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Spatial variability and digital mapping of Zn content in soil and foliage of wheat producing area in district Jhelum-Pakistan

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Abstract

Evaluation of agricultural land management practices with reference to precision agriculture depends upon knowledge of soil spatial variability. This research work was carried out to illustrate the spatial heterogeneity of bioavailable and foliage Zn content in wheat fields of Jhelum which contributes most of the wheat producing area in Pothwar region of Pakistan. Soil samples were obtained from surface (0-15 cm) and subsurface (15-30 cm) from 90 selected (sparse) sites to cover the whole area for preparing precise digital maps. Coordinates were recorded using GPS receiver (Garmine*e-trex*). Data were subjected to descriptive statistics to examine the central tendency of data. Geostatistical technique (semivariogram) was applied to compare the spatial dependence of the data sets. Digital maps classifying the surveyed area into differential nutrient status zones were prepared by using ordinary kriging. Soils of the surveyed area were categorized as slightly to strongly alkaline and generally low in organic matter content. A widespread bioavailable and foliage Zn deficiency was observed in the surveyed area. Bioavailable Zn was found to be moderately (15-30 cm) to strongly spatial dependent (0-15 cm), while foliage Zn was moderately spatial dependent. Moderate to strong spatial dependence is considered as a pre-requisite for digital mapping. The results indicated a need for site specific Zn management keeping in view the soil heterogeneity.

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Introduction

Earlier studies have indicated that about 30 to 49 % of world's total area is Zn deficient (Sillanpaa, 1990; Wojcik, 2007). Zinc deficiency in the agricultural soils of Pakistan is attributed to alkaline pH calcareousness, low organic matter contents and coarse texture which results in the formation of insoluble compounds of Zn like insoluble calcium zincate, (Rashid *et al.*, 1997; Ahmed *et al.*, 2010). The availability of Zn to crops declines hundred times for each unit increase in soil pH in the range 4 to 9 (Lindsay, 1972).

Reduction in grain yield and poor nutritional quality are main consequences of Zn deficiency in wheat. It is immobile in plants and the deficiency symptoms appear on young leaves first. Mild deficiency of Zn in wheat leads to chlorotic and necrotic streaks, light green to white in color, appearing on either side of leaf midrib. Lower leaves become chlorotic and short, having normal width, as a result of severe Zn deficiency (Alloway, 2008). Middle-aged leaves often wilt, bend and collapse ultimately, showing more necrosis. Being typically sporadic in the field, its deficiency symptoms develop rapidly depending on the degree of stress. Application of Zn fertilizers or foliar sprays for treating its deficiency can increase crop yields as well as improve resistance to 'footrot' fungal disease**(**Gooding and Davies, 1997**)**.

Zinc is a vital element for all life forms and soil is the fundamental source of its supply for plants, animals and human beings. Soil tests provide basic information about plant available nutrients level while foliage analysis is tool used for diagnosing nutrient contents within plants tissue. Overall plant nutrient contents indicate their bioavailable accumulation in various plant parts. Therefore, nutrient content in plants is related to its quantity available in soil (Celik and Katkat, 2007). In Pakistan, widespread Zn deficiency in soils under agronomic crops and orchards is well documented (Rashid *et al.*, 1997: Ahmed *et al.*, 2010). It is estimated that 47% of total area of Pakistan is Zn deficient and lack of use of Zn fertilizer leads to 27.8% decrease in in crop yield (Alloway, 2008). Average yield of wheat in Pakistan is about 2.26ton ha^{-1} which is 3 times less than the research potential of the crop (Aslam, 2016).

Fertilizer nutrient application in Pakistan is usually done based on uniform recommendation leading to over or under fertilization in cultivated areas causing severe yield losses (Ahmed *et al.*, 2014). As soil heterogeneity is responsible for uneven adsorption, absorption and uptake of plant nutrients, traditional fertilization practices result in spatially distributed nutrient deficiencies ultimately damaging land resources (Jin and Jiang, 2002). Increase in population and hike of fertilizers prices require some scientific and more sophisticated techniques to increase fertilizer use efficiency and to avoid economic losses. Spatial variability in soil physico-chemical properties and nutrient levels is well documented (Wang *et al.*, 2009; Patil *et al.*, 2010; Ahmed *et al.*, 2014; Ahmed *et al.*, 2017:) Lack of consideration of spatial heterogeneity of soil physico-chemical properties and nutrients leads to uniform recommendation of fertilizer in Pakistan. Uniform application of fertilizers on provincial basis alongwith many other factors is playing havoc with fertilizer use efficiency (Rizwan *et al.*, 2016). Nutrient application to the soil according to spatially variable rate technology i.e., where and how much needed is the solution to the problem. Keeping in view the importance of soil spatial variability for site specific nutrient management, this research work aimed to characterize the spatial variability using geo-statistics and geographical information system. Consequently, district Jhelum was delineated in to various management zones as an exemplary model for Pothwar region.

