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Quantitative Assessment and GIS-Based Interpolation Approach for Mapping Soil HealthIndicatorsinChinnar WildlifeSanctuary,WesternGhats, India

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Abstract

Human activities such as modern agriculture, land-use changes, and different pollution are drastically altering soilstructure and functions. The present study aimed to apply Inverse Distance Weighting (IDW) method to interpolate thesoil 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, totalorganic carbon and cation exchange capacity were analysed using standard analytical methods. The laboratory result isexecuted in ArcGIS® 10.8. and spatial interpolation of soil health indicators has been performed. Results of the studyfound that the assessed soil health indicators in the study area is relatively optimum level. In addition to that spatialinterpolation mapexhibit variation in Vellaikalmala and Champakkadu regions. Field observation and vegetationassessmentfoundthatdrydeciduousforestofChampakkaduregionhasexperienceddegradationduringrecentperiod.

Keywords:Soil,IDW,SoilHealthIndicators,GIS,ProtectedAreas,Soilmanagement

I. Introduction

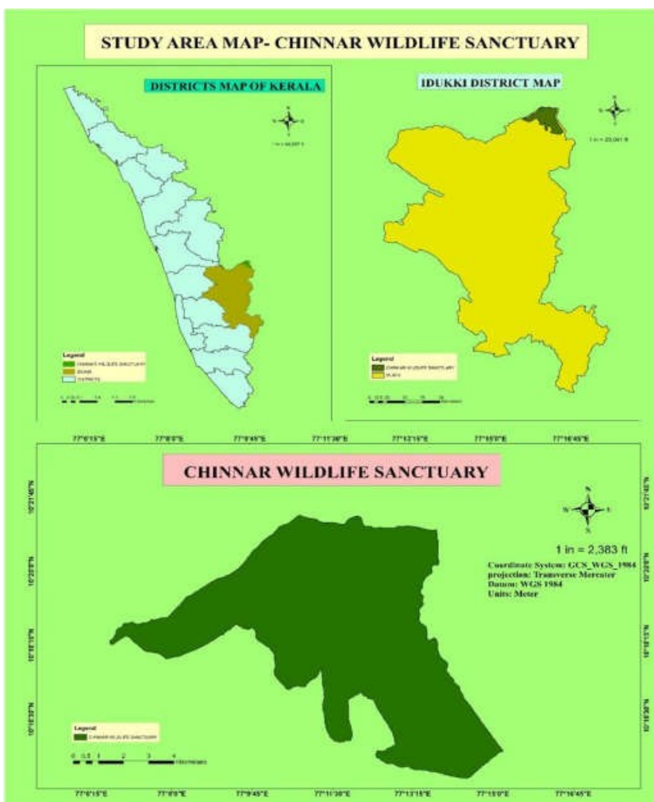
Soil is an important component of the ecosystem because it supports a wide range of microhabitats, improves thebiogeochemical cycle, and aids in the preservation of ecosystem products and services. Soils also serve as sinks forgreenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (NRCS 2011, Oertel etal., 2016). A brief study on peatlands and climate change published bythe IUCN in 2021,reveals the soil absorbsroughly one-quarter of all greenhouse gas emissions each year, with a significant portion of this stored in peatland orpermafrost (IUCN 2021). These facts remind us how important healthy soils are for healthy plant growth, as well as formaking the landscape more resilient to the effects of climate change. Numerous studies have found that soil degradationcaused by anthropogenic activity occurs regularly everywhere in the world. Chen et al., (2000) investigated the effects ofpotentially significant human disturbances on forest ecosystems and reported that intensive human activities frequentlydisruptedthenitrogenandphosphoruscycles.Prasannakumaretal.,(2011)reportedthatapproximately5.37to8.4

