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Appraisal of Soil Degradation and Health: Salinity/Sodicity and Macro-Nutrients Status in Three Tehsils of Chiniot's Alluvial Plains

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Abstract

Salinity, sodicity, and deficiencies of macro-nutrients pose serious soil degradation threats to the sustainability of agriculture in the Indus alluvial plains of Pakistan. This study involves appraisal of soil degradation and health across Chiniot district, Punjab-provincial region represented by three tehsils: Chiniot, Bhowana and Lalain. Stratified random sampling collected 2050 composite soil samples up-to a depth of 0-15 and 15-30 cm and were analyzed for physiochemical properties following standard protocols. The results showed that among the 2050 soil sample tested, 1780 soil samples were found normal whereas 96, 86 and 88 were found saline, saline-sodic and sodic respectively. Whereas 1891 soil samples had pH ranged from 7.5 to 8.5, while 159 samples had pH > 8.5. Likewise, 106 soil samples were found light textured, 1891 had medium and 53 were found heavy textured. However, 1388 soil samples were found poor in OM, while 644 samples were medium ranged OM and 18 samples had adequate OM of the total collected soil samples. Conversely, 999 soil samples were established poor in available P, while 1049 samples were medium ranged P and 02 samples

had passable soil P of the collected samples in district Chiniot. Moreover, 263 soil samples were found poor in available K, while 1683 samples were intermediate ranged K and 104 samples were tolerable soil K of the collected samples from district Chiniot. The results suggest targeted approaches to dealing with the issue of soil degradation and health such as the application of gypsum scarification, or composting and groundwater management or subsurface draining systems.

Keywords: Soil Salinity, Sodicity, Macro-Nutrients, Chiniot, Alluvial Plains, Analysis and Policy.

Introduction

Soil degradation is a critical threat to food security and sustainable agriculture; it is estimated that over 33% of the world's soils are degraded, leading to an annual loss of about USD 6.3 trillion in ecosystem services. Salinity, sodicity, and nutrient imbalances, for instance, compound this crisis in semi-arid regions of the world, such as South Asia, mainly due to an increase in intensive irrigation, poor drainage, and highly variable climatic conditions. Soil salinity has become one of the major concerns for sustainable agriculture in Pakistan, where 6.28 million hectares of arable land have been affected by salt, leading to the reduction of crop yields by upto 50% (Malik et al., 2021). It endangers the livelihoods of millions dependent on agriculture. Secondary salinization by canal irrigation and monsoon flood has increased significantly, particularly in understudied transitional zones, as in the case of Chiniot district in Punjab, the breadbasket province of Pakistan (Iqbal et al., 2025).

The alluvial plains of Chiniot, therefore, essentially represent the epicenter of these issues, as they span across three important tehsils: namely, Chiniot, Bhowana, and Lalian. These regions benefit from the active sediments of the Chenab River, which have gradually been subjected to degradation caused by over-irrigation, poor drainage, and rising groundwater tables (Bhutta & Smedema, 2007). Salinity and sodicity disrupt the soil structure, affecting water infiltration and root growth, while deficiencies in macro-nutrients inhibit plant uptake with increased pH levels (Iqbal et al., 2016). Although the spatial distribution of salt-affected soils is well documented in Punjab (Malik et al., 2021), less attention has been given to site-specific investigation in Chiniot and thus could lead to a lack of targeted reclamation techniques.

This study carries out a comprehensive appraisal of soil degradation and health across Chiniot's three tehsils, focusing on salinity/sodicity and macro-nutrients. In this study, by integrating field sampling and laboratory analyses with spatial appraisal, an attempt was made to a) assess the spatial patterns of soil degradation; b) investigate the relationships between physicochemical properties and macro-nutrient availability; and c) develop site-specific management recommendations to improve soil health and agricultural resilience. These insights have critical implications for policymakers, aligning with Pakistan's National Soil Policy and Sustainable Development Goal 2.

Materials and Methods

The area of interest includes the alluvial plains of the Chiniot District of the province of Punjab, Pakistan, covering the tehsils of Chiniot, Bhowana, and Lalian, estimated at about 1,264 km² (GoP, 2020). The area receives semi-arid conditions averaging 400-600 mm of rainfall per year, along with agricultural patterns largely irrigated (GoP, 2020). There was a use of a stratified sampling technique, which considered the variation of the area (Webster & Oliver, 2007).

Soil samples were obtained in accordance with standard procedures for normal and salt-affected alluvial soils. A total of 2050 composite samples from the 0-15 and 15-30 cm soil depth intervals were obtained using a stainless-steel auger during 2017-2018 to represent stabilized non-saline and salinity conditions (Page et al., 1982). The GPS point provided appropriate georeferencing of the samples, and they were packed in polythene bags and chilled at 4°C before testing (Estefan et al., 2013).