Materials and methods

Soil and plant tissue sampling

A field survey was conducted to determine Zn contents and diagnosing the Zn deficiency in wheat fields of district Jhelum (Fig. 1). Ninety wheat growing fields were selected randomly and composite soil samples were collected from surface (0-15 cm) and subsurface (15-30 cm). Diagnostic plant samples, i.e., recently matured youngest leaves at maximum tillering stage, were also collected from the same fields. Leaf samples were washed with distilled water and air dried followed by drying in hot air oven maintained at 70C° and further processed for analysis. Soil samples were air dried, ground with wooden mortar and pestle, passed through 2 mm sieve and stored for analyses. Coordinates of each sampling site were recorded for precise site identification.

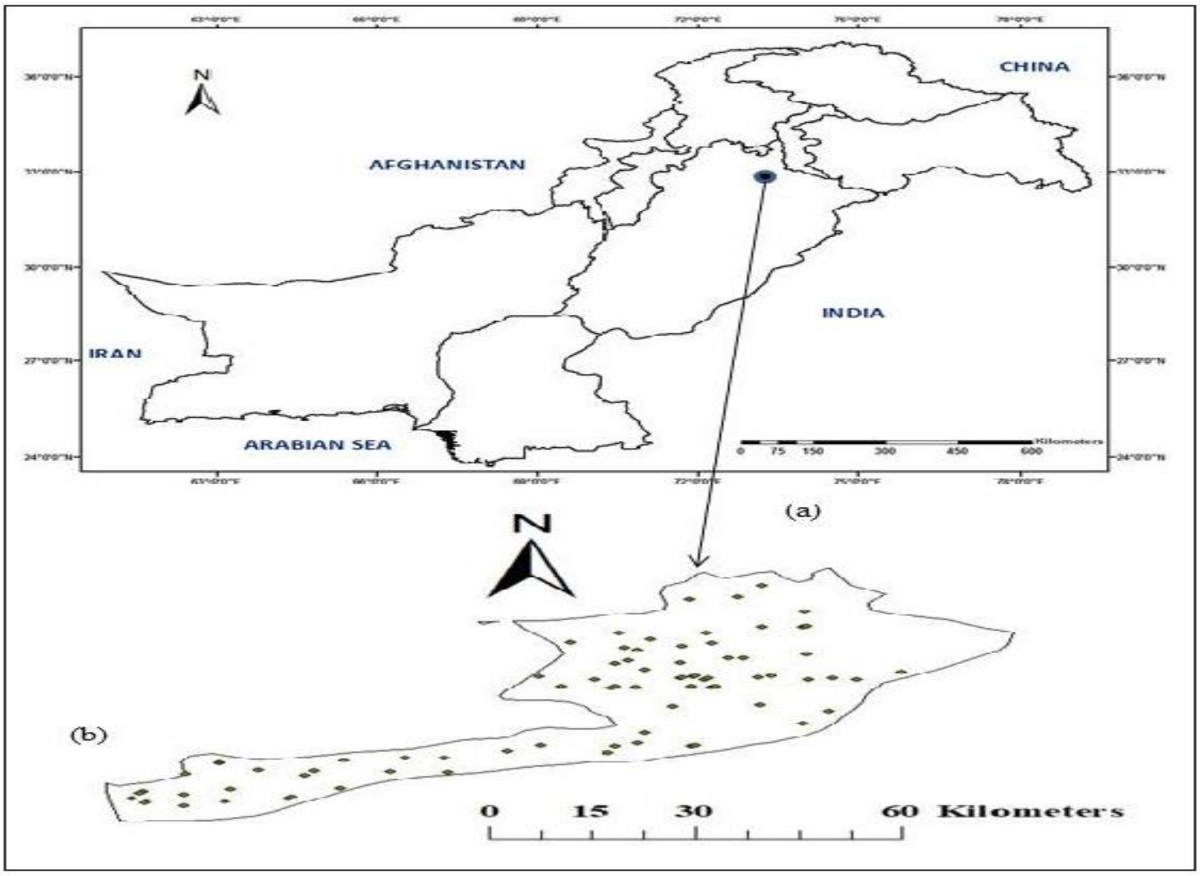

Fig. 1. Geographical location of the surveyed area (a) Pakistan, (b) Jhelum districtindicating sampling distribution.

