Quantitative Assessment and GIS-Based Interpolation Approach for Mapping Soil Health Indicators in Chinnar Wildlife Sanctuary, Western Ghats, India

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Abstract

Human activities such as modern agriculture, land-use changes, and different pollution are drastically altering soil structure and functions. The present study aimed to apply Inverse Distance Weighting (IDW) method to interpolate the soil fertility of the samples collected from the Chinnar Wildlife Sanctuary, a protected area of Western Ghats, Kerala, India. Important soil health indicators such as soil moisture content, pH, electrical conductivity, organic matter, total organic carbon and cation exchange capacity were analysed using standard analytical methods. The laboratory result is executed in ArcGIS® 10.8. and spatial interpolation of soil health indicators has been performed. Results of the study found that the assessed soil health indicators in the study area is relatively optimum level. In addition to that spatial interpolation map exhibit variation in Vellaikal mala and Champakkadu regions. Field observation and vegetation assessment found that dry deciduous forest of Champakkadu region has experienced degradation during recent period.

Keywords: Soil, IDW, Soil Health Indicators, GIS, Protected Areas, Soil management

I. Introduction

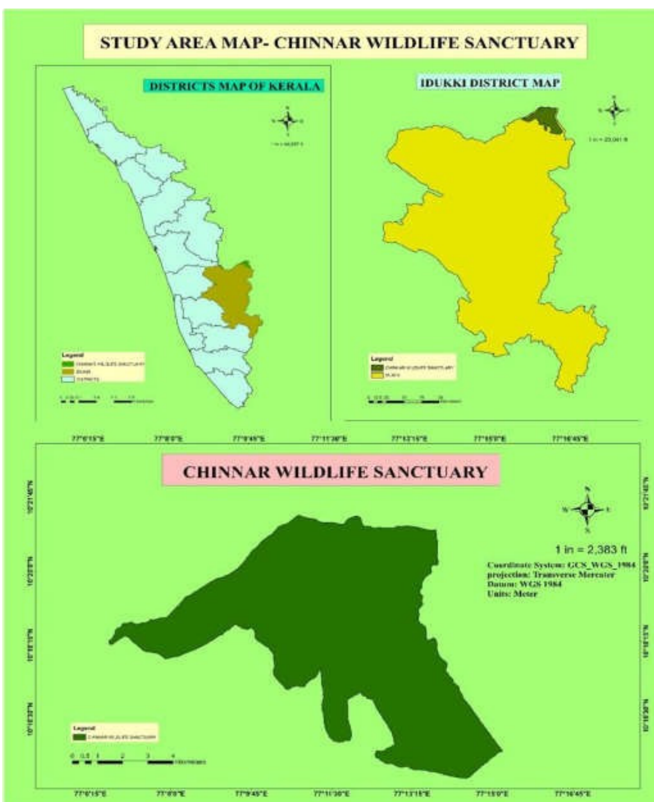
Soil is an important component of the ecosystem because it supports a wide range of microhabitats, improves the biogeochemical cycle, and aids in the preservation of ecosystem products and services. Soils also serve as sinks for greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (NRCS 2011, Oertel et al., 2016). A brief study on peatlands and climate change published by the IUCN in 2021, reveals the soil absorbs roughly one-quarter of all greenhouse gas emissions each year, with a significant portion of this stored in peatland or permafrost (IUCN 2021). These facts remind us how important healthy soils are for healthy plant growth, as well as for making the landscape more resilient to the effects of climate change. Numerous studies have found that soil degradation caused by anthropogenic activity occurs regularly everywhere in the world. Chen et al., (2000) investigated the effects of potentially significant human disturbances on forest ecosystems and reported that intensive human activities frequently disrupted the nitrogen and phosphorus cycles. Prasannakumar et al., (2011) reported that approximately 5.37 to 8.4