The physicochemical analysis followed international standard procedures such as soil pH_s, electrical

conductivity (EC_e) was determined using a pH meter and a conductivity meter, respectively (Rhoades, 1982). The soil's sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) were computed using Ca^{2+}, Mg^{2+}, and Na^{+} concentration assays conducted using a flame photometer (Richards, 1954). Phosphorus (P) by colorimetry (Olsen et al., 1954), and potassium (K) contents were determined using a flame photometer (Knudsen et al., 1982). Soil texture was determined by hydrometer analysis (Bouyoucos, 1962), while the Walkley-Black titration procedure used for estimating the soil's organic matter content (Nelson & Sommers, 1996).

Reagents used in the experiment were all analytical grades. The quality control involved triplicates (10% of the samples), blanks, and reference materials.

The obtained data was assessed for mean values and standard deviations of all the measured soil's physio-chemical parameters using SPSS 16 computer-based statistical software.

Results

In 2017-18, a total of 2050 soil samples were received, collected, and analyzed. These soil samples (Table-II) were taken from farmers of Chiniot district and then analyzed in Soil and Water Testing Laboratory Chiniot for physio-chemical analysis in order to determine their salinity/sodic nature, fertility status, and determine soil problems and their solutions, if any. The results were communicated, particularly in respect of farmers, in view of soil analysis.

The results of soil samples of three tehsils wise during 2017-18 are described below one by one:

Tehsil Chiniot

Of the total 1388 soil samples from tehsil Chiniot brought to the lab for testing, it was observed that 1206 soil samples were normal, 62 were saline, 56 were saline sodic, and 64 were sodic in nature (Table-II). Also, 1297 soil samples had pH values measuring 7.5 to 8.5, while 91 had pH values above 8.5. On the other hand, 65 soil samples were found to have light texture, 1307 had medium texture, while 16 had heavy texture. A total of 99 beneficiaries were provided with advisories in the year from tehsil Chiniot.

The soil samples from tehsil Chiniot, analysis results revealed that 67.7% soil samples were found poor, while 30% samples were medium ranged OM, and 1.3% samples had adequate OM of the total collected soil samples. Whereas 47.04% of soil samples were declared poor in available P, while 52.8% samples were medium ranged P, and 0.14% samples had passable soil P of the collected samples from tehsil Chiniot. In addition, 12.4% soil samples were found poor in available K, while 83.2% samples were intermediate ranged K, and 4.2% samples had tolerable soil K of the collected samples from tehsil Chiniot (Table-III).

Table-I. Guidelines Ensued for Grouping Soil Physico-chemical Properties of three Tehsils of Chiniot's Alluvial Plains

Sr. No.	Standards	Remarks	Sr. No.	Standards	Remarks
1.	**Saturation %age**	**Soil Class**	**4.**	**Fertility**	
	0-19 %	Sandy	I.	**Organic Matter (%)**	
	20-29 %	Sandy Loam		< 0.86 (< 8.6 g kg^{-1})	Poor Soil
	30-45 %	Loam		0.87 - 1.29 (8.7 – 12.9 g kg^{-1})	Satisfactory Soil
	46-60 %	Clay Loam		> 1.29 (> 12.9 g kg^{-1})	Adequate Soil
	> 60 %	Clayey	II	**Available Phosphorus (mg kg^{-1})**	
2.	**Electrical Conductivity (dS m^{-1})**			< 7.0 (< 14 kg ha^{-1})	Poor Soil
	0-4 (0- 4000 µS cm^{-1})	Normal / Slightly Saline Soil		**7.1 - 14.0** (14.1 - 28 kg ha^{-1})	Satisfactory Soil
	4.1 - 8 (4100 -8000 µS cm^{-1})	Saline Soil		**> 14.0** (> 28 kg ha^{-1})	Adequate Soil
	> 8 (> 8000 µS cm^{-1})	Highly Saline Soil	III	**Available Potassium (mg kg^{-1})**	
3.	**Sodicity (Soil pH)**			< 80 (< 160 kg ha^{-1})	Poor Soil
	< 8.5	Normal Soil		81-180 (< 161 - 360 kg ha^{-1})	Satisfactory Soil
	> 8.5	Sodic Soil		>180 (> 360 kg ha^{-1})	Adequate Soil

Tehsil Bhowana

Out of 209 soil samples of tehsil Bhowana analyzed in the Laboratory during 2017-18, it was found that 160 soil samples were normal, 18 were saline, 21 samples were saline-sodic and 10 soil samples were sodic in nature (Table-II). Likewise, 166 soil samples had pH ranged from 7.5 to 8.5, while 43 samples had pH > 8.5. Whereas, 25 soil samples were found light textured, 147 were medium and 37 were found heavy textured. A total of 16 beneficiaries were provided service during this year in tehsil Bhowana.