Soil and plant analysis

The prepared soils were subjected to physico-chemical analyses for soil particle distribution by hydrometer method (Gee and Bauder, 1982), soil pH and electrical conductance by 1:2 suspension (Mclean, 1982), $CaCO_3$ contents by Leoppert *et al*., (1984), soil organic matter by Nelson and Sommers, (1982) and AB-DTPA extractable Zn (Soltanpour and Workman, 1979).

Plant leaf samples were wet digested using nitric-perchloric diacid mixture acid (2:1) and were analyzed for Zn by atomic absorption spectroscopy (Ryan *et al*., 2001).

Statistics and geostatistical analysis

Descriptive statistics including mean, standard deviation, kurtosis and skewness were applied to the data set obtained for soil physico-chemical properties as well as bioavailable and foliage Zn content. Co-efficient of variance (CV) was used to examine the variability of determined parameters.

The parameters having CV< 15% were grouped as least variable whereas those having CV between 15 to 35% were categorized as moderately variable, while those having CV> 35% were categorized as highly variable. Digital soil maps were prepared using GPS coordinates in Arc-GIS 10.5 software. Semivariogram analysis was run to evaluate degree of spatial dependence of the studied variables (Bhatti *et al.*, 1991). Three parameters i.e. nugget variance (C_o), sill (C_o + C) and range (a) were used to describe the structure of semivariogram. The nugget variance represents experimental error or spatial variation at distances smaller than the sampling interval (Burgess, 1980), sill shows the maximum semi variance that represents the variability, Range is distance beyond which the samples behave independently. Spatial class ratios (nugget/sill ratio expressed in %) are used to define different classes of spatial dependence. A variable having spatial ratio ≤25 % was considered strongly spatial dependent, moderate spatial dependency if the spatial ratio is between 25 to 75 % and weak spatial dependence if the ratio is > 75 % (Cambardella *et al.*, 1994; Attar *et al.*, 2012).

Spatial interpolation was done using ordinary kriging due to its remarkable flexibility. Accuracy of the interpolation was validated for comparing various models using mean error (ME), mean standard error (MSE), average standard error (ASE), root mean squared error (RMSE) and root mean square standardized error (RMSSE) (Robinson and Metternicht, 2006). Correctness of prediction was revealed if ASE was close to RMSE (Hani *et al.*, 2010). Isarithmicmaps were generated for spatial distribution of Zn, after the establishment of spatial dependence. The study area was classified into various zones based on Zn content.

Results and discussion

Physico-chemical properties of soils

Data pertaining to soil physico-chemical properties have been presented in Table 1.

Table 1. Summary statistics of physico-chemical properties of soils in surveyed area (n=90).

Physico-chemical Properties	Depth (cm)	Mean	Minimum	Maximum	*S.D	**CV	Skewness	Kurtosis
pH	0-15	7.88	6.69	8.69	0.41	5.20	0.50	-0.19
	15-30	7.97	7.07	8.91	0.36	4.51	-0.58	0.25
EC (dS m^{-1})	0-15	0.11	0.03	0.45	0.063	57.27	-0.19	0.39
	15-30	0.098	0.02	0.46	0.061	62.24	-0.26	0.37
O.M (%)	0-15	0.75	0.16	1.20	0.49	65.33	2.00	-0.12
	15-30	0.71	0.13	0.95	0.34	47.88	0.86	-0.39
$CaCO_3$ (%)	0-15	4.95	0.47	18.40	4.54	91.71	0.59	0.25
	15-30	5.05	0.45	20.70	4.75	94.05	0.65	-0.25
Sand (%)	0-15	59.79	4.98	91.78	16.49	27.59	0.52	0.36
	15-30	57.82	3.57	89.82	15.36	26.56	0.59	-0.25
Silt (%)	0-15	21.53	1.45	45.00	11.59	53.83	0.69	0.35
	15-30	23.52	2.50	49.00	10.69	45.45	0.82	0.25
Clay (%)	0-15	18.12	6.77	27.53	5.37	29.63	0.26	-0.25
	15-30	18.31	8.88	28.65	4.36	23.81	0.39	-0.24

*Standard Deviation, **Co-efficient of variance.

