Analyzing Spatial Variability Of Soil Properties Using GIS-Based Geostatistical Method For A Cluster Of Five Villages Of Telangana State, India

Abhilash Maryada[1] and T.Vijaya Lakshmi*[2]
[1]Research Scholar, Centre for Environment, JNTUH; maryadaabhilash@gmail.com
[2]Assistant Professor, Centre for Environment, JNTUH; maryadaabhilash@yahoo.com
***Correspondence: maryadaabhilash@yahoo.com**

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Abstract:
Soil properties are key factors for agriculture and the environment. Land productivity is lost due to lack of proper land management causing degradation of soil. By evaluating the spatial variability of soil properties assessment can be done to the ruined land. In the present study, soil properties are analyzed and a map showing their variation is prepared in a GIS environment. Using a portable GPS unit, 11 random samples were collected from the cluster of an area of 46.41 sq km of five villages of telangana state. Soil parameters like pH, N, P, K, EC, organic matter, moisture content and water holding capacity are measured for pre-monsoon and post-monsoon. A comparative study is done for soil properties on Pre and Post monsoon. Spatial variation maps of soil properties were prepared by using Ordinary kriging technique in ArcGIS.

1. INTRODUCTION

Soil spatial variability is needed for intensive management of agriculture, development of natural resources accurate information on [1, 2]. Sustainability in agriculture can be attained by restoring soil properties [3]. Distribution of soil properties is the main factor to understand the natural communities [4] in the area and bio-physical process [5]. In a usual soil survey, properties of soil are noted at a particular location and the same is allocated to the entire unit which is not accurate. At the same time, Classical statistics is not appropriate for calculating the spatial distribution of soil properties at an unsampled location. There is a need for monitoring the soil properties continuous, as they change with the position [6]. Different geostatistical techniques are accepted for interpolating spatial variation of soil properties such as physical, chemical and biological [7-11]. These techniques are efficient for the study of spatial allocation of soil characteristics and their inconsistency and reducing the variance of assessment error and execution costs [11-13]. Ordinary Kriging technique is found to be better than the other geostatistical techniques for spatial variability of soil properties [14-17]. For good yield and implement strategies on agriculture, it is important to have an accurate estimation of soil properties spatial distribution. This will facilitate sustainable ecological management practices and farming by detecting site-specific soil conservation [18]. The present study is concerned with evaluating the soil properties like soil pH, Nitrogen (N), Phosphorus (P), Potassium (K), electrical conductivity (EC), organic matter moisture content and water holding capacity using standard and geostatistical methods to know the spatial involvement between soil nutrients in agriculture potential area for site-specific soil management practices.

2. MATERIALS AND METHODS

2.1 Study area:

A pilot study was carried out in five villages of Jangoan and Warangal Urban District. It is located to the western part of the district, geographically between 79°20'26'' & 79°26'6'' E longitude, 17°52'22'' & 17°59'11'' N latitude and falls on toposheet number 56 O/5 of 1:50,000 scale. National Highway 163 passes through the study area. It is 120 km far from Hyderabad and 26 km far from Warangal. The study area is spread around an area of 46.41 sq. km. with a total population of 12,942. The study area is dominated by grey granodiorite soil type. Paddy is the major crop followed by cotton and maize. Agro-climatic Region for the study area is Southern Plateau and Hills region with an average rainfall of 800-1150 mm. Soils in the study area are mostly chalka soils (sandy loam) and are followed by black soil (regur) and dubba (loamy sands).

Table 1 List of Villages under Study

S.No	Village Name	Mandal	District
1.	Mallikudurla	Velair	Warangal Urban
2.	Jhanakipur	Dharmasagar	Warangal Urban
3.	Kyathampalli	Dharmasagar	Warangal Urban
4.	Thatikyala	Dharmasagar	Warangal Urban
5.	Chinnapendyala	Chilpur	Jangaon
6.			