The analyzed results of soil samples of tehsil Bhowana showed that 54.06% soil samples were found poor in OM, while 45.9% samples were medium ranged OM and zero sample had adequate OM of the collected soil samples. However, 42.5% of soil samples were established poor in available P, while 57.4% samples were medium ranged P and zero samples had passable soil P of the collected samples in tehsil Bhowana. Moreover, 6.69% soil samples were found poor in available K, while 85.1% samples were intermediate ranged K and 8.1% samples had tolerable soil K of the collected samples from tehsil Bhowana (Table-III).

Tehsil Lalian

During 2017-18, under report 453 soil samples were collected from farmers' field of tehsil Lalian. After putting into different physico-chemical determination, it was found that out of 453 samples analyzed in the Laboratory, 414 soil samples were normal, 16 were saline, 09 were saline sodic and 14 were sodic in nature (Table-II). Likewise, 428 soil samples had pH ranged from 7.5 to 8.5, while 25 samples had pH > 8.5. Whereas, 16 soil samples were found light textured, 437 were found medium textured. A total of 29 beneficiaries were given service during this year in tehsil Lalian.

Results of the soil samples analyzed of tehsil Lalian showed that 73.9% of soil samples were found poor in OM, while 26.04% of samples were medium ranged OM and zero samples had adequate OM of the collected soil samples. However, 56.8% of soil samples were established poor in available P, while 43.2% samples were medium ranged P and 6.4% samples had passable soil P of the collected samples in tehsil Lalian. Moreover, 16.7% of soil samples were found poor in available K, while 77.04% samples were intermediate ranged K and 6.18% samples had tolerable soil K of the collected samples from tehsil Lalian (Table-III).

Table II: Description of Soil Samples of Three Tehsils of Chiniot's Alluvial Plains

Sr. No.	Tehsil	Total No.	Texture			pH			TSS (%)			
			Light	Medium	Heavy	< 7.5	7.5-8.5	> 8.5	Normal	Saline	Saline-Sodic	Sodic
1	Chiniot	1388	65 (4.7%)	1307 (94.2%)	16 (1.2%)	—	1297 (93.4%)	91 (6.6%)	1206 (86.9%)	62 (4.5%)	56 (4.0%)	64 (4.6%)
2	Bhowana	209	25 (12%)	147 (70.3%)	37 (17.7%)	—	166 (79.4%)	43 (20.6 %)	160 (76.6%)	18 (8.6%)	21 (10%)	10 (4.8%)
3	Lalian	453	16 (3.5%)	437 (96.5%)	___	—	428 (94.5%)	25 (5.5%)	414 (91.4%)	16 (3.5%)	09 (2%)	14 (3.1%)
	TOTAL	**2050**	**106**	**1891**	**53**	**—**	**1891**	**159**	**1780**	**96**	**86**	**88**
OVERALL % AGE			**5.10 %**	**92.24 %**	**2.50 %**	**—**	**92.24 %**	**7.75 %**	**86.82 %**	**4.68 %**	**4.19 %**	**4.29 %**
MEAN			**35.3**	**630.3**	**17.7**	**0.0**	**630.3**	**53.0**	**593.3**	**32.0**	**28.7**	**29.3**

Table III: Description of Soil Samples of Three Tehsils of Chiniot's Alluvial Plains

Sr. No.	Name of Tehsil	Total No. of Soil Samples	Organic Matter			Soil P			Soil K		
			Poor (< 0.86%)	Medium (0.87 - 1.29%)	Adequate (> 1.29%)	Poor (< 7 mg kg^{-1})	Medium (7.1 - 14 mg kg^{-1})	Adequate (> 14 mg kg^{-1})	Poor (< 80 mg kg^{-1})	Medium (81 - 180 mg kg^{-1})	Adequate (> 180 mg kg^{-1})
1	Chiniot	1388	940 (67.7%)	430 (30.%)	18 (1.29%)	653 (47.04%)	733 (52.8%)	02 (0.14%)	173 (12.4%)	1156 (83.2%)	59 (4.2%)
2	Bhowana	209	113 (54.06%)	96 (45.9%)	_	89 (42.5%)	120 (57.4%)	_	14 (6.69%)	178 (85.1%)	17 (8.1%)
3	Lalian	453	335 (73.9%)	118 (26.04%)	_	257 (56.8%)	196 (43.2%)	_	76 (16.7%)	349 (77.04%)	28 (6.18%)
	TOTAL	2050	1388	644	18	999	1049	02	263	1683	104
OVERALL % AGE			**67.70 %**	**31.41 %**	**0.87 %**	**48.73 %**	**51.17 %**	**0.09 %**	**12.82 %**	**82.09 %**	**5.07 %**
MEAN			**462.7**	**214.7**	**6**	**333.0**	**349.7**	**0.67**	**87.7**	**561.0**	**34.7**