million tonnes of soil are lost in forest ecosystems due to human activities. Furthermore, Dror et al., (2021) found that human activities such as modern agriculture, land-use changes, and pollution are the primary determinants of soil quality degradation. In 2017, the FAOled Global Soil Partnership Report revealed that cultivated land around the world erodes 75 billion tons (Pg) of soil each year, resulting in an estimated annual economic loss of $400 billion. In India, an estimated 147 million hectares (Mha) of land has deteriorated due to water erosion (94 Mha), acidification (16 Mha), floods (14 Mha), drought (9 Mha), salinity (6 Mha), and 7 Mha due to a combination of other factors (Bhattacharyya et al.,2015). According to the desertification and land degradation atlas of India report (2016), 29.3 % of the country experienced land degradation between 2011 and 2013. The majority of land degradation has been reported in Kerala, Rajasthan, Andhra Pradesh, Orissa, and Madhya Pradesh (Mythili and Goedecke, 2016). In Kerala, a total of 71.28 % of the geographical area has been eroded, whereas, in Idukki, where the study area is located, about 96.3 % of the geographical area is eroded (Sreepriya 2020). Severe soil degradation has significant environmental consequences (Pimentel, 2006) including biodiversity decline and degradation of ecosystem services (Pacheco et al., 2018). Urgent actions are needed to prevent soil degradation and restore degraded soil productivity. This necessitates systematic soil knowledge, and characterization of basic resources such as soil, water, climate, and biodiversity issues. An effective way to create strategies for reducing soil deterioration and sustaining healthy soil is to employ GIS-based spatiotemporal analysis of soil health indicators. Santoso et al. (2018) interpolated soil properties in central Java, western Indonesia, employed the inverse distance weighting (IDW) technique. Mueller et al., (2004) and Qiao et al., (2018) attempted to characterize soil samples and evaluated the relative performance of inverse distance weighted (IDW) and ordinary kriging (OK) in Kentucky and Beijing, respectively. Srivastava et al., (2019) assessed 82 soil samples collected in Varanasi City, India, and remote sensing data to compare the performance of four widely used interpolation methods such as distance weighting (IDW), spline, ordinary kriging models, and kriging with external drift (KED) interpolation techniques. However, there haven't been studies on spatial interpolation of soil health indicators in Kerala. Despite this, few researchers have employed GIS techniques and modeling approaches for other objectives. For example, Prasannakumar et al., (2011) investigated the spatial prediction of soil erosion risk in the Siruvani River watershed in the Attapady valley of Kerala, India using the IDW and RULSE approach. Similarly, Chinnasamy et al., (2020) and Libin et al., (2019) used remote sensing data, GIS and Universal Soil Loss Equation (USLE) to evaluate soil erosion in Kerala and Vamanapuram River basins. Chinnar Wildlife Sanctuary, a protected area of the Western Ghats has experienced severe anthropogenic stress in recent years (Sasi and Kumara 2018). The natural vegetation types, particularly dry deciduous forests and scrub jungles of the sanctuary have been reduced at an alarming rate. If the intensity of vegetation degradation increases, the population of soil organisms and microbial activities will decrease. It is due to a reduction in organic matter constituents, unfavorable soil microclimate, abnormal soil erosion, and depletion of soil nutrients (Kooch et al., 2022).

In the present study, an attempt was made to find out the soil quality of Chinnar Wildlife Sanctuary by integrating fieldwork, lab analyses, and interpolation method in GIS utilized for mapping soil health indicators. To evaluate the relationship between regional hydrology, ecology, and physical geography, soil moisture content was examined. To understand the physical condition of the soil, the pH of the soil was measured. Soil electrical conductivity (EC) was measured to evaluate soil health across the landscape by measuring soil salinity, soil organic matter (SOM), and soil organic carbon. Spatial interpolation method such as inverse distance weighting (IDW) is employed to estimate unsampled locations using values from nearby weighted locations.

II. Material and Methods

A) Details of the Study Area



Chinnar Wildlife Sanctuary is a protected area of the Southern Western Ghats located in the Devikulam taluk of Idukki district, Kerala, India (Figure 1). The sanctuary covers an area of 90.44 km^2 and is located between latitudes 10°15' - 10°21' N and longitudes 77°5' - 77°16' E. It was designated as a Wildlife Sanctuary in August 1984, and it is considered one of the most important protected areas in the Western Ghats due to its ecological significance. The sanctuary receives an annual rainfall of 500 mm, and the temperatures vary from 18°C to 25°C, respectively. The soil is sandy to sandy loam in texture. Major vegetation includes Southern tropical thorn forest (Scrub jungle), Southern dry mixed deciduous forest (Dry deciduous forest), Southern moist mixed deciduous forest (Moist deciduous forest), Tropical riparian fringing forest (Riparian Forest), Southern montane wet temperate forest (Hill shola forest) and Southern montane wet grassland (Grasslands).

Fig 1. Boundary map of Chinnar Wildlife Sanctuary

B) Method Adopted For Soil Sampling

Field visits and sampling was conducted between 2019 (Post monsoon) and 2020 (Pre-monsoon) from different locations of the sanctuary. The geo-coordinates of each sample were recorded using a global positioning system (GPS, GARMIN SKU: 010-01504-20, India) as shown in Table 1. A total of 13 soil samples were collected at a depth of 15 cm from 5 to 6 different vegetation types for laboratory analysis of soil health indicators. Before collecting the sample, the surface litter, unwanted materials, and pebbles were removed from the sampling spot, and a "v" shape pit of up to 15 cm was made by scraping the sides. The collected samples were thoroughly mixed and the bulk is reduced by quartering about 500 gm of composite samples were used for the analysis. The samples were dried in the shade for 2-3 days before sieving with a 2mm sieve plate and stored in an airtight container for laboratory analysis (Sannappa and Manjunath 2013).