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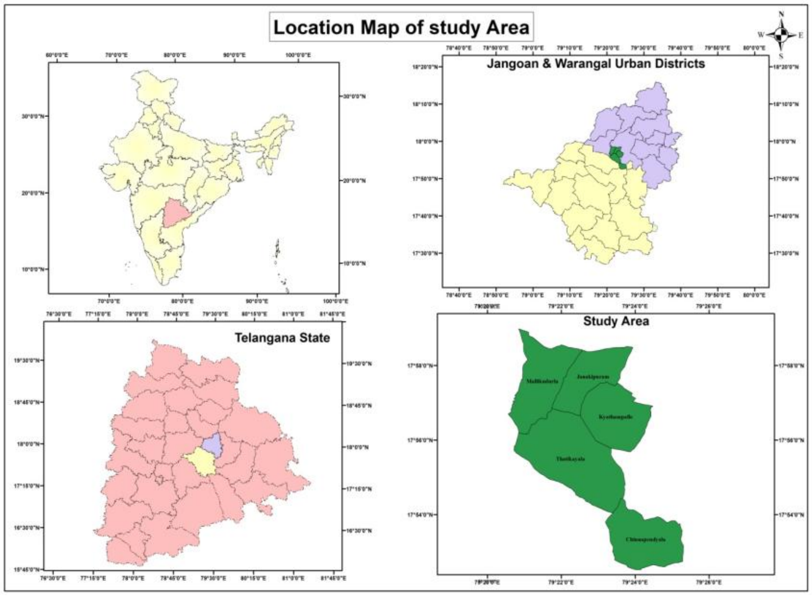
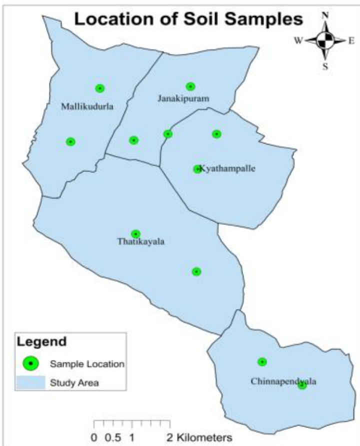


Figure 1 Location map of the study area



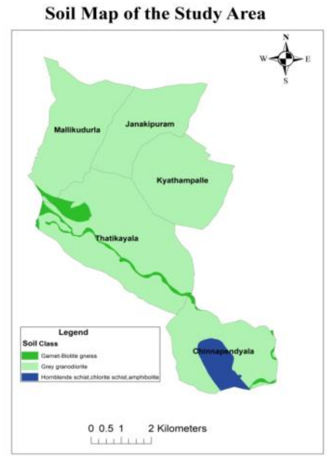


Figure 2(a) Sample locations of Soil samples **Figure 2(b)** Sample locations of Soil Map of the Study Area

2.2 Sample collection:

Through random sampling, a total of 11 soil samples were collected in the field for the whole study area. Soil samples were collected for two seasons Pre-monsoon (January-March) and Post-monsoon (July-September) for the year 2018. A portable GPS Unit (Trimble Juno) is employed to detect the spatial location from each sample. Well mixed composite soil sample is made by collecting undisturbed soil samples at depths of 0–20 cm with five soil cores each.

2.3 Parameters analyzed:

Collected soil samples are dried and conceded through a 2mm sieve for laboratory analysis textural characteristics. Soil properties like soil pH, Nitrogen (N), Phosphorus (P), Potassium (K), electrical conductivity (EC), organic matter, moisture content and water holding capacity are determined using the standard analytical methods.

2.4 Geostatistical methods:

From classical statistics, the geostatistical method is developed using variability analysis and spatial distribution method. The ordinary kriging (OK) interpolation method was used for prediction of the values of the unmeasured sites (un-samples locations) x_0 by assuming the $z^*(x_0)$ equals the line sum of the known measured value (field measured value). Ordinary kriging process is calculated by the following equation [19]:

$$z^*(x_0)=\sum_{i=1}^{n} \lambda_i z(x_i)$$

Where $z^*(x_0)$ is the predicted value at position x_0, $z(x_i)$ the known value at sampling site x_i, λ_i is the weighting coefficient of the measured site and n is the number of sites within the neighborhood searched for the interpolation.

