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Spatial Variance in Soil Parameters and their Evaluation using Multivariate Analysis Technique

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Abstract: ***This research was conducted to formulate a model for the identification of the most representative soil quality parameters for periodic and long term soil management. Our soil quality indices were pH, Electrical Conductivity, water holding capacity, the moisture content of the soil, nitrate content, ash content, and concentration of metals such as aluminum, lead, iron,and zinc. In our study,nine sampling locations were selected in the riverine zone of three rivers of Valsad district on the banks of the river in it'supperto lower reach. Each site had 6 subsites collected over a span of 6 months. Here in this paper, Principle Component Analysis is utilized to analyze our data of physiochemical soil parameters formulate a predictive relationship between soil quality indices and agricultural management. Spatial variance observed in the soil physiochemical parameters was due to a change in the land use pattern as well as due to natural factors such as distance from the sea.Accordingly, there was a change in the plant diversity of the various sites. This heterogeneity in soil quality can be utilized in designing a paradigm of site-specific soil reclamation and management, which will be cost-effective and environmentally friendly.It can help us to check anthropogenic activities in specific sites to control site-specific irregularities of parameters.***

Keywords: Physiochemical Parameters, Multivariate data reduction, Agglomerative clustering

1. Introduction

The soil is an invaluable resource to mankind. Soil science is divided into two different branches namely – Edaphology (influence of soil on living organisms) and Pedology (description and classification of the soil). The soil organism density depends upon several environmental factors. In general, the mean prokaryotic density in the soil is more than mean eukaryotic density. Factors other than environmental and anthropogenic influence are biological interferences such as ant and termites cause much denudation of soil around their hill, or the mixing of soil by the activity gopher, millipede, termite (pedoturbation) orrhizodeposition of organic matter and dead cells by the plants in their rhizosphere.Plants such as conifers or oak tree alter the soil characteristic around its root (Pouyat et al, 2002). Soil heterogeneity is the most challenging factor in soil quality analysis. The mineralis an essential component in plant metabolism and its availability depends on the pH of the soil.

Many physiochemical parameters are used for soil quality monitoring and analysis. Biological approaches are also used to monitor soil quality. Soil enzymatic activity level is also monitored to find the level of soil nutrient gain due to microbial activity (Badiane et al, 2001; Bossio et al, 2005). PLF analysis sometimes was done for determining soil microbial activity and thus soil condition (Frostegard et al, 2011). Healthy soil will have abundant soil microbes that are manifested by the presence of a high concentration of soil enzymes. Landsat Thematic Image Data were also used for soil quality determination (Kwartong et al, 1989) by detecting the change in land use pattern. Land use pattern alters the quality of the soil by altering the microbial pattern of soil (Nsabimana et al, 2004). Disturbance in soil caused by a change in the land use pattern can be analyzed by Principal Component Analysis technique (Ku et al, 1995). Agricultural practices such as the addition of sulfur-based fertilizer or soil tillage or pesticide addition alter the soil characteristic and this alteration study is analyzed using PCA (Sena et al, 2002; Wander et al, 1999). River and estuarine sediment soil condition can also be analyzed using PCA (Reid et al, 2009).

Land use change is the primary cause of altered property of soil. Human-induced change in soil pH and loss of Soil Organic Carbon (SOC) has been well studied in many countries (Don et al, 2011). Ancient agricultural practice of tillage reduces the soil organic carbon. Industrialization induced an increase of oxides of carbon, nitrogen,andsulfur when deposited in dry form react with soil water creating acids, thus reducing the soil pH. Soil degradation due to erosion by water is mainly due to denudation of surface soil due to conversion of forests to agricultural land, industrial or urban land (Yaalon, 2007 and Yang, 2003). However modern techniques of irrigation of agricultural field and orchards with treated urban wastewaterhave shown to increase the enzymatic activity of soil microbes and increase in the nutrientcontent of soil without any negative effect on soil microflora and field crops either (Meli et al, 2002).