Table 1. Sample locations and coordinates of samples collected from Chinnar wildlife sanctuary

SLNO	SAMPLING LOCATIONS	GEOCOORDINATES
1.	Alampetty (S1)	10^0 16’ 20.59"N 77^0 11' 48.84"E
2.	Alampetty (S2)	10^0 16' 13.17 " N 77^0 11' 42.12 " E
3.	Vellaikal mala (S3)	10^0 19’ 25.4"N 77^0 11' 20.2"E
4.	Vellaikal mala (S4)	10^0 16' 16.22"N77^0 11' 39.45"E
5.	Jallimala (S5)	10^0 16’ 24.50"N 77^0 11' 41.04"E
6.	Jallimala (S6)	10^0 19’ 02.4"N 77^0 11' 19.3"E
7.	Olikkudi (S7)	10^0 18’ 49.5"N 77^0 11' 12.2"E
8.	Olikkudi (S8)	10^0 19’ 14.7"N 77^0 11' 22.8"E
9.	Champakkadu (S9)	10^0 19' 49.42"N 77^0 13' 06.94"E
10.	Champakkadu (S10)	10^0 21’ 04.54"N $77^0$13.45'45.30"E
11.	Palapetty (S11)	10^0 19' 56.76"N 77^0 13' 10.88"E
12.	Palapetty (S12)	10^0 21' 10.98"N 77^0 12' 31.74"E
13.	Eachampetty (S13)	10^0 30’ 47.13"N 77^0 11' 46.15"E

C) Soil Health Indicator Analysis

A brief overview of the parameters analysed, a summary of the soil indicators, and analysis methods are given in Table 2. In this study, some of the most important soil chemical properties were chosen based on the literature. These are the most important health indicators for assessing the soil quality of Chinnar Wildlife Sanctuary (Gelybo et al., 2018).

Table 2. Potential soil health indicators used for the analysis, units, description, and analysis method

Soil Health Indicator	**Units**	**Analysis Method**
pH		PCS Multiparameter tester
Soil moisture	Percentage	Gravimetric method
Electrical conductivity	*mS/cm*	Multiparameter tester
Soil organic carbon	(g m^{-2})	Walkley and Black rapid dichromate oxidation technique
Soil organic matter	Percentage	Walkley and Black rapid dichromate oxidation technique
Cation exchange capacity	*(meq/100 g)*	Ammonium acetate method of

D) Inverse Distance Weighted Method (IDW)

The spatial interpolation was conducted using the Inverse Distance Weighted (IDW) interpolation available in the ArcGIS® Geostatistical Analyst toolbar. IDW is based on Tobler's first law of geography, which was published in 1970. According to the law, it is defined as “everything is related to everything else, but near things are more related than distant things” (Tobler 2004).The basic principle of IDW interpolation is using a weighted linear combination set of sample points, it counts on the two statistical and mathematical methods to create surfaces and calculate the predictions of unmeasured points (Khouni et al., 2021). The general equation used for the IDW (Eq. (1)) is as follows:

$$x^* = (w_1x_1 + w_2x_2 + w_3x_3 + \dots + w_nx_n)/(w_1 + w_2 + w_3 + \dots + w_n) \qquad \dots(Eq.1)$$

Where x^* is the unknown value at a location to be determined, w is the weight, and x is the known point value.The IDW technique is used in this study to generate spatial distribution maps of soil health indicators to evaluate soil quality in an ecologically important protected region of the Western Ghats. The overall step involved in the study has shown in Figure.2.

