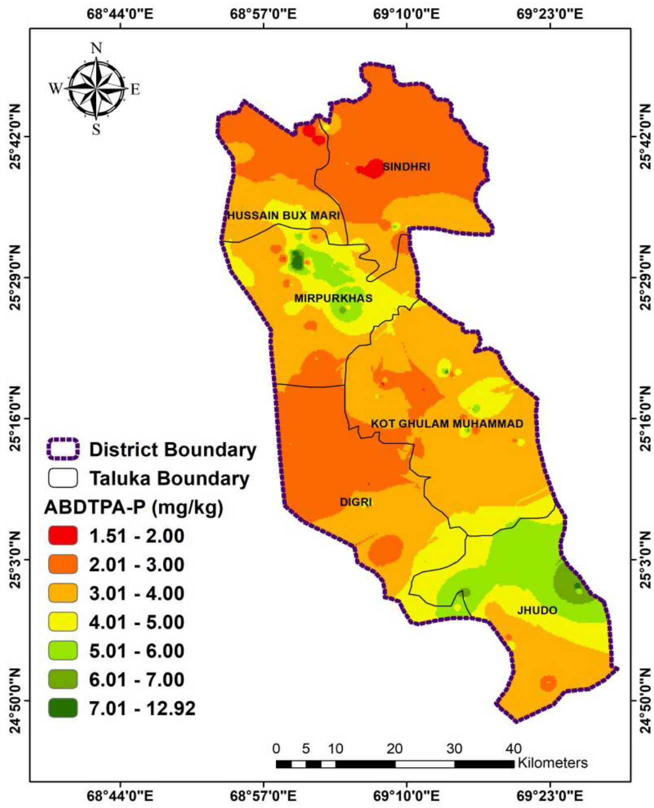

Figure 9: *Spatial distribution of Soil ABDTPA-P content (mg kg-1) in Mirpurkhas, Sindh, Pakistan.*

This first-ever research study was conducted for the delineation of soil physico-chemical traits of district Mirpurkhas, Sindh, Pakistan through digital soil mapping using Geospatial techniques. The study involved soil survey and sampling, soil analyses and development of soil spatial variability maps of selected soil properties using IDW method in ArcGIS software.

District Mirpurkhas is the world-renowned hub of high-quality mangoes and, hence, known as the 'City of Mangoes'. In addition to its being the center of the 'King of fruits', it is blessed with all types of agriculture activities involving a variety of crops grown over there since centuries, as an important part of Indus civilization. The district has a well-organized canal irrigation system. The soil parent material of district Mirpurkhas is composed of river alluvium with the dominant soil series including Sultanpour, Matli, Miani, Rustam and Sindhelianwali (FAO, 2017). It has been reported (FAO, 2017) about the soils of district Mirpurkhas that the soil pH ranged from 7.15 to 9.7 (mean 8.20), electrical conductivity (dS m^{-1}) ranged from 0.08 to 36.8 (mean 2.10 dS m^{-1}) and organic matter (%) ranged from 0.1 to 2.11 (mean 0.81), available phosphorus (P) (mg kg^{-1}) ranged from 1.0 to 52 (mean 4.90) while potassium (K) (mg kg^{-1}) from 26 to 400 (mean 203). The total cultivated area of district Mirpurkhas is 206,482 ha while the non-cultivated area is 118,244 ha and the irrigated area is 202,837 ha. The main crops of district Mirpurkhas are wheat, rice, cotton, sugarcane, and mango. Rabi cropping (sown around mid-November) involves wheat and orchards while Kharif cropping (sown at the start of first monsoon rains) involves sugarcane, cotton, and fodders (FAO, 2017). It has been reported by the FAO (2017) that the farming community of district Mirpurkhas avail analytical facilities of government and private sector labs for soil testing (29 %) and water analysis (19 %).