milliontonnes of soil are lost in forest ecosystems due to human activities. Furthermore, Dror et al., (2021) found thathuman activities such as modern agriculture, land-use changes, and pollution are the primary determinants of soil qualitydegradation.In2017,theFAOledGlobalSoilPartnershipReportrevealedthatcultivatedlandaroundtheworlderodes75 billion tons (Pg) of soil each year, resulting in an estimated annual economic loss of $400 billion. In India, anestimated 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 etal.,2015). According to the desertification and land degradation atlas of India report (2016), 29.3 % of the countryexperienced 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 % ofthe geographical area has been eroded, whereas, in Idukki, where the study area is located, about 96.3 % of thegeographical 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). Urgentactions are needed to prevent soil degradation and restore degraded soil productivity. This necessitates systematic soilknowledge, and characterization of basic resources such as soil, water, climate, and biodiversity issues. An effective wayto create strategies for reducing soil deterioration and sustaining healthy soil is to employ GIS-based spatiotemporalanalysis 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 tocharacterize soilsamplesand evaluated the relative performance of inverse distance weighted(IDW) and ordinarykriging (OK) in Kentucky and Beijing, respectively. Srivastava et al., (2019) assessed 82 soil samples collected inVaranasi City,India,and remote sensing data tocompare the performance of four widelyused interpolation methodssuch as distance weighting (IDW), spline, ordinary kriging models, and kriging with external drift (KED) interpolationtechniques. However, there haven't been studies on spatial interpolation of soil health indicators in Kerala. Despite this,fewresearchershaveemployedGIStechniquesandmodelingapproachesforotherobjectives.Forexample,Prasannakumar et al., (2011) investigated the spatial prediction of soil erosion risk in the Siruvani River watershed in theAttapady valley of Kerala, India using the IDW and RULSE approach. Similarly,Chinnasamy et al., (2020) and Libin etal.,(2019)usedremotesensingdata,GISandUniversalSoilLossEquation(USLE)toevaluatesoilerosioninKeralaand Vamanapuram River basins. Chinnar Wildlife Sanctuary, a protected area of the Western Ghats has experiencedsevere anthropogenic stress in recent years (Sasi and Kumara 2018). The natural vegetation types, particularly drydeciduous forests and scrub jungles of the sanctuary have been reduced at an alarming rate. If the intensity of vegetationdegradationincreases,thepopulationofsoilorganismsandmicrobialactivitieswilldecrease.Itisduetoareductionin organic matter constituents, unfavorable soil microclimate, abnormal soil erosion, and depletion of soil nutrients (Koochet al.,2022).

Inthepresentstudy,anattemptwasmadetofindoutthesoilqualityofChinnarWildlifeSanctuarybyintegrating fieldwork, lab analyses, and interpolation method in GIS utilized for mapping soil health indicators. Toevaluate the relationship between regional hydrology, ecology, and physical geography, soil moisture content wasexamined. To understand the physical condition of the soil, the pH of the soil was measured. Soil electrical conductivity(EC)wasmeasuredtoevaluatesoilhealthacrossthelandscapebymeasuringsoilsalinity,soilorganicmatter(SOM),and soil organic carbon. Spatial interpolation method such as inverse distance weighting (IDW) is employed to estimateunsampledlocations using values from nearby weightedlocations.

II. MaterialandMethods

A) Detailsof theStudyArea



Chinnar Wildlife Sanctuaryisaprotectedareaofthe SouthernWesternGhats located in the Devikulamtalukof Idukkidistrict, Kerala, India(Figure1).Thesanctuarycovers anareaof90.44km^{2}and islocatedbetweenlatitudes10^{o}15'-10^{o}21'Nandlongitudes 77^{o}5'-77^{o}16'E.Itwasdesignatedasa Wildlife Sanctuary in August1984,anditisconsideredoneof the most important protectedareasintheWesternGhats due to its ecological significance.Thesanctuaryreceivesan annualrainfall of 500 mm,andthetemperaturesvaryfrom 18°C to 25°C, respectively.Thesoilissandytosandy loamintexture.Major vegetationincludesSoutherntropical thorn forest (Scrub jungle),Southerndrymixeddeciduous forest (Dry deciduous forest), Southern moist mixed deciduousforest(Moist deciduous forest), Tropical riparian fringingforest(Riparian Forest), Southern montane wet temperateforest (Hill sholaforest)andSouthernmontanewetgrassland(Grasslands).

Fig1.BoundarymapofChinnarWildlifeSanctuary

B) MethodAdoptedForSoilSampling

Field visits and sampling was conducted between 2019 (Post monsoon) and 2020 (Pre-monsoon) from different locationsof the sanctuary. The geo-coordinates of each sample were recorded using a global positioning system (GPS, GARMINSKU:010-01504-20,India)asshowninTable1.Atotalof13soilsampleswerecollectedatadepthof15cmfrom5to6 different vegetation types for laboratory analysis of soil health indicators. Before collecting the sample, the surfacelitter, unwanted materials, and pebbles were removed from the sampling spot, and a "v" shape pit of up to 15 cm wasmade by scraping the sides. The collected samples were thoroughly mixed and the bulk is reduced by quartering about500 gm ofcomposite samples were usedfortheanalysis.Thesamplesweredriedinthe shadefor 2-3 daysbeforesieving with a 2mm sieve plate and stored in an airtight container for laboratory analysis (Sannappa and Manjunath2013).