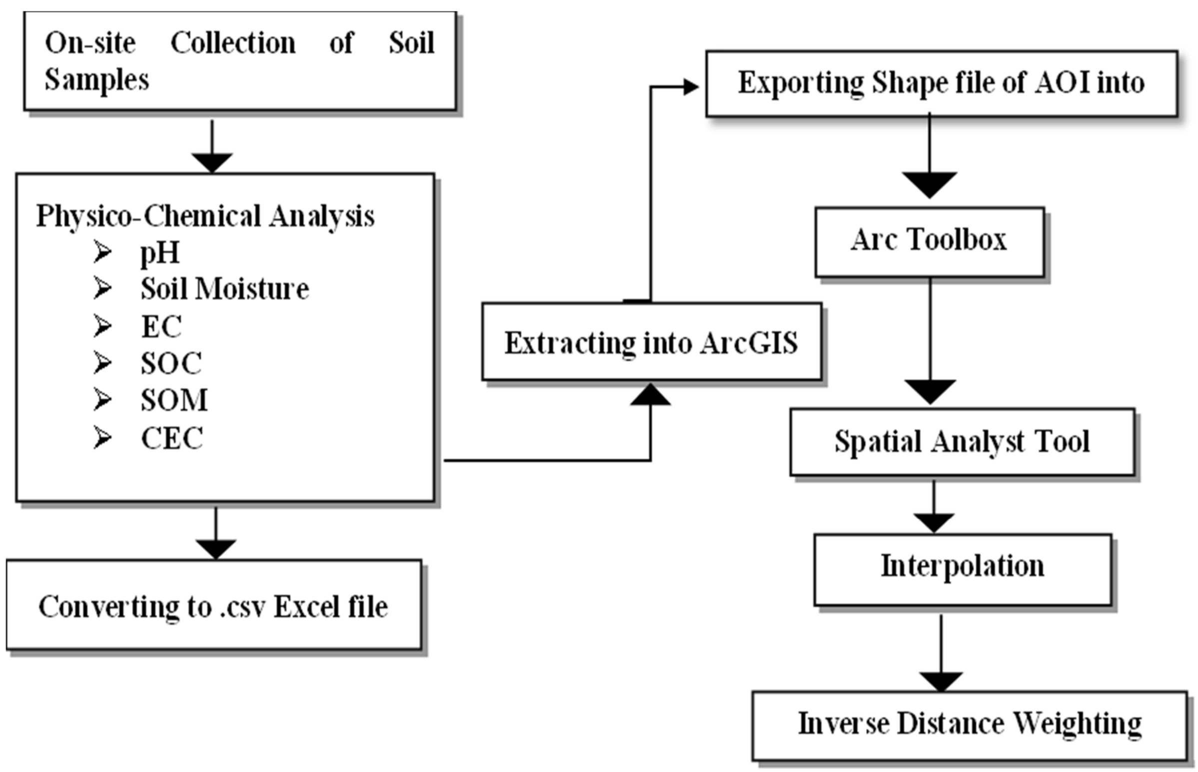


Fig. 2. Diagrammatic representation of the steps involved in the study

111. Results and Discussion

Physio-chemical parameters of the soil samples collected from different vegetation types were analyzed using standard methods and the results are given in Table 3.

Table 3.Result of Physico-chemical parameter analysis of the samples

SL. NO	PARAMETERS	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	MEAN	S.D
1	Moisture Content	54.89	53.8	30.12	27.67	26.77	23.76	22.04	16.53	22.04	15.55	14.91	28.007	13.93
2	Soil pH	4.16	4.49	4.56	4.95	5.62	5.75	6.2	6.34	6.2	6.44	6.66	5.57	0.89
3	Electrical Conductivity	109.9	170.3	226	287	343	352	357	376	402	444	458	320.47	111.21
4	Organic Matter	5.08	5.03	4.99	4.96	4.82	3.98	3.6	3.49	2.9	2.36	2.31	3.95	1.09
5	Total Organic Carbon	2.95	2.92	2.9	2.88	2.8	2.31	2.1	2.03	1.74	1.37	1.34	2.30	0.62
6	Cation Exchange Capacity	9	11.8	12.68	13.4	13.56	16.4	17.4	17.8	18.08	18.4	18.56	15.18	3.24

A) Soil Moisture Content: -

In the present study, it is found that soil moisture content varies from 11.49 % to 54.89 % respectively. Venkatesh et al., (2011) assessed soil moisture patterns in the moist tropical regions of Western Ghats in order to understand the spatiotemporal variation in soil moisture content between different land covers and found that there was no significant change in mean soil moisture. However, the present study reports that there was a significant change in the mean soil moisture across land covers. The interpolation maps exhibit low spatial variation in soil moisture content from the Champakkadu region and high spatial variation from Vellaikkal mala region (Figure 3).The precipitation was the primary controlling factor for soil moisture variability in the surface, shallow and middle soil layers. Seasonal variation in the precipitation may be a reason for soil moisture content variation in those regions. The contribution of flow from bedrock to the soil may be another possible explanation for the persistence of high soil moisture content in the Vellaikal mala region of the sanctuary.

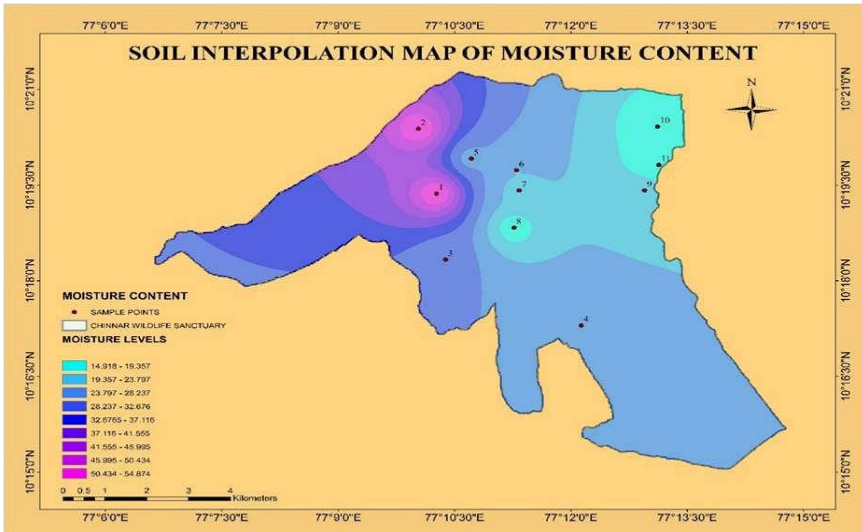


Fig 3 Spatial Interpolation map of Soil Moisture Content

B) pH: -

In the study area, the pH of the soil samples varies from 4.16 to 7.57. This may be due to the presence of carbonates and aluminum in the soil which leaches during the monsoon leads to acidic nature.