2.5 Spatial maps generation:

Soil samples are analyzed and parameters are attached to the location as attributes. Using ordinary kriging technique available in ArcGIS 10.5 version spatial distribution maps are generated.

3. RESULT AND DISCUSSION:

From the samples collected from the study area, soil parameters like pH, Nitrogen (N), Phosphorus (P), Potassium (K), Electrical Conductivity (EC), Organic Matter, Moisture Content and Water Holding Capacity are analyzed for pre-monsoon and post-monsoon. The quality of the data is ensured through careful standardization. Table 2 and Table 3 shows the results of soil parameters at the sample locations for pre-monsoon and post-monsoon respectively. Statistics of the soil parameters like minimum, maximum, mean, standard deviation, skewness and kurtosis for each soil property for pre-monsoon and post-monsoon are shown in Table 4 and Table 5. There is a variation in the soil properties from season to season even at the same location. This may due to agriculture landfills, usage of fertilizers and open dumping.

Table 2 Pre Monsoon Water Samples and Parameters Analyzed

S.No.	Sample Name	pH	N (mg/g)	P (mg/g)	K (mg/g)	EC (µS/cm)	Organic Matter (mg/g)	Moisture Content (%)	Water Holding Capacity (%)
1.	Chinnapendyala soil sample 1	7.98	0.036	0.024	0.021	106	2.65	0.95	31.9
2.	Chinnapendyala soil sample 2	7.26	0.034	0.026	0.018	89	2.65	0.41	14.5
3.	Kyathampally soil sample 1	8.22	0.07	0.052	0.015	242	4.64	0.72	26
4.	Kyathampally soil sample 2	7.01	0.038	0.029	0.034	121	3.31	0.48	15.6
5.	Janakipur soil sample 1	7.9	0.034	0.02	0.035	102	2.65	0.35	29.3
6.	Janakipur soil sample 2	8.16	0.041	0.029	0.02	142	4.64	0.59	33.3
7.	Janakipur soil sample 3	7.49	0.122	0.06	0.015	330	5.96	0.39	15.2
8.	Mallikudrula soil sample1	7.84	0.047	0.039	0.025	215	3.98	0.87	23.7
9.	Mallikudurla soil sample 2	7.31	0.036	0.026	0.04	135	3.98	1.85	35.8
10.	Thatikyala soil sample1	8.48	0.032	0.02	0.041	98	1.99	0.7	34.3
11.	Thatikyala soil sample2	8.55	0.063	0.042	0.021	321	4.64	0.86	18.5

Table 3 Post Monsoon Water Samples and Parameters Analyzed

S.No.	Sample Name	pH	N	P	K	EC	Organic	Moisture	Water

			(mg/g)	(mg/g)	(mg/g)	(µS/cm)	Matter (mg/g)	Content (%)	Holding Capacity (%)
1.	Chinnapendyala soil sample 1	6.74	0.043	0.056	0.103	129.3	2.6	0.48	15.6
2.	Chinnapendyala soil sample 2	7.93	0.043	0.03	0.077	99.5	1.9	0.4 8	18.8
3.	Kyathampally soil sample 1	7.32	0.1	0.058	0.228	334	2.6	0.46	24.5
4.	Kyathampally soil sample 2	7.53	0.05	0.031	0.112	158.7	3.4	0.55	31.8
5.	Jankipur soil sample 1	6.8	0.04	0.03	0.07	145	2.6	0.66	19
6.	Janakipur soil sample 2	6.71	0.039	0.027	0.1	46.6	6	2.74	19.9
7.	Janakipur soil sample 3	7.04	0.063	0.105	0.135	114	2.3	0.49	23.7
8.	Mallikudrula soil sample1	7.96	0.055	0.047	0.094	102.6	1.1	0.49	15.3
9.	Mallikudurla soil sample 2	6.58	0.115	0.023	0.461	467	6	0.43	40.5
10.	Thatikyala soil sample1	8.9	0.034	0.065	0.048	394	3.8	0.63	41.3
11.	Thatikyala soil sample2	7.48	0.043	0.033	0.06	397	2.3	0.43	25.6