Instead of doing extensive soil sampling which will be tedious, costly and errors, we can reduce the number of soil parameters to be sampled. Later using these reduced number of representative parameters for precision farming. Precision farming is a very economical and environment-friendly technique where agricultural input is given only to the sites where it is needed (Lopez et al, 2002). Thus there will be no pollution of river or lake water by runoff of excess fertilizers and pesticides during the rainy season. For the evaluation of the health of an ecosystem, we need to analyze the environmental parameters of the sites under study. In our study, we have studied, analyzed and prepared a model of soil parameters.The main factors that are to be considered while doing precision farming are – to prepare a soil map and database of soil of the area; get the GPS location of the sites from where sampling was done and controlling the site-specific application of nutrition, pesticide, fertilizer, and water (Cambardella and Karlen,1999). Soil maps used will be depicting the various physiochemical soil indices. Later a semivariogram can be prepared based on this reduced dataset (Mueller et al, 2004 and 2001). Such minimum dataset model based on the most representative indicator from a large data set is very popular in European countries as is obvious from the regression-based technique used by Andrews and Carroll, 2001. Kriging method of accessing the spatial distribution of soil pollutant has been used by Cattle et al in 2002 to evaluate the spatial and temporal variation of soil.

2. Methods

Location of the sampling sites

Our study area, Valsad is situated at 20.59992* N and 72.9342* E, between Gulf of Khambat and the Western Ghats. Valsad district of South Gujarat, India has an area of 2947km. It has an average elevation of 42 feet. Each river has three sampling sites – in its upper, middle and lower reaches. Lower reach sites were river bank areas downstream of pollution sources such as industries and CETP (Common Effluent TreatmentPlant).

Figure 1: The spatial location of the nine sampling sites of Valsad District, Gujarat, India

Kolak river sampling sites – Kolak River bank sites –1A (Salvav village), 1B (Tukawara village), 1C (Vatar village); Damanganga River bank sites- 2A (Chanod village), 2B (Namdah village), 2C (Zari village); Par River bank sites – 3A (Bhinwara village), 3B (Atul village), 3C (Umarsadi village)

Description of the sites - The climate is tropical here. The summers have heavy rainfall and winters have very little rainfall. The average temperature here is 26.9*C and Valsad gets 1963mm of annual precipitation. Valsad district of South Gujarat is having mostly fertile coastal alluvial soil, with some regions having red soil, black soil, sandy soil,and clayey soil. The soil in Dharampur and Khaprada taluks has black soil suitable for cotton and sugarcane and Valsad and Pardi has coastal alluvialsoil suitable for coconut, chikoo, kaju, sprouts, and bamboo.

Each river bank had three sampling sites – in the upper, middle and lower reach riverside zone. Kolak riverside in its upper reach is purely agricultural, while industrial in middle and lower reaches. Damanganga riverside sampling site in upper reach has agricultural land surrounding it, in the middle reach, it had brickfields industries and CETP and the lower reaches it is having industries and construction work. Par in upper and middle lower reach is purely agricultural and in its lower reach, it has few industries along with mango and teak plantation.

Method of soil collection - Extensive soil sampling was done for three sites of riverside ecotone of each of three rivers for a period of six months. Each sampling site of 1000 m, was further subdivided into six sub-sampling sites of 100m each. Every month one sampling was done from each subsampling site of the rivers. Each sampling was done from the first 100m subplot following transect sampling layout along with a sloping surface. Sampling sites were 60 m to 65 m apart (Wollenhaupt et al, 1994; Franzen and Peck, 1995). In each subplot sampling grid was established and soil was collected by coring from a depth of 30cm from five sub - sub-sampling sites. Soil from five subsampleswasmixed to remove heterogeneity and so that we get a more representative sample of the surrounding area. The soil is collected from a depth of 30 cm as soil parameters show drastic variation over a very short span of time (Lui D et al, 2006). The soil sample so collected was then analyzed for physiochemical parameters.