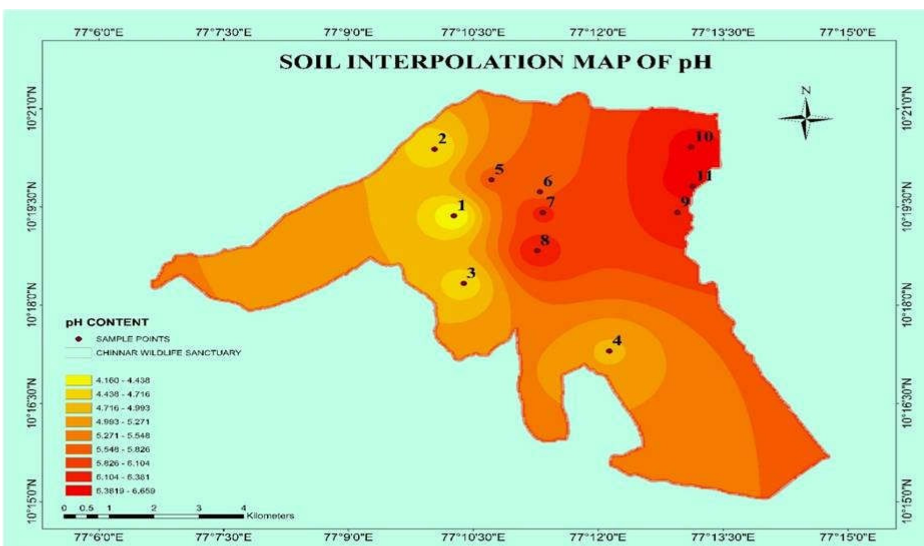


Fig 4 Spatial Interpolation map of pH

Chandran et al., (2012), reported that pH in the deciduous forest ranged from 4.22 to 7.3. The interpolation map envisages that soil pH was significantly higher in the Vellaikkal mala and lower in the Alampetty, Jallimala and Champakkadu regions (Figure 4). Generally, pH in the Western Ghats ranges from acidic to neutral (Hassan and Majumdar 1990).

C) Electrical Conductivity:

In the study area, electrical conductivity varied from 109.9 – 534 mS cm^{-1}which shows electrical conductivity is at optimum level. The optimal values of electrical conductivity for fertile soils should be in the range of 110 – 570 (mS cm^{-1}) (Cook and Walker, 1992). The interpolation map depicts the variation in electrical conductivity of soil samples collected in the regions of Vellaikkal mala and Champakkadu (Figure 5). The soil in Vellaikal mala is rich in organic matter due to the dense vegetation, which aids in the retention of cations and thus improves the soil's electrical conductivity level. Clay and muddy soils are much more likely to retain cations and the loss of nutrients will be much less than sandy soils. The low electrical conductivity levels in Champakkadu soil samples could be attributed to the collapse of clay minerals, the formation of base oxides, and the generation of coarse sand-size particles, which can enclose base oxides (Verma et al., 2019).

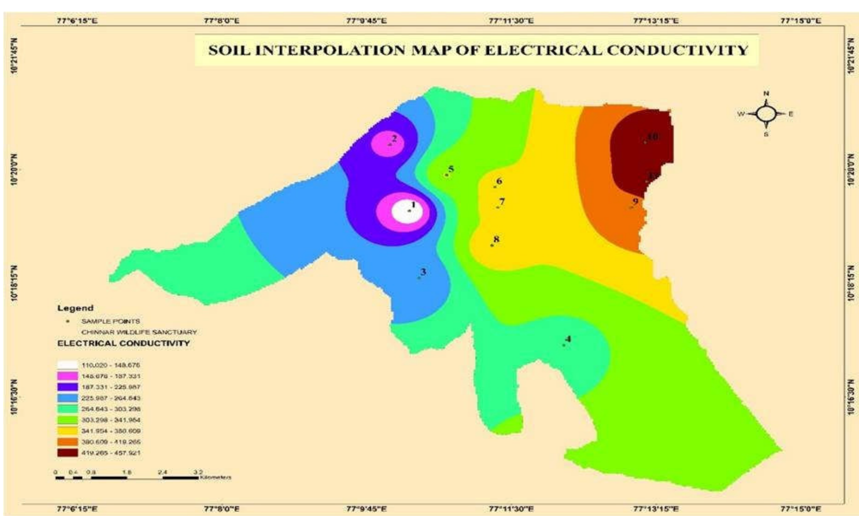


Fig 5 Spatial Interpolation map of Electrical Conductivity

D) Soil Organic Matter: -

In the sample locations, organic matter ranged from 1.01 % to 5.08 % and the interpolation map depicts the variation in organic matter of soil samples collected in the regions of Vellaikkal mala, Olikudi, Eachampetty, and Champakkadu (Figure.6). The optimal value for organic matter in agricultural soil, according to Osman et al., (2013), is 2% by weight and forest mineral soils typically contain 1–5% organic matter by weight, but no threshold level has been established for forest soils. USDA (2011) reported optimum levels of soil organic matter which include sands (2%), loams (34%), and silts/clays (5%). In Chinnar wildlife sanctuary soil texture varies from sandy-to-sandy loam. The riparian zone where the samples were taken is sandy. This could be a reason for the low level of soil organic matter in the area studied. The climate is another important aspect that influences soil organic matter. High temperature in the sanctuary causes organic matter decays faster which reduces organic matter in the soils.