Table1.SamplelocationsandcoordinatesofsamplescollectedfromChinnar wildlifesanctuary

SLNO	SAMPLINGLOCATIONS	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.	Vellaikalmala(S3)	10^0 19’25.4"N$77^0$11'20.2"E
4.	Vellaikalmala(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"N77^0 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"N77^0 13'10.88"E
12.	Palapetty(S12)	10^0 21'10.98"N77^0 12'31.74"E
13.	Eachampetty(S13)	$10^0$30’47.13"N$77^0$11'46.15"E

C) SoilHealthIndicatorAnalysis

A brief overview of the parameters analysed, a summary of the soil indicators, and analysismethods are given in Table 2. In this study, some of the most important soil chemical propertieswere chosen based on the literature. These are the most important health indicators for assessingthesoil quality of Chinnar WildlifeSanctuary(Gelybo et al.,2018).

Table2. Potentialsoilhealthindicatorsusedfortheanalysis,units,description,andanalysismethod

SoilHealthIndicator	**Units**	**AnalysisMethod**
pH		PCSMultiparametertester
Soilmoisture	Percentage	Gravimetricmethod
Electricalconductivity	*mS/cm*	Multiparametertester
Soilorganiccarbon	(gm^{-2})	WalkleyandBlack rapid dichromateoxidationtechnique
Soilorganicmatter	Percentage	WalkleyandBlack rapid dichromateoxidationtechnique
Cationexchangecapacity	*(meq/100g)*	Ammoniumacetatemethodof

D) InverseDistanceWeightedMethod(IDW)

ThespatialinterpolationwasconductedusingtheInverseDistanceWeighted(IDW)interpolation available in the ArcGIS® Geostatistical Analyst toolbar. IDW is based on Tobler'sfirst 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 basicprinciple of IDW interpolation is using a weighted linearcombinationsetofsamplepoints,itcountsonthetwostatisticalandmathematicalmethodstocreate surfaces and calculate the predictions of unmeasured points (Khouni et al., 2021). The general equationusedforthe IDW(Eq.(1)) is as follows:

$x^* = (w_1 x_1 + w_2 x_2 + w_3 x_3 + ... + w_n x_n) / (w_1 + w_2 + w_3 + ... + w_n)$ …(Eq.1)

Where x^* is the unknown value at a location to be determined, w is the weight, and $x$is theknown point value.The IDW technique is used in this study to generate spatial distribution mapsof soil health indicators to evaluate soil quality in an ecologically important protected region oftheWesternGhats. Theoverall stepinvolved inthestudy hasshown inFigure.2.