Parameters

The soil is naturally heterogeneous, there will be spatial variation in various parameters (Cambardella and Karlen, 1999). This spatial difference within a few centimeters in the soil occurs naturally due to the action of soil micro as well macro-organisms in the rhizosphere as well as other abiotic causes. Heterogeneity of soil quality indices also causes a spatialdifference in the floral and faunal diversity. But in recent past, it was observed by researchers that anthropogenic effects like acid rain or solid waste dumping or dry precipitation of vehicle exhaust are altering the soil characteristic and thus altering the soil biodiversity. One parameter can influence other parameters.This study of various physiochemical parameters helps in detection of soil quality and its spatial variations which can be used in environmental monitoring.

(a) pH – Optimal pH of the soil for healthy plant growth lies from 5.5 to 7.0. There are many plants that can tolerate higher and lower pH. Acidic soil has poor incorporation of the organic layer with an underlying mineral layer but good internal drainage and good waterholding capacity.However, at low pH aluminum toxicity damages the roots.In alkaline soil, there is slow infiltration, poor water conductivity, and poor water availability of water to plant roots. Under such conditions,the soil becomes hard and cloddy and have poor aeration. Soil pH is dependent upon a number of factors such as – (1) parent material of rock such as weathering of silicate, aluminosilicate,and carbonate increases pH, (2) warm humid condition promotes acidity, (3) in dry climate soil weathering is less intense and soil pH is neutral or alkaline, (4) root respiration and decomposition of organic matter by microbes produces CO_2 that reacts with water to form carbonic acid, (5) some plant roots also releases organic acids, (6) ammonium fertilizers undergo nitrification to form nitrate and hydrogen ions, (7) insufficient leaching or irrigation with high bicarbonate water can increase pH, (8) soil is more acidic in cases of rapid weathering of parent rock.

(b) Electrical conductivity – Electrical conductivity is the concentration of dissolved salts in the soil solution, measured in millisiemens and microsomes. Electrical conductivity is mainly due to fertilizer application through natural weathering of minerals also contributes to EC. Chemical fertilizers are rich in mineral salt but organic fertilizers contain a low amount of salts.EC is directly related to temperature and rainfall. Electrical conductivity is low in well-drained soil and in arid areas, little leaching occurs due to scanty rainfall and salts accumulate near the soil surface. Electrical conductivity is an indicator of soil quality as both high and low EC will stunt plant growth, reduce yield and ultimately cause plant death. This occurs because plants need salt as a nutrient but excess salt will damage nutrient conductivity in the plant. However, tolerance or threshold of EC will vary according to size and species of plant. Generally, 1 to 3 mS/cm is the tolerance range for healthy plants.

(c) Weight loss after drying – Gravimetric moisture content of the soil is the ratio of the mass of water containing soil and that of dry soil. Minerals dissolve in soil solution and are easily taken up by soil during water absorption. The moisture content of soil determines which type of plants can be grown in it.

(d) Water holding capacity – It is the total amount of water held by the soil against gravity. It depends upon the temperature and transpiration rate of plants. The texture of soil also determines the soil water holding capacity – sandy soil has lowest WHC and clay has the maximum WHC. It can be increased by adding organic matter and carbonates. Water is held in capillaries small enough to hold water against gravity and large enough to be absorbed by plant roots.

(e) Nitrogen as nitrate – Nitrogen is absorbed by plants in the form of nitrate. Nitrate is very essential for plant growth as it is required in the preparation of amino acids. Runoff and heavy leaching can deplete the soil of nitrate. This can be replenished by the application of chemical and organic fertilizers. Soil rich in nitrate causes vigorous plant growth and better yield.

(f) Ash content – Ash content of the soil is mostly due to plant or wood ash used by farmers since long to improve soil fertility. Ash is rich in nutrients but leaching will deplete the nutrients. Ash content if added in bulk can raise the pH of the soil and affected the soil bacterial number and composition.

(g) Aluminum -Aluminum becomes available in low pH condition of soil and presence or absence of different ions. Excess aluminum prevents the absorption of other ions and thus cause a mineral deficiency in plants.