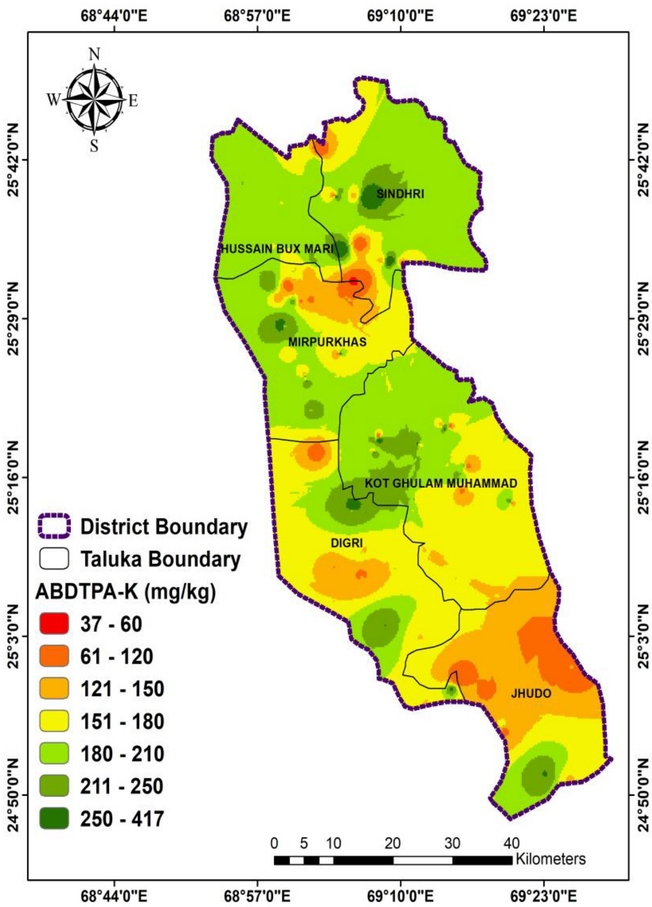

Figure 10: *Spatial distribution of Soil ABDTPA-K (mg kg-1) content at Mirpurkhas, Sindh, Pakistan.*

Despite its being very important contributor in agriculture sector, no dedicated study has been found in the literature to address the subject of soil variability for delineating the soil problems of this important region. The results of this study highlighted that the soils of district Mirpurkhas, Sindh were slightly to moderately medium-textured type involving eight main soil textures, i.e., silt loam > silty clay > loam and sandy clay > sandy clay loam (Figures 2 and 3). The soils were medium to excessively high in salinity (Figures 4 and 5), slightly to medium alkaline (Figures 4 and 6), medium to high in organic matter (Figures 4 and 7), mostly deficient in P (Figures 8 and 9) and marginal to adequate in K (Figures 8 and 10).

The preliminary studies on this subject of soil properties monitoring did not account for the spatial variation and the sampling of soils in these studies was not based on recording coordinates and developing spatial variability maps. Hence, it was not possible to benefit from the data generated in these studies for future reference. Nonetheless, the results obtained from these studies can be used to compare soil properties and fertility scenarios of same or different locations of Sindh on an average basis.

Talpur (2002) reported that majority (70%) of surface soils of taluka Kunri were poor in organic matter content. Talpur and Rajpar (2006) reported that the soil of district Mirpurkhas were generally heavy in texture, medium alkaline in reaction, low in organic matter and adequate in Olsen's P. Hence, it is important to note that soil P has been rigorously mined from year 2006 till date from district Mirpurkhas. FAO (2017) reported that the available P in district Mirpurkhas ranged from 1 to 36 mg kg^{-1} (avg. 3.86 mg kg^{-1}). Talpur and Rajpar (2006) and reported that, the soil of district Mirpurkhas were adequate in available Panhwar (2016) reported that the ABDTPA-K content of chilli growing areas of taluka Kunri was adequate. FAO (2017) reported that the available K in district Mirpurkhas ranged from 26 to 400 (mean 203).

The GPS and GIS based soil fertility maps are being developed to delineate soil fertility issues at district level (Mishra *et al*., 2017). However, little or no work has been done in Pakistan on this important subject. Hence, it becomes imperative to conduct such studies at district level in Pakistan to develop soil spatial variability maps to provide guideline to the farming community and extension workers on site-specific nutrient management.

Conclusion and Recommendations

The results of present study highlighted the existence of soil variability in district Mirpurkhas, Sindh, Pakistan which must be kept in mind while taking soil management and fertilizer application related decisions. The farming community and extension workers are advised to refer to these digital soil maps as their practical guide for efficient, eco-friendly and cost-effective fertilizer management system, which may promote healthy environment and low-input sustainable agriculture.

Acknowledgements

We are grateful to the district administration and farming community of district Mirpurkhas, Sindh, Pakistan for their technical and logistic help during soil survey.

Novelty Statement

For the first time, soil variability of district Mirpurkhas, Sindh, Pakistan has been explored and GIS based digital soil maps have been developed using IDW interpolation technique for the use of farming community and extension workers to take soil management and fertilizer application decisions on site-specific basis. Keeping in mind the ever-increasing price of chemical fertilizers and fertilizer losses due to imbalance fertilization, this study gives information for agricultural and environmental sustainability.

Author's Contribution

Rashid Saraz and Saiqa Amur both equally contributed as first authors by conducting soil survey, soil analysis, literature review, preparing initial draft of manuscript and proof-reading of all drafts of manuscript.

Zia-ul-hassan conceived the idea, planned, and executed the study, designed field survey proforma, financed field survey, technically helped in soil and data analyses, reviewed all drafts of manuscript, and submitted for publication as corresponding author.

Naheed Akhter Talpur supervised soil chemical analysis in laboratory, preparation of charts, development of GIS maps, helped in writeup of Results section and edited the final draft of manuscript.

Inayatullah Rajpar provided chemicals and facilities required for this study and provided useful edits in all drafts of manuscript.

Muhammad Sohail Memon developed GIS based digital soil spatial variability maps, edited Materials and Methods section, and helped in the preparation of first draft of manuscript.

Muhammad Nawaz Kandhro reviewed all drafts and provided useful edits, helped in formatting the final draft.

Khalid Hussain Talpur reviewed initial draft of manuscript and updated literature for introduction, discussion sections and done proof-reading of final draft.

Nizamuddin Depar helped in soil analysis interpretation and finalizing Results section.

All authors read and approved the final manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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