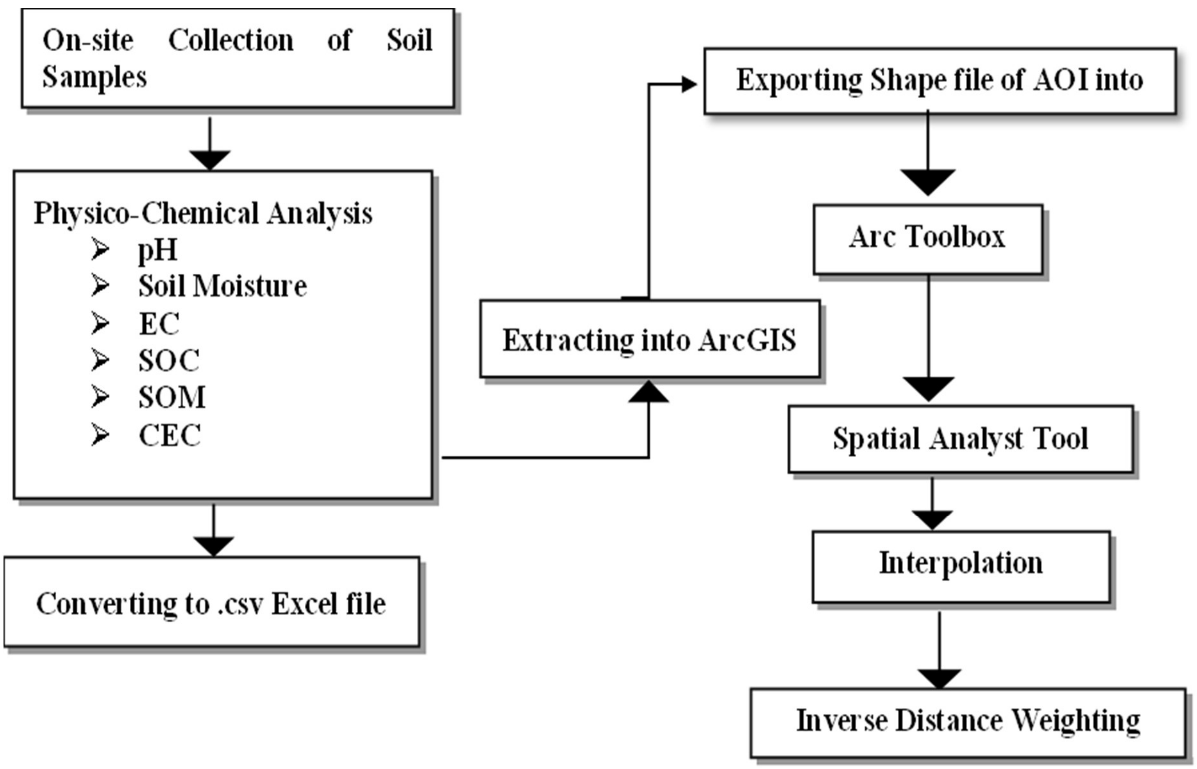


Fig.2.Diagrammaticrepresentation ofthestepsinvolved inthestudy

111.ResultsandDiscussion

Physio-chemical parameters of the soil samples collected from different vegetation types wereanalyzedusingstandardmethods andtheresults aregivenin Table3.

Table3.ResultofPhysico-chemicalparameteranalysisofthesamples

SL. NO	PARAMETERS	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	MEAN	S.D
1	MoistureContent	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	SoilpH	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	ElectricalConductivity	109.9	170.3	226	287	343	352	357	376	402	444	458	320.47	111.21
4	OrganicMatter	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	CationExchangeCapacity	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) SoilMoistureContent:-

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 regionsof Western Ghats in order to understand the spatiotemporal variation in soil moisture contentbetween different land covers and found that there was no significant change in mean soilmoisture. However, the present study reports that there was a significant change in the mean soilmoisture across land covers. The interpolation maps exhibit low spatial variation in soil moisturecontent 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 thesurface, shallow and middle soil layers. Seasonal variation in the precipitation may be a reasonfor soil moisture content variation in those regions. The contribution of flow from bedrock to thesoil may be another possible explanation for the persistence of high soil moisture content in theVellaikalmalaregion of thesanctuary.