Table 4 Summary statistics of soil properties for Pre-Monsoon

S.No	Soil Property	Mean	Median	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
1.	pH	7.84	7.9	7.01	8.55	0.51	-0.17	1.82
2.	Nitrogen (N) (mg/g)	0.05	0.04	0.03	0.12	0.03	1.91	5.67
3.	Phosphorous (P) (mg/g)	0.03	0.03	0.02	0.06	0.01	0.83	2.46
4.	Potassium (K) (mg/g)	0.03	0.02	0.02	0.04	0.01	0.45	1.64
5.	EC (µS/cm)	172.82	135	89	330	89.67	0.82	2.14
6.	Organic Matter (mg/g)	3.73	3.98	1.99	5.96	1.195	0.25	2.16
7.	Moisture Content (%)	0.74	0.70	0.35	1.85	0.42	1.69	5.43
8.	Water Holding Capacity (%)	25.28	26	14.5	35.8	8.23	-0.14	1.44

Table 5 Summary statistics of soil properties for Post-Monsoon

S.No	Soil Property	Mean	Median	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
1.	pH	7.36	7.32	6.58	8.9	0.70	0.85	2.999
2.	Nitrogen (N) (mg/g)	0.06	0.043	0.03	0.12	0.03	1.37	3.32
3.	Phosphorous (P) (mg/g)	0.05	0.03	0.02	0.11	0.03	1.35	4.12
4.	Potassium (K) (mg/g)	0.135	0.1	0.048	0.461	0.118	2.13	6.41
5.	EC (µS/cm)	217.06	145	46.6	467	149.24	0.573	1.67
6.	Organic Matter (mg/g)	3.15	2.6	1.1	6	1.58	0.93	2.75
7.	Moisture Content (%)	0.71	0.49	0.425	2.74	0.68	2.78	8.875
8.	Water Holding Capacity (%)	25.1	23.7	15.3	41.3	9.15	0.795	2.329

pH: Negative logarithm of hydrogen ion concentration is called pH and measured using pH meter (FE20, Mettle Toledo, Switzerland). Ph minimum is 7.01 for pre-monsoon and 6.58 for post-monsoon while the maximum is 8.55 and 8.9 for post-monsoon. The standard deviation for pre-monsoon is 0.51 and 0.7 for post-monsoon. Mean is 7.84 pre-monsoon and 7.36 for post-monsoon indicating alkalinity of the soil. The decrease in the soil pH may be due to soil acidification where leaching occurs due to rainfall [20]. Spatial maps produced by kriging indicate that higher concentrations of pH are in the central part of the study area for both the seasons. The larger extent of high pH is observed for pre-monsoon compared to post-monsoon.

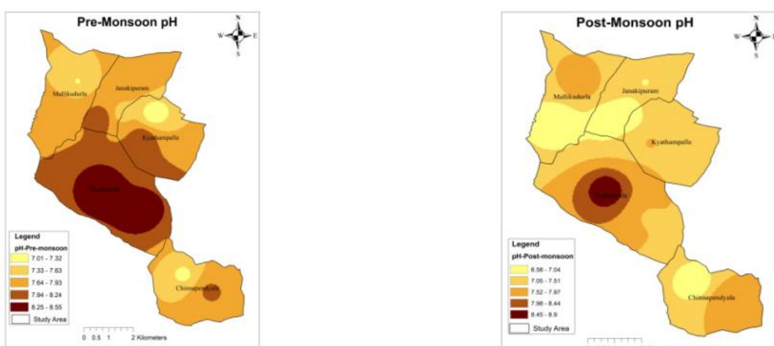


Figure 4 Spatial Maps of pH

Nitrogen (N): N values range from 0.02 mg/g to 0.04 mg/g for pre-monsoon and 0.03 mg/g to 0.12 mg/g for post-monsoon. Stand deviation and mean for pre-monsoon are 0.03 mg/g and 0.06 mg/g while for post-monsoon are 0.12 mg/g and 0.14 mg/g. Higher availability of nitrogen in post-monsoon is due to better root growth and higher urease activity of root exudates [21]. The spatial map indicates that higher values of N are in the central part of the study area for the pre-monsoon while for post-monsoon higher values are observed in the west and east part of the study area