Major soil physico-chemical properties and biological properties like aeration, infiltration, water retention, nutrient absorption and microbial activities are affected by proportion of sand, silt and clay (Rizwan *et al.*, 2016; Gupta, 2004).

Sandy loam was the dominant textural class observed in area found in more than 32 % of the total analyzed samples followed by Sandy clay loam texture occurring in 29 % of analyzed soil samples. Other textural classes prevailing in the surveyed area were “Loam, Sand and

Sandy Loam” but with fewer occurrences. The electrical conductivity (EC) in the surface soils varied from 0.03 to 0.45dS m^{-1} with a mean value of 0.11 ± 0.063dS m^{-1} while in the subsurface, it ranged from 0.02 to 0.46 dSm^{-1} with the mean value of 0.098± 0.061. Electrical conductivity of soil reflects the salt concentration in the soils. Soil EC values less than 4 dSm^{-1} indicated that soils were free from the salinity and sodicity hazard.

Table 2. Assessment of bioavailable Zn (mg kg^{-1}) status in the studied area.

Nutrient	Depth (cm)	Mean	Minimum	Maximum	S.D*	C.V**%	Kurtosis	Skewness
Bioavailable Zn	0-15	0.84	0.14	2.90	0.50	59.52	1.25	1.46
	15-30	0.62	0.12	1.92	0.35	56.45	1.5	1.30
Foliage Zn	----	26.0	7.0	67.0	14.37	55.69	1.65	1.25

Soil pH is an important parameter which indicates chemical nature of the soil (Shalini *et al.*, 2003). Since it gives measures of the activity of hydrogen ions in the soil hence it reflects whether soil in question is acid or alkaline. Data indicated that soil pH varied from 6.69 to 8.69 with a mean value of 7.88 ± 0.41 in the surface soils and7.07 to 8.91 with the mean value of 7.97±0.36in the subsurface soil (Table 1). According to the pH data, majority of the soils were alkaline in nature probably due to the indigenous parent material, calcareousness and low organic matter (Latif *et al.*, 2008; Khalid *et al.*, 2012).

Soil organic matter is believed to be essential component of soil health. It is virtually from plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms.

Table 3. AB-DTPA Soil Zn critical values* used for surveyed area**.**

Micronutrient	Low	Marginal	Adequate
		µg g^{-1}	
Zn	< 0.9	0.9 - 1.5	> 1.5

*(Soltanpour, 1985).

It includes a wide range of organic compounds and materials such as humic substances, carbohydrates, proteins, and plant residues (Foth and Ellis, 1997). Organic matter values in soils ranged from 0.16 to 1.2 % with mean value of 0.75 ± 0.49in the surface soils (Table 1). While in lower surface soils it varied from the 0.13 to 0.95% with mean value of 0.71 ±0.49. Data Table 1 revealed that about two third (67%) of samples were poor in soil organic matter contents where sonly 20% were in satisfactory range, and only 3% were in adequate range.

Table 4. Foliage Zn critical values* used for surveyed area.

Micronutrient	Low	Marginal	Adequate
		µg g^{-1}	
Zn	< 25	25 - 150	> 150

*Neubert *et al.* (1970).

The high summer temperatures which exceeds 45 °C resulting in rapid decomposition is among many factors for low organic matter in the area. Calcium carbonate ($CaCO_3$) is considered as one of the main factors controlling soil pH and thus limits the bioavailability of nutrients in soils. In surface soil its content ranged from 0.47 to 18.4% with the mean value of 4.95 ±4.54 while in the subsurface profile it varied from 0.45 to 20.7% with the mean value of 5.05 ± 4.75. The data indicated that majority of the soils in surveyed area were slightly calcareous to strongly calcareous. As the CV value of soil pH was found less than 15% it was categorized as least variable while clay and sand contents in the surveyed area were found medium variable as the CV values of these variables were found between 15 and 35% both in the surface and subsurface soils. Other physico-chemical properties like EC, organic matter, $CaCO_3$ and silt contents were categorized as highly variable having CV value >35%.

Table 5. Parameters related to semivariogram models and interpolation of zinc in soil and foliage.

Nutrient	Depth (cm)	Model	Range (Ao)	Nugget/Sill (%)	ME[a]	RMSSE[b]	ASE[c]	RMSE[d]
Zn (Soil)	0-15	Spherical	0.47	23.94	0.0087	1.56	0.35	0.52
	15-30	Spherical	0.011	32.31	0.0005	0.85	0.37	0.31
Zn (Foliage)	-------	Spherical	26.59	26.59	-1.08	1.17	12.00	14.58

[a]Mean Error;[b]Rootmean square standardized error;[c]Average standardize error; [d]Root mean square error.