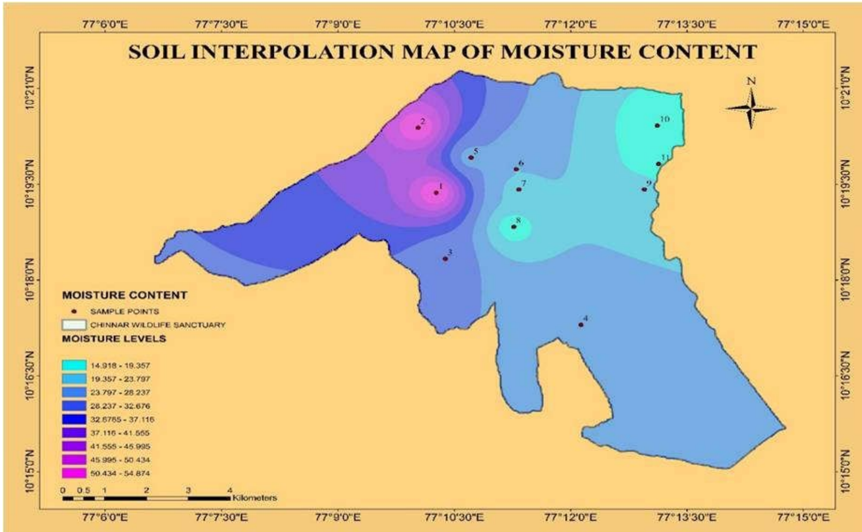


Fig3SpatialInterpolationmapofSoilMoistureContent

B) pH:-

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

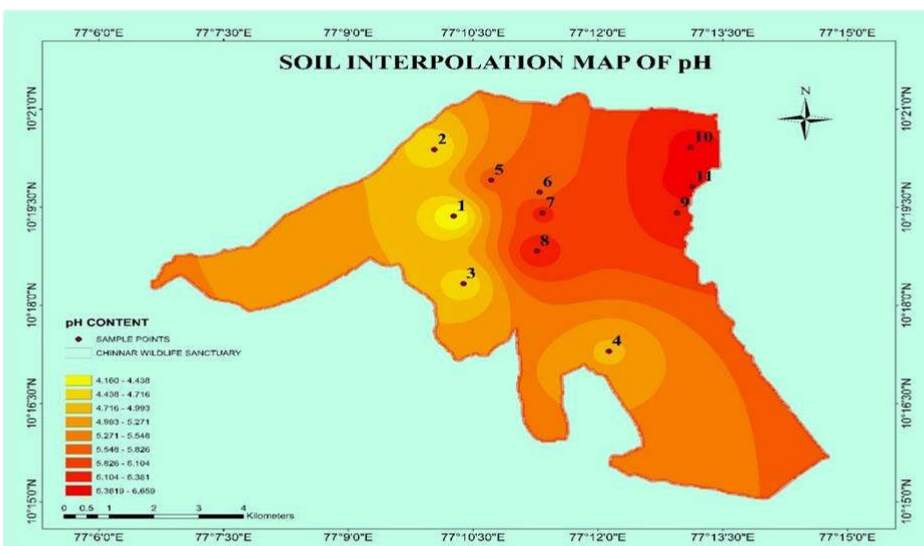


Fig4SpatialInterpolationmapofpH

Chandran et al., (2012), reported that pH in the deciduous forest ranged from 4.22 to 7.3. Theinterpolation map envisages that soil pH was significantly higher in the Vellaikkal mala andlower in the Alampetty, Jallimala and Champakkadu regions (Figure 4). Generally, pH in theWesternGhats rangesfrom acidictoneutral (Hassanand Majumdar1990).

C) ElectricalConductivity:

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

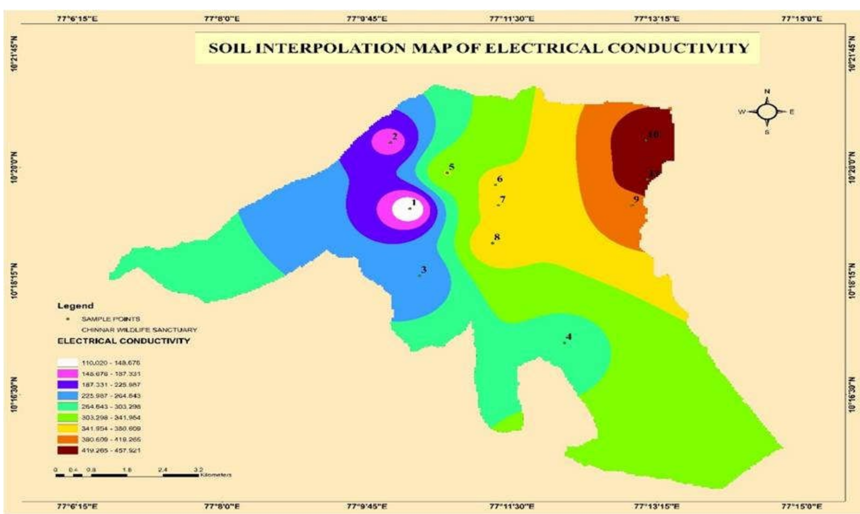


Fig5SpatialInterpolationmapofElectricalConductivity

D) SoilOrganicMatter: -

In the sample locations, organic matter ranged from 1.01 % to 5.08 % and the interpolation mapdepicts 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 inagricultural soil, according to Osman et al., (2013), is 2% by weight and forest mineral soilstypically contain 1–5% organic matter by weight, but no threshold level has been established forforest 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 fromsandy-to-sandy loam. The riparian zone where the samples were taken is sandy. This could be areason for the low level of soil organic matter in the area studied. The climate is anotherimportant aspect that influences soil organic matter. High temperature in the sanctuary causesorganicmatterdecaysfasterwhichreduces organicmatterin thesoils.