Figure 5 Spatial Maps of Nitrogen

Phosphorous (P): Phosphorous range for pre-monsoon is 0.02 mg/g to 0.06 mg/g and 0.02 mg/g to 0.11 mg/g for post-monsoon. Standard deviation and mean are 0.01 mg/g and 0.03 mg/g for pre-monsoon and 0.03 mg/g and 0.05 mg/g for post-monsoon respectively. Change in P mineralization from organic matter decomposition is affected by factors such as temperature, rainfall, soil aeration, moisture and salinity. Soils with pH range 6 to 7.5 are best for P-availability, while pH range 7.5 to 8.5 and below 5.5 confines P-availability [22]. Parts of the northern region and southern region have higher concentrations while lower concentrations are accumulated in the central part of the study area for pre-monsoon. The northern part of the study area has the lower concentrations while higher concentrations are towards north-western part and towards the southern part of the area.

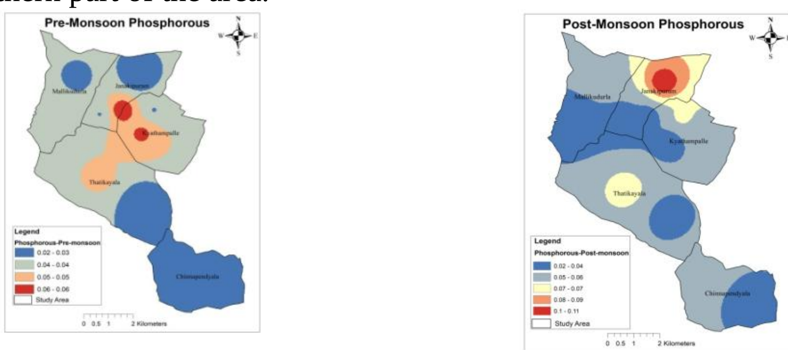


Figure 6 Spatial Maps of Phosphorous

Potassium (K): K values range from 0.03 mg/g to 0.12 mg/g for pre-monsoon and 0.048 mg/g to 0.461 mg/g for post-monsoon. Stand deviation and mean for pre-monsoon are 0.01 mg/g and 0.03 mg/g while for post-monsoon are 0.12 mg/g and 0.14 mg/g. The increase in the values may be attributed to the deprived drainage condition of the soil and an unnecessary dose of fertilizers in this area [23]. Pre-monsoon spatial map of K indicated that higher values are observed from west to east but for post-monsoon, it is concentrated on the west side of the study area.

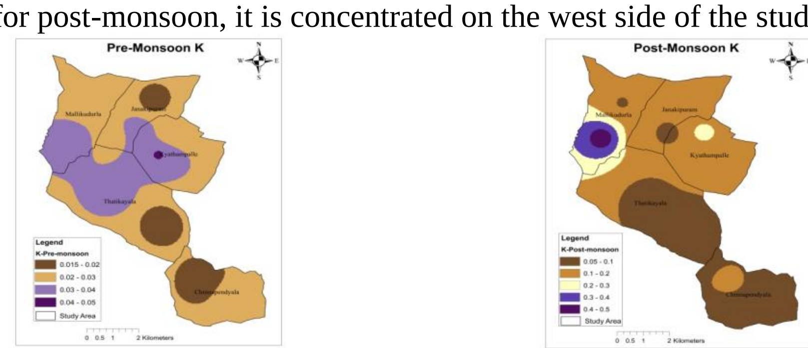


Figure 7 Spatial Maps of Potassium

Electric Conductivity (EC): availability of nutrients is indicated by EC in the soil. Increase in EC indicates more negatively charged sites in the soil, and therefore the more cations held in the soil. Minimum and maximum of EC for pre-monsoon are 89 and 330 μS/cm (micro siemens per centimeter) and 46.6 and 467 μS/cm for post-monsoon. Standard deviation is 89.67 μS/cm and 149.24 μS/cm for pre-monsoon and post-monsoon respectively. Mean for pre-monsoon is 172.82 μS/cm and 217.06 μS/cm for post-monsoon. Increase in soil EC is due to the accumulation of salts in the root zone. This is caused by irrigation with water which is high in salts or in amounts very low to leach salts [24]. Spatial distribution map of EC shows that the lower values of EC are towards the northern and southern part of the study area, in between, there is a deviation towards higher values.