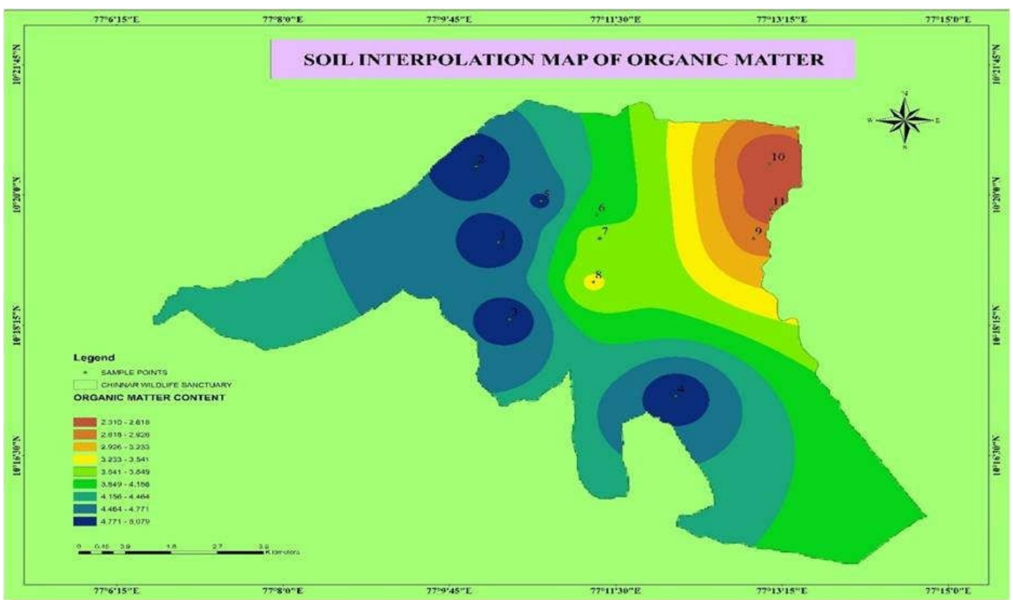


Fig 6 Spatial Interpolation map of organic matter

E) Total Organic Carbon: -

The organic carbon in the study area ranges from 2.95 % to 2.04 %. The interpolation map shows that organic carbon is higher in the Vellaikkal Mala, Olikkudi, and Eachampetty regions, and lower in the Jallimala and Champakkadu regions (Figure.7). Ramachandran et al., (1995) reported that soil organic carbon was significantly higher in the Chinnar wildlife sanctuary. The study also found that vegetation cover has a significant impact on organic carbon up to 1.5 m in depth. Soil organic carbon is proportional to tree density; the higher the tree density, the higher the organic carbon. Field observation and biodiversity assessment results found that tree density is high at Vellaikal mala hence the area has a high content of soil organic carbon. Generally, soils which are having total organic carbon content greater than 0.75% are said to be highly fertile soil.

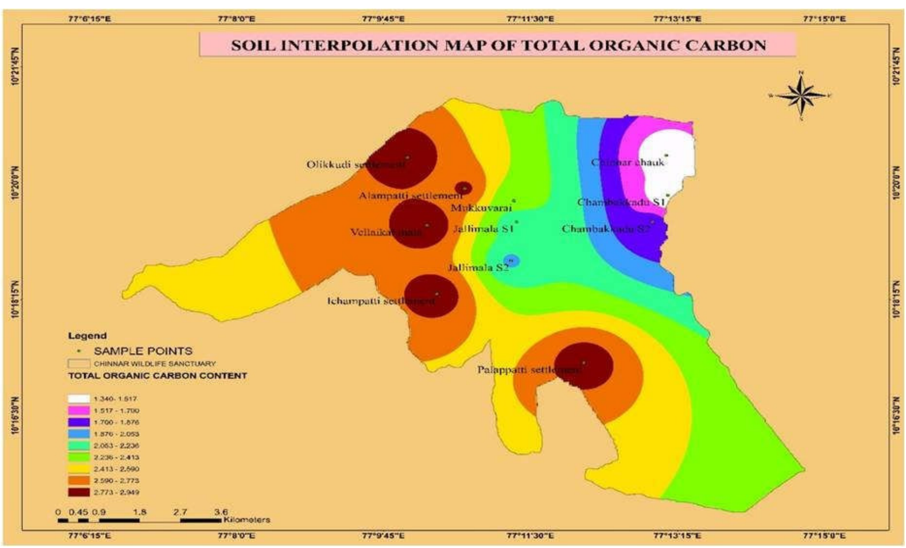


Fig 7 Spatial Interpolation map of organic carbon

F) Cation Exchange Capacity:

In the present observation, the cation exchange capacity concentration of the soil samples ranges between 9.41 to 20.24 (meq/100 g). Subramanian et al., (2005) classified the concentration of CEC in the soil as very low (<5), low (5 – 15), medium (15-25), high (25 – 40) and very high (>40)indicating that the concentration is medium in study area. Interpolation map shows high cation exchange capacity in the soil sample collected from Vellaikal mala, Olikudi region (Figure 8).It could be due to the presence of humus in the soil, which is the end product of decomposed organic matter. The less decomposed organic matter in the Champakkadu causes a reduction in soil CEC by limiting cation exchange due to the absence of an electrical charge.