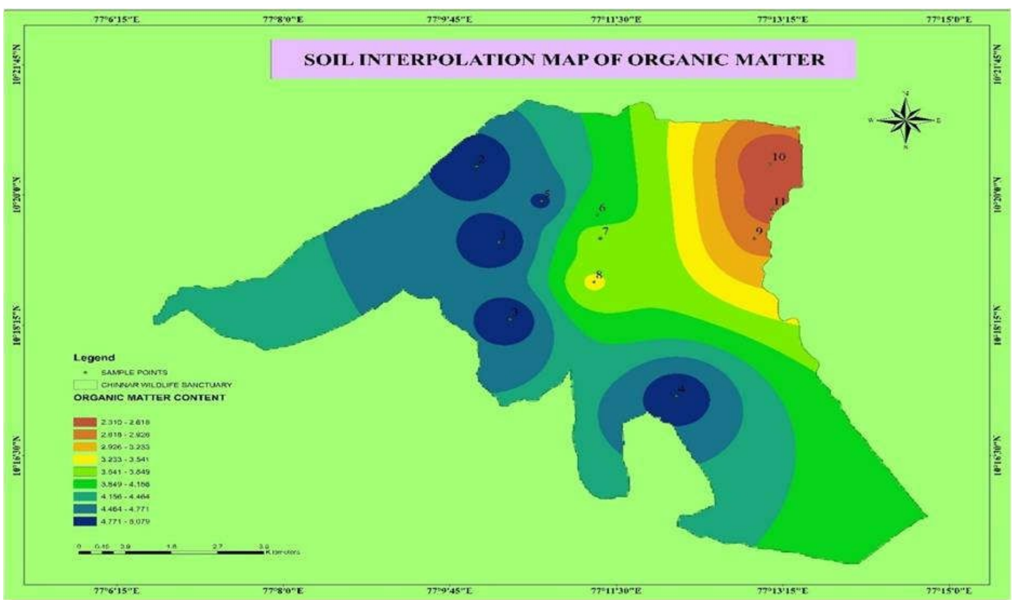


Fig6SpatialInterpolationmapoforganicmatter

E) TotalOrganicCarbon:-

The organic carbon in the study area ranges from 2.95 % to 2.04 %. The interpolation map showsthat organic carbon is higher in the Vellaikkal Mala, Olikkudi, and Eachampetty regions, andlowerintheJallimalaandChampakkaduregions(Figure.7).Ramachandranetal.,(1995)reported that soil organic carbon was significantly higher in the Chinnar wildlife sanctuary. Thestudy also found that vegetation cover has a significant impact on organic carbon up to 1.5 m indepth. Soil organic carbon is proportional to tree density; the higher the tree density, the higherthe organic carbon. Field observation and biodiversity assessment results found that tree densityishighatVellaikalmalahencetheareahasahighcontentofsoilorganiccarbon.Generally,soilswhicharehavingtotalorganiccarboncontentgreaterthan0.75%aresaidtobehighlyfertilesoil.

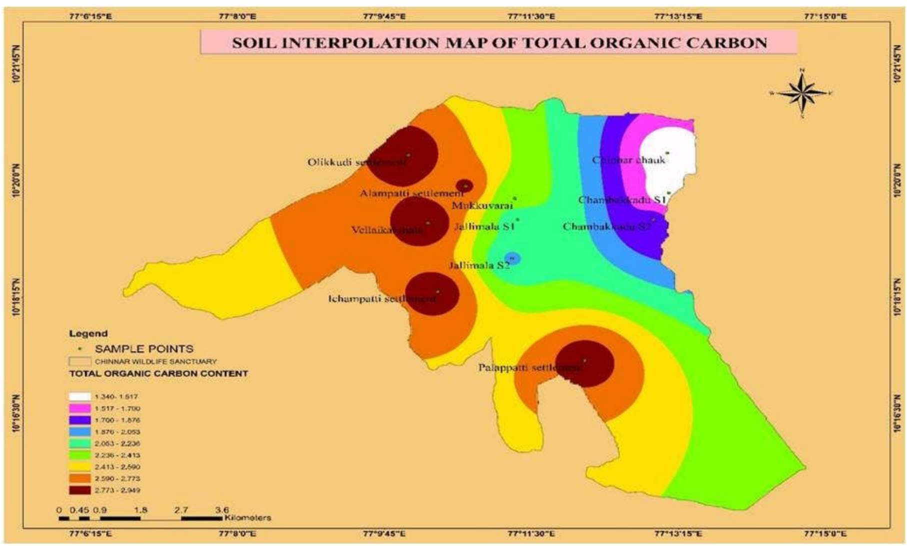


Fig7SpatialInterpolationmapoforganic carbon

F) CationExchangeCapacity:

In the present observation, the cation exchange capacity concentration of the soil samplesrangesbetween9.41to20.24(meq/100g).Subramanianetal.,(2005)classifiedtheconcentration of CEC in the soil as very low (<5), low (5 – 15), medium (15-25), high (25 – 40)andveryhigh(>40)indicatingthattheconcentrationismediuminstudyarea.Interpolation map shows high cation exchange capacity in the soil sample collected fromVellaikal mala,Olikudiregion(Figure8).Itcouldbedueto the presence ofhumusinthesoil, which is the end product of decomposed organic matter. The less decomposed organic matterin the Champakkadu causes a reduction in soil CEC by limiting cation exchange due to theabsenceofanelectrical charge.

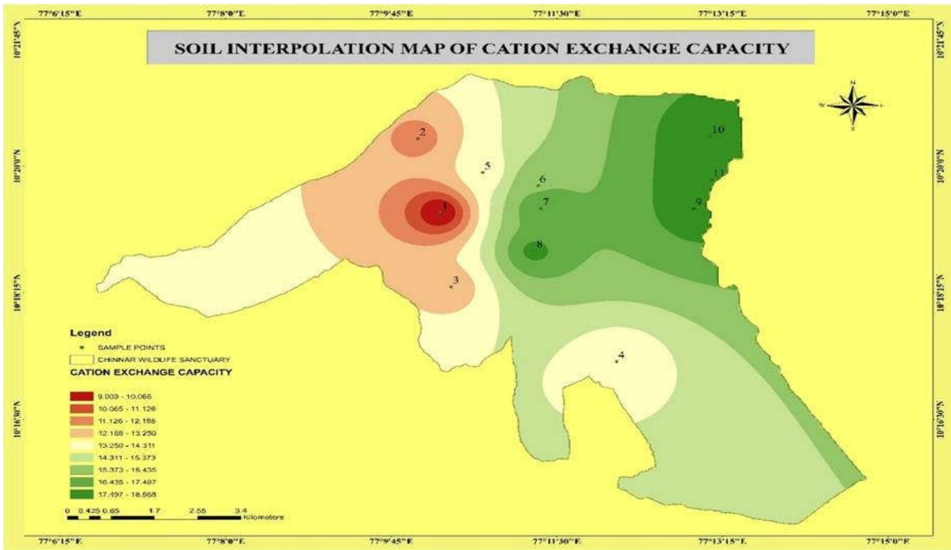


Figure8SpatialInterpolationmapofCationExchangeCapacity

IVCONCLUSION

Soil is the basic requirement for the survival of life. Over the years, human-induced activitieshave deteriorated the quality of soil drastically. The present study aims to determine the soilquality of Chinnar Wildlife Sanctuary, Western Ghats of Kerala, India. The samples collectedfrom thirteen sites in the study area have been used for Physical and Chemical analysis. Resultsshowed that the overall content of soil moisture, pH, electrical conductivity, cation exchangecapacity, and spatial distribution of organic matter and organic carbon in the study area wasrelatively optimal. In addition to that an increasing and decreasing trend in soil health indicatorshas been observed at certain locations, particularly in the Vellaikal mala and Champakkaduregions.Field observation and vegetation assessment found that the dry deciduous forest of theChampakkaduregionhasexperienceddegradationduringrecentperiod.Degradationofvegetationcouldbeareasonforalteringsoilhealthindicatorsofthestudyarea.Understanding thespatialdistributioncharacteristicsofsoilusingGISplayacrucialroleindevelopingappropriate land use planning, and the formulation of accurate forest protection policies. On thewhole,thedataobtainedfromthestudycanbeutilizedforsite-specificmanagement,andassessing physical, chemical and biological properties of soil can be used for better soil resourcemanagement.

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