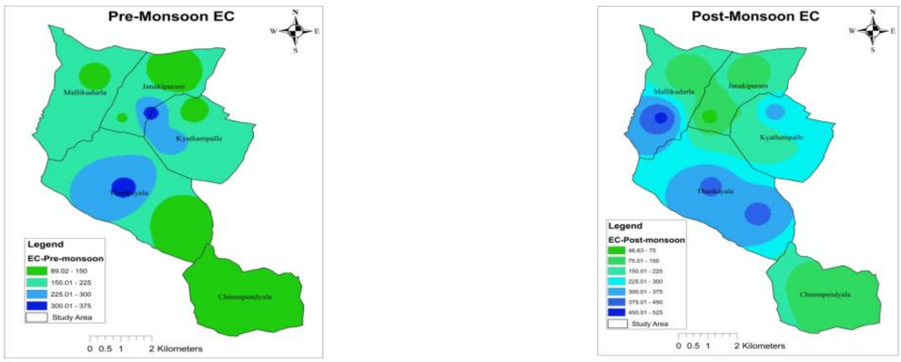


Figure 8 Spatial Maps of EC

Organic Matter: Minimum and maximum values for pre-monsoon are 1.99 mg/g and 5.96 mg/g while standard deviation and mean are 1.2 mg/g and 3.73 mg/g. Post-monsoon minimum and maximum values are 1.1 and 6 while the mean and standard deviation are 3.15 mg/g and 1.58 mg/g. Changes in Climatic conditions, such as rainfall, moisture, temperature, and soil aeration alters the rate of organic matter decomposition which affects the organic matter content in the soil. [25]. The southern part of the study area has higher values of organic matter for pre-monsoon and lower values towards the north-western part. In addition to the pre-monsoon's spread in the southern region, post-monsoon has a higher concentration in the northern part of the study area. Lower concentration of organic matter for post-monsoon is towards north-western part of the study area but not spread as pre-monsoon.

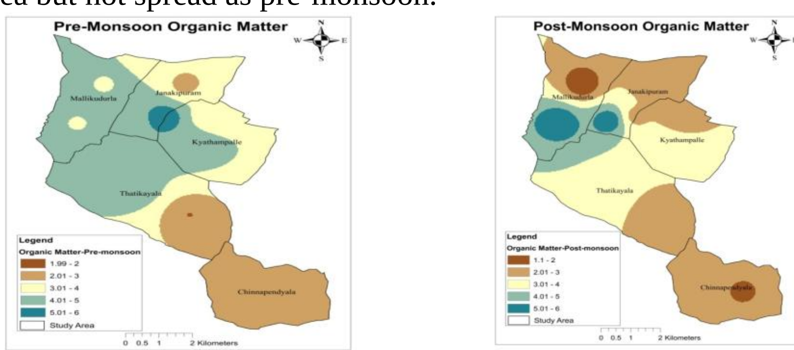


Figure 9 Spatial Maps of Organic Matter

Moisture Content: minimum and maximum value of moisture content for pre-monsoon are 0.35% and 1.85% and 0.43% and 2.74% for post-monsoon. Standard deviation is 0.42% for pre-monsoon and 0.68% for post-monsoon. Mean is 0.74% for pre-monsoon and 0.71% for post-monsoon. Penetration of precipitated water provides the moisture content in the soil. Its substance in soil relies on the water holding capacity of the soil, soil texture, evaporation, porosity, etc. [26]. The north-west part of the study area has higher values for pre-monsoon while the central part has higher values for post-monsoon. Rest of the study area has lower values of moisture content.