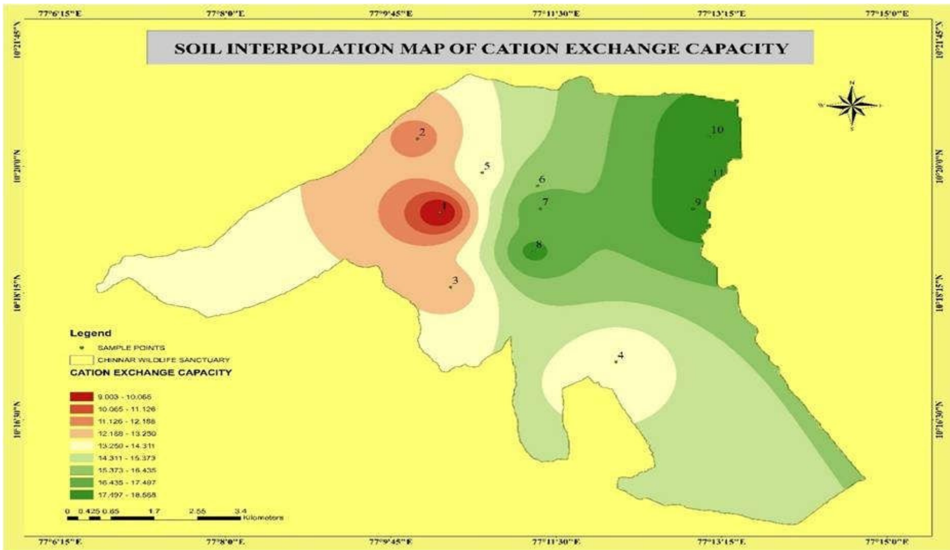


Figure 8 Spatial Interpolation map of Cation Exchange Capacity

IV CONCLUSION

Soil is the basic requirement for the survival of life. Over the years, human-induced activities have deteriorated the quality of soil drastically. The present study aims to determine the soil quality of Chinnar Wildlife Sanctuary, Western Ghats of Kerala, India. The samples collected from thirteen sites in the study area have been used for Physical and Chemical analysis. Results showed that the overall content of soil moisture, pH, electrical conductivity, cation exchange capacity, and spatial distribution of organic matter and organic carbon in the study area was relatively optimal. In addition to that an increasing and decreasing trend in soil health indicators has been observed at certain locations, particularly in the Vellaikal mala and Champakkadu regions. Field observation and vegetation assessment found that the dry deciduous forest of the Champakkadu region has experienced degradation during recent period. Degradation of vegetation could be a reason for altering soil health indicators of the study area. Understanding the spatial distribution characteristics of soil using GIS play a crucial role in developing appropriate land use planning, and the formulation of accurate forest protection policies. On the whole, the data obtained from the study can be utilized for site-specific management, and assessing physical, chemical and biological properties of soil can be used for better soil resource management.

REFERENCES

Bashan, Y., Salazar, B. G., Moreno, M., Lopez, B. R., and Linderman, R. G. (2012). Restoration of eroded soil in the Sonoran Desert with native leguminous trees using plant growth-promoting microorganisms and limited amounts of compost and water. Journal of environmental management, **102**, 26-36.

Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K.M. and Franzluebbers, A.J., (2015). Soil degradation in India: Challenges and potential solutions. *Sustainability*, **7**(4), pp.3528-3570.

Chandran, R.T.S., Joshi, N.V., Joshi, D., Kumar, M. and Series, S.C., (2012). Soil quality across diverse landscapes in Central Western Ghats, India.

Chen, G. X., Yu, K. W., Liao, L. P., and Xu, G. S. (2000). Effect of human activities on forest ecosystems: N cycle and soil fertility. *Nutrient Cycling in Agroecosystems*, **57**(1), 47-54.

Chinnasamy, P., Honap, V. U., andMaske, A. B. (2020). Impact of 2018 Kerala floods on soil erosion: Need for post-disaster soil management. *Journal of the Indian Society of Remote Sensing*, **48**(10), 1373-1388.

Cook, P. G., and Walker, G. R. (1992). Depth profiles of electrical conductivity from linear combinations of electromagnetic induction measurements. *Soil Science Society of America Journal*, **56**(4), 1015-1022.

Dror, I., Yaron, B., and Berkowitz, B. (2021). The Human Impact on All Soil-Forming Factors during the Anthropocene. *ACS Environmental Au*, **2**(1), 11-19.

GSP (2017). Global Soil Partnership Endorses Guidelines on Sustainable Soil Management http://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/416516/ (2017).

Hassan, M. M., andMazumder, A. H. (1990). Distribution of organic matter in some representative forest soils of Bangladesh. *Indian Journal of Forestry*, **13**(4), 281-287.

IUCN (2021). Peatlands and climate change.Last reviewed on November 2021. Retrieved on 01 April 2022https://www.iucn.org/resources/issues-briefs/peatlands-and-climate-change

Khouni, I., Louhichi, G., and Ghrabi, A. (2021). Use of GIS based Inverse Distance Weighted interpolation to assess surface water quality: Case of Wadi El Bey, Tunisia. *Environmental Technology & Innovation*, **24**, 101892.