Zinc indexing in soil and foliage

Zinc content in the surface soil (0-15 cm) ranged from 0.14 to 2.90 mg kg^{-1} with mean value of 0.84±0.50 (Table 2). In the subsurface (15-30 cm) it varied from 0.12 to 1.92 mg kg^{-1} with the mean value of 0.62±0.35 (Table 2). Bioavailable Zn content at the surface soils and subsurface soils were found highly variable as the co-efficient of variance value was found more than 35% (Table 2). Upon comparison with threshold levels established by Soltanpour (1985) 60 and 80 percent of total analyzed samples were found deficient in bioavailable Zn content in the surface and subsurface soil (Table 3). Zinc content in the foliage of wheat ranged from 7 to 67 mg kg^{-1} with the mean value of 28.62± 14.37 mg kg^{-1}. Zinc content in the foliage of wheat was also found highly variable as the co-efficient of variance value was found more than 35%. Eighty five percent of the total plant samples were found deficient in Zn content when evaluated with the threshold levels (Table 4) described by Neubert *et al.* (1970).

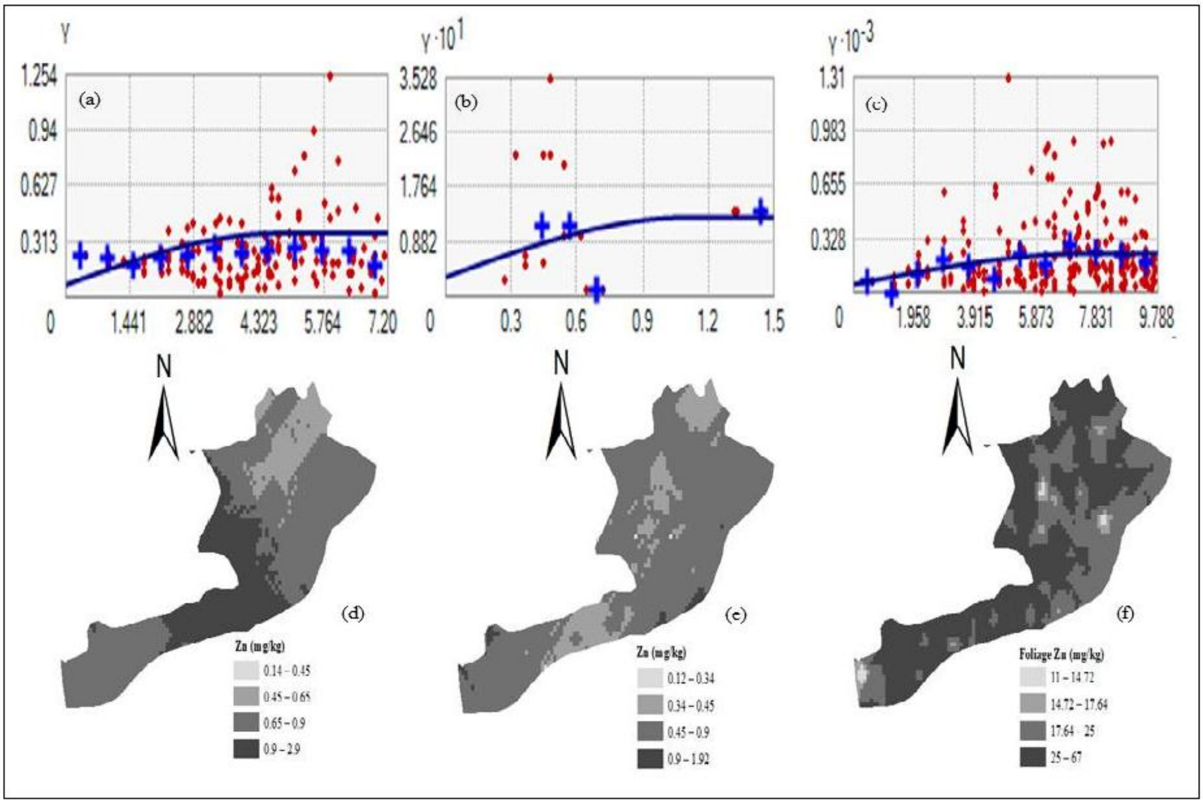

Fig. 2. Semivariograms (a) Zn content (0-15 cm) (b) Zn content (15-30 cm) (c) Foliage Zn and spatial distribution maps (d) Zn content (0-15 cm) (e) Zn content (15-30 cm) (f) Zn content in foliage.