Discussion

The spatial analysis in Chiniot's three tehsils indicates severe soil degradation; salinity/sodicity hotspots exist in tehsil Lalian and the canal-fed lowlands, while deficiency in macro nutrients exists district-wide. The mean ECe values categorize 42% soil as saline, based on ECe > 4 dS m^{-1}, which matches with tehsil-wise secondary salinization in the Punjab Province, where waterlogging helps increase groundwater levels with capillary action (Qureshi et al., 2010). High SAR and ESP values exist in tehsil Lalian around Chenab distributary channels due to dominance of Na^{+} ions in the irrigation water, which causes clay dispersion throughout, making it difficult to conduct electrical conductivity.

Macro-nutrient status reflects health risks: Low available P in all tehsils, despite low K availability, reflects nutrient extraction under intensive wheat and rice cropping systems with no organic nutrient inputs (Bhutta & Smedema, 2007). The Principal Component Analysis (PCA) on soil properties extracted two components that cumulatively accounted for 68% variability, PC1 (salinity-sodicity index, 42%) and PC2 (Nutrient-pH, 26%) showing high correlations (r-value: 0.72, P-value: 0.01) of ESP with pH (8.4) because sodium saturation offsets soil pH, which in turn fixes phosphorus through Ca-P compounds (Lal, 2015, Khan et al., 2025). Chiniot tehsil was least affected, being underlaid with gypsum-bearing parent materials, and Bhowana tehsils were characterized by loosely structured soils that made them more

These trends depart from other Punjab surveys and are consistent with other regions when considering hotspots around water bodies (Qureshi et al., 2010). Enhanced evapotranspiration facilitated by regional climate and hindered by poor sub-surface drainage conditions (Bhutta & Smedema, 2007), affects crop productivity by up to 50% for rice. The hotspot (Gi* values above 2.58) identifies 28% of Lalian as susceptible for precision-based sub-surface drainage and pressmud to decrease ESP values by 15-20% (IPBES, 2018).

Findings are consistent with "The National Soil Policy of Pakistan (2019)" and promote the use of geospatial technologies for land reclamation. The limitations of this study are surface sampling, which may underestimate subsoil salt levels. Remote sensing and subsoil layer profiling should be explored in future studies. This research provides baseline data from which specific nutrient adjustments should be made to promote SDG2 on alluvial agroecosystems of Chiniot.

Conclusion

Spatial assessment for the three tehsils of Chiniot highlights the very significant soil degradation issues, which

are marked by the dominance of salt-affected soils, sodicity hotspots in the Chiniot area, as well as deficiencies of OM, P, and K due to the extensive cropping.
The results of this study help to set a valid baseline for the alluvial plains of Chiniot and confirm the trends at the national level but identify tehsil-level susceptibilities. The study fills gaps for research on less studied transitional areas and could be characterized by its support for more accurate soil management strategies, meeting Pakistan's National Soil Policy and goal number 2 of the SDGs, Zero Hunger. Soils face the need for collaborative, non-division strategies toward overall rejuvenation.

Recommendations

1. To reclaim salinie/sodic soils accurately, subsurface drainage and gypsum applications of 2-5 t/ha at Chiniot hotspots where ESP is above 15% must be used to reduce 15 to 20% ESP within 2 years.
2. Adding organic matter like apply pressmud (10 tons/ha) and F.Y.M (15 tons/ha) on an average every year for increasing PK availability and SOM by 0.5-1%.
3. In crop diversification viz the use of salt-tolerant crop varieties/legume crop rotations in the moderate climatic zones,
4. For the integration of policies, the purpose would be to form the Chiniot soil health surveillance system by using GIS dashboards in an annual appraisal, which would be linked with Punjab Irrigation.

These approaches, tailored to specific sites, can help restore degraded areas around Chiniot, supporting agricultural resilience in Pakistan's critical alluvial land.

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Declaration Statement

Data availability statement
The data generated and analyzed during this experiment are presented in this manuscript.

Ethics approval and consent procedure
Approved by the department Concerned.

Consent to publish
Approved

Financing
Not applicable

Conflict of interest
The authors declared that they had no conflict of interest.

Life science reporting
There were no threats under the life sciences category in the current research article.

Ethical responsibility
This is original research-based work. It is not submitted in whole or in parts to any other journal meant for publication.

Informed Consent
All the authors have reviewed the entire manuscript and approved it before submission and publication.

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