Kooch, Y., Amani, M. and Abedi, M., (2022). Vegetation degradation threatens soil health in a mountainous semi-arid region. *Science of the total Environment*, **830**, p.154827.

Libin, B. S., Sukanya, S. N., Thrivikramji, K. P., andChrips, N. R. (2019). Geomatics Model of Soil Erosion in Chittar Sub-Watersed, Vamanapuram River Basin, Kerala, India. *International Research Journal of Engineering and Technology*, **6**(3), 1658-1664.

Mueller, T. G., Pusuluri, N. B., Mathias, K. K., Cornelius, P. L., Barnhisel, R. I., and Shearer, S. A. (2004). Map quality for ordinary kriging and inverse distance weighted interpolation. *Soil Science Society of America Journal*, **68**(6), 2042-2047.

Mythili, G., Goedecke, J. (2016). Economics of Land Degradation in India. In: Nkonya, E., Mirzabaev, A., von Braun, J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. *Springer*, Cham. https://doi.org/10.1007/978-3-319-19168-3_15

NRCS (2011). Soil quality for environment health, updated: September 19, 2011, Retrieved on 01 April 2022. http://soilquality.org/functions/nutrient_cycling.html

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., &Erasmi, S. (2016). Greenhouse gas emissions from soils—A review. *Geochemistry*, **76**(3), 327-352.

Osman, K. (2013). Organic Matter of Forest Soils. In: Forest Soils. *Springer*, Cham. https://doi.org/10.1007/978-3-319-02541-4_4

Pacheco, F. A. L., Fernandes, L. F. S., Junior, R. F. V., Valera, C. A., andPissarra, T. C. T. (2018). Land degradation: Multiple environmental consequences and routes to neutrality. *Current Opinion in Environmental Science and Health*, **5**, 79-86.

Pimentel, D., (2006). Soil erosion: a food and environmental threat. *Environment, development and sustainability,* **8**(1), pp.119-137.

Prasannakumar, V., Shiny, R., Geetha, N., andVijith, H. J. E. E. S. (2011). Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: a case study of Siruvani river watershed in Attapady valley, Kerala, India. *Environmental Earth Sciences*, **64**(4), 965-972.

Qiao, P., Lei, M., Yang, S., Yang, J., Guo, G., and Zhou, X. (2018). Comparing ordinary kriging and inverse distance weighting for soil as pollution in Beijing. *Environmental Science and Pollution Research,* **25**(16), 15597-15608.

Ramachandran, K. K., Balagopalan, M., and Nair, P. V. (1995). Use pattern and chemical characterisation of the natural salt licks in Chinnar Wildlife Sanctuary. *Kerala Forest Research Institute (KFRI) Research Report,* **94,** 18.

SAC, I. (2016). Desertification and land degradation atlas of India (Based on IRS AWiFS data of 2011-13 and 2003-05). Ahmedabad: Space Applications Centre, ISRO, Ahmedabad, India, 219.

Sannappa, B., and Manjunath, K. G. (2013). Fertility status of soils in the selected regions of the Western Ghats of Karnataka, India. *Scholars Academic Journal of Biosciences (SAJB), Sch. Acad. J. Biosci*, **1**(5), 200-208.

Santoso, P. B., Apriyono, A., andSuryani, R. (2018). Inverse distance weighting interpolated soil properties and their related landslide occurrences. In *MATEC Web of Conferences* (Vol. **195**, p. 03013). EDP Sciences.

Sasi, R., Kumara, H.N. (2018). Conservation Status of Large Mammals in Chinnar Wildlife Sanctuary, Western Ghats, India. In: Sivaperuman, C., Venkataraman, K. (eds) Indian Hotspots. Springer, Singapore,287-296. https://doi.org/10.1007/978-981-10-6983-3_16

Singh, K., Pandey, V. C., Singh, B., & Singh, R. R. (2012). Ecological restoration of degraded sodic lands through afforestation and cropping. Ecological Engineering, **43**, 70-80.

Sreepriya, P., and Balasubramanian, R. (2020). Soil degradation in Kerala state and a case study on socio-economic impact due to flood in its Idukki district. *Journal of Applied and Natural Science*, **12**(2), 159-164

Srivastava, P. K., Pandey, P. C., Petropoulos, G. P., Kourgialas, N. N., Pandey, V., and Singh, U. (2019). GIS and remote sensing aided information for soil moisture estimation: A comparative study of interpolation techniques. *Resources*, **8**(2), 70.

Tobler, W. (2004). On the first law of geography: A reply. *Annals of the Association of American Geographers*, **94**(2), 304-310.

Venkatesh, B., Lakshman, N., Purandara, B. K., and Reddy, V. B. (2011). Analysis of observed soil moisture patterns under different land covers in Western Ghats, India. *Journal of hydrology*, **397**(3-4), 281-294.

Verma, S., Singh, D., Singh, A. K., and Jayakumar, S. (2019). Post-fire soil nutrient dynamics in a tropical dry deciduous forest of Western Ghats, India. *Forest Ecosystems*, **6**(1), 1-9.

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, **37**(1), 29-38.