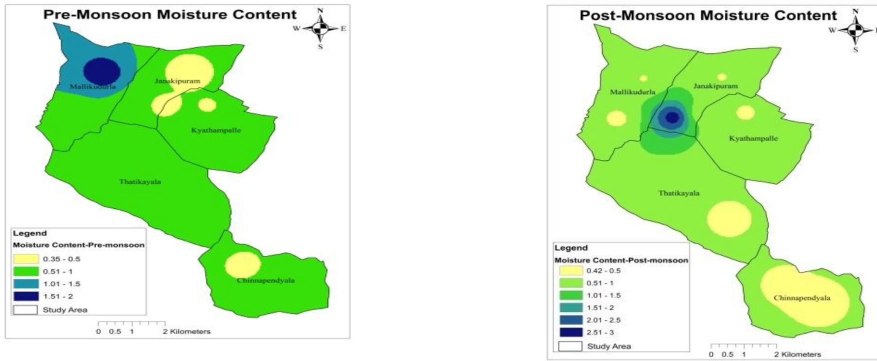


Figure 10 Spatial Maps of Moisture Content

Water Holding Capacity: WHC ranges from 14.5% to 35.8% for pre-monsoon and 15.3% to 41.3% for post-monsoon. Mean is 25.28% for pre-monsoon and 25.1% for post-monsoon. Standard deviation is 8.23% and 9.15% for pre-monsoon and post-monsoon. Water holding capacity depends on the texture of the soil [27]. Hence there is no much change in the water holding capacity of the soil pre and post-monsoon. From spatial of water holding capacity, pre-monsoon values are scattered over the whole study area. Chinnapendyala village of the study area has low water holding capacity for post-monsoon while the north-western part has the higher concentrations.

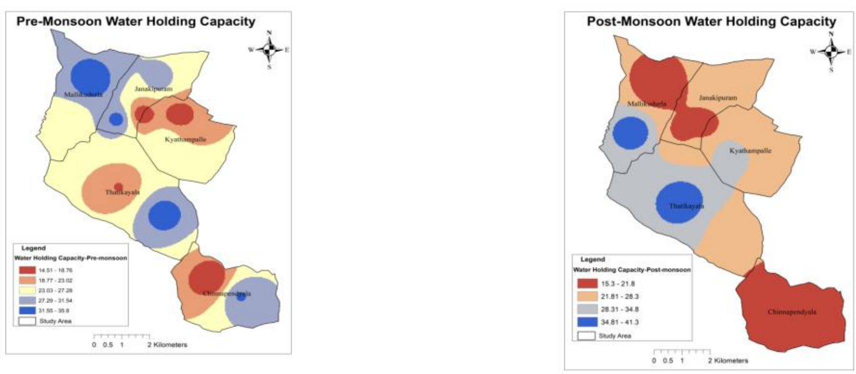


Figure 11 Spatial Maps of Water Holding Capacity

4. CONCLUSION:

Soil conservation at large scale can be done by understanding the geographical distribution and precision mapping of soil properties. Using Ordinary kriging method of geostatistical model spatial maps were developed for two seasons for eight soil properties namely soil pH, nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), soil organic matter, moisture content and water holding capacity and a comparative analysis is done. Higher dosage of fertilizers, agriculture disposals and dumping are causing variation in the soil properties season to season even at the same location. The results showed the importance to understand the soil parameters spatial variability for two seasons to improve the quality of the soil. For future research, large numbers of soil samples are required as the present study has been limited by small soil samples. The present study can help the farmers and policy makers to understand the seasonal change and improve soil quality.