Spatial variability of Zn content in the soil and foliage

The semivariogram models and best-fit model parameters for bioavailable Zn content in soil at two depths (0-15 and 15-30 cm) and Zn content in the foliage of wheat are presented in Table 5. Bioavailable and foliage Zn showed a positive nugget which may attributed to sampling error and short-range spatial variability associated with the random and inherent variability (Wang *et al.*, 2009). Spatial structure of bioavailable Zn at both depths and foliage was best described by spherical model and their spatial ratios were less than 75% each which indicated the existence of strong to moderate spatial dependence and range for bioavailable Zn was 0.47 and 0.011 km at both depths while foliage Zn indicated moderate spatial dependency at the range of 26.59 km. The spherical isotropic model is a modified quadratic function for which at some distance A_o pairs of points will no longer be auto correlated and the semivariogram reaches an asymptote (Robertson, 2008). Best spatial description of Zn content in the soil and foliage of wheat fields indicated higher variability of Zn content in the smaller areas. Moderate to strong spatial dependence of studied nutrient can be attributed to inherent factor including soil forming factors i.e., parent material which plays a key role in maintaining the spatial variability (Cambardella *et al.*, 1994). However, the anthropogenic activities like ploughing and planking in area may have also contributed to the maintenance of spatial structure of the Zn in the surface soils (Ahmed *et al.*, 2014). Increase in the spatial dependence with the increasing depth indicated that the spatial structure in the lower depth was controlled by the inherent factors like parent material and soil forming processes instead of human interventions.

Very low ME and RMSSE values indicated a higher accuracy of prediction of Zn content in the soil and foliage. Very close ASE and RMSE values in the surface (0.35 and 0.52) in the surface, subsurface (0.37 and 0.31) and foliage Zn content (12.00 and 14.58) indicated higher accuracy of ordinary kriging for preparing digital maps of the variables (Table 5). According to the results of the study geostatistics based maps for indicating spatially variable bioavailable Zn at 0-15 cm and 15-30 cm and foliage Zn content were prepared. Maps prepared for the Zn content in the soil and foliage using ordinary kriging has also indicated the spatial dependence (Fig. 2). Similar techniques have successfully been used by other researchers to categorize the area into low, medium and high nutrient content for site specific nutrient management (Eltaib *et al.*, 2002: Ahmed *et al.*, 2014). Our results were in line with (Thakor *et al.*, 2014) who referred to the significant role that GIS along with geo-statistics can play for preparing isaritmic/thematic maps of for zinc status in the soils of district of Gujrat state in India. Our results were also in agreement with Ahmed *et al.* (2014) who observed the strong spatial dependence of bioavailable Zn in agricultural soils of tehsils Murree, Punjab, Pakistan and found the sophisticated techniques of GIS coupled with geo-statistics as a potential tool for mapping the bioavailable Zn for site specific nutrient management using semivariogram modelling followed by kriging for preparing thematic maps. Our results were also supported by Ahmed *et al.*, 2017 who compared various geostatistical techniques for comparing their efficiency for preparing thematic maps of soil variables for site specific management. They found inverse distance weighting, polynomial interpolation technique, and kriging modelling having equal potential for interpolation of soil variables.

Generated maps could be a torch bearing guide for scientist and extension workers to conduct field trials in the delineated areas to recommend spatially variable Zn doses in the surveyed area. These will also be helpful to farmers to get information about the Zn status of their fields. Researchers and policy makers can also benefit from the generated information in their planning and policy making.

Conclusion

Zinc deficiency is one of the main factors hampering wheat yield in the rainfed area of district Jhelum. A widespread deficiency of Zn in the soils and foliage of wheat was observed in district Jhelum. Bioavailable Zn was moderate (15-30 cm) to strongly spatial dependent (0-15 cm). Foliage Zn was found to be moderately spatial dependent. Moderate to strong spatial dependence considered as a pre-requisite for digital mapping. Moderate to strong spatial dependence of the nutrient indicated that site-specific Zn nutrition management in the area could be an answer to loss of fertilizer due to its application according to the traditional, uniform recommendation on provincial basis. Researchers and fertilizer agencies can use the generated information in implementing/execution of their research and development activities. Farmers can also benefit from this information by exploring Zn status of the soils by a glance on the maps.

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