5. REFERENCES:

1. D.L. Karlen, B.J. Wienhold, S. Kang, T.M. Zobeck, S.S. Andrews (2011). Indices for Soil Management Decisions, USDA-ARS/UNL Faculty, Paper 1381 http://digitalcommons.unl.edu/usdaarsfacpub/1381.
2. H. Lin, D. Wheeler, J. Bell, L. Wilding (2005). Assessment of soil spatial variability atmultiple scales, Ecol. Model. 182, 271–290.
3. S. Zandi, A. Ghobakhlou, P. Sallis (2011). Evaluation of spatial interpolation techniques for mapping soil pH, International Congress on Modelling and Simulation, Perth, Australia, 12–16 December, pp. 1153–1159.
4. T.M. Palmer (2003). Spatial habitat heterogeneity influences competition and coexistence in an African acacia ant guild, Ecology 84, 2843–2855.
5. S. Kumar, T.J. Stohlgem, G.W. Chong (2003). Spatial heterogeneity influences native and nonnative species richness, Ecology 87, 3186–3199.
6. Burrough, P. A. (1993). Soil variability: a late 20th century view. Soils Fert., 56, 529-562.Y.
7. Fromm H, Winter K, Filser J (1993). The influence of soil type and cultivation system on the spatial distributions of the soil and microorganisms and their interactions. Geoderma 60:109–118.
8. Wigginton JD, Lockaby BG, Trettin CC, Nelson EA, Kolka RK, Wisniewski J (2000). Soil organic matter formation and sequestration across a forested floodplain chronosequence. In: Proceeding of workshop held at Clemson University, 12–14, pp 141–155.
9. Vieira VA, Mello CR, Lima JM (2007). Spatial variability of soil physical attributes in small watershed. Ciencia e Agrotecnologia 31(5):1477–1485.
10. Zheng Z, Zhang FR, Ma FY (2009). Spatiotemporal changes in soil salinity in a drip irrigated field. Geoderma 149:243–248.
11. Liu L, Wang H, Dai W, Lei X, Yang X, Li X (2014). Spatial variability of soil organic carbon in the forestlands of northeast China. J For Res 25(4):867–876.
12. Saito, H., McKenna, A., Zimmerman, D.A., Coburn, T.C., (2005). Geostatistical interpolation of object counts collected from multiple strip transects: ordinary kriging versus finite domain kriging. Stoch. Environ. Res. Risk Assess. 19, 71–85.
13. Behera, S.K., Shukla, A.K., (2015). Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable Potassium, calcium and magnesium in some cropped acid Soils of India. Land Degrad. Dev. 26, 71–79.
14. U. Weller, W.Z. Castell, M. Sommer, M. Wehrhan (2002). Kriging and Interpolation with Radial Base Functions a Case Study, http://citeseerx.ist.psu.edu/viewdoc/ versions?doi= 10.1.1.73.1305.
15. T.P. Robinson, G.M. Metternicht (2006). Testing the performance of spatial interpolation techniques for mapping soil properties, Comput. Electeronics 50, 97–108.

16. Hengl T, Rossiter DG, Stein A (2004). Soil sampling strategies for spatial prediction by correlation with auxiliary maps. Aust J Soil Res 41(8):1403–1422.
17. Bhunia GS, Shit PK, Maiti R (2016). Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). J Saudi Soc Agric Sci. doi:10.1016/j.jssas.2016.02.001.
18. C.A. Cambardella, T.B. Moorman, J.M. Novak, T.B. Parkin, D.L. Karlen, R.F. Turco, A.E. Konopka (1994). Field-scale variability of soil properties in central Iowa soils, Soil Sci. Soc. Am. J. 58, 1501–1511.
19. Wang, Z. Q. (1999). Geostatistics and its application in ecology. Beijing: Science Press, 35, 96.
20. Reuss, J. O. (1980). Simulation of soil nutrient losses resulting from rainfall acidity. Ecological Modelling, 11(1), 15-38.
21. Shilpkar, P., Shah, M. C., Modi, K. R., & Patel, S. M. (2010). Seasonal changes in microbial community structure and nutrients content in rhizospheric soil of Aegle marmelos tree. Annals of Forest Research, 53(2), 135-140.
22. NRCS: Soil Phosphorous, available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051878.pdf, accessed on 7 April 2019.
23. Bohn, H. L., Myer, R. A., & O'Connor, G. A. (2002). Soil chemistry. John Wiley & Sons.
24. NRCS: Soil Electrical Conductivity, available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052803.pdf, accessed on 20 May 2019 .
25. NRCS: Soil Organic Matter, available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053140.pdf, accessed on 2 June 2019.
26. O'Geen, A. T. (2012). Soil Water Dynamics. Nature Education Knowledge 3(6):12.
27. Ball, J. (2001). Soil and water relationships.