(h) Zinc - Zinc is a micronutrient of the plant, but low pH increases the bioavailability of zinc causing zinc toxicity. Excess zinc can compete with phosphorous and other nutrients for uptake and cause their deficiency.

(i) Iron - Iron is a micronutrient of the plant but excess iron can stunt plant growth and metabolism. It is soluble at low pH. Iron complexes readily with phosphates, carbonates, calcium, magnesium,and hydroxides present in the soil, making them biologically unavailable.

(j) Heavy metals –Heavy metals such as Cr, Co, Ni, Cu, Zn, and Pb are anthropogenically introduced. These substances are harmful to plants in trace amounts also as they accumulate inside the plants (Facchinelli et al, 2001)

Statistical Analysis

Multivariate analysis techniques are used to find the correlation between various soil quality parameters and draw a conclusion about soil condition (Deng et al 2008). Though other techniques such as partial least squaresregression orneural network (PLS – NN) are also used for soil analysis (Janik et al, 2009). Factor analysis, Principal Component Analysis, Cluster Analysis,and Discriminant Analysis are various multivariate analysis techniques that are used for data reduction to gain more clarity about the soil, air as well as water condition (Alberto et al, 2001). The same statistical techniques can be used to analyze other environmental gradients also. Multivariate analysis techniques are very important and essential techniques in soil quality assessment and its proper management(Golobocanin et al, 2004). Impact of various soil parameters on the vegetation is visualized by Principle Component Analysistechnique. Principle Component Analysis (PCA) uses the correlation between various parameters to group all the parameters into two or three component groups so that we can visualize the soil condition more accurately and formulate measures to improve soil condition if any is needed.

3. Result and Discussion

The knowledge of the spatial variation of soil parameters canhelp us model a stochastic pattern that can be used to implement site-specific management practice to reclaim the soil from the particular irregularity of specific parameters. Evaluation of soil properties can indicate soil suitability for specific agriculture. Soil quality directly determines the type of vegetation it will support. For example, mangroves can tolerate high EC and high TDS which other plants can't tolerate. However, some soil properties lack spatial variance(Lopez Granados et al, 2002). Here in Table 1, we are discussing descriptive statistics. Mean and Standard Deviation are classical descriptors that suggest that all our soil quality physiochemical parameters are normally distributed.

Here in Valsad, we have coastal alluvial soil which has a neutral pH ranging from 6.5 to 8.4. From Table 1, we can observe that the mean pH of the nine sampling points is alkaline which is normal. The zinc concentration and EC of soil showed a maximum standard deviation. The electrical conductivity of coastal alluvial soil will naturally high due to the high presence of minerals in coastal areas. Other parameters such as water content of the soil, water holding capacity, nitrogen as nitrate, ash content and metals like aluminum, lead and the iron did not much vary from the mean, which signifies that there is a less spatial variance of these parameters. All the parameters showed little temporal variation with a change of season. Change in physiochemical properties of soil alters the habitat of microbes and other soil organisms as well as plants. As a result of which many exotic and invasive species of plants can be found to increase their population and the demography of endemic or native species are reduced. The viability of plants and animals are thus influenced by alteration of soil characteristic. But here in our study site, we do not find the much spatial variance of soil quality indices. The vegetation here is also more or less homogenousexcept for horticultural plantation and agricultural fields where plants are introduced for economic benefit. Those areas that have been urbanized or put to industrial use showed the presence of many exotic species and reduction or total absence of the endemic plants. Such a trend in altered vegetation will cause an imbalance in the ecosystem.

Table 1: Descriptive Statistics

Soil Quality Parameters	*Mean*	*Std. Deviation*	*Analysis N*
pH	7.19	0.82	54
Electrical conductivity, µs/cm	1174	435	54
Weight loss after drying, %	27	15	54
Water holding capacity, ml/gm	0.57	0.12	54
Nitrogen as nitrate, %	1.61	0.82	54
Ash content, %	49.6	10.82	54
Aluminum, %	0.07	0.07	54
Lead, ppm	3.02	1.7	54
Zinc, ppm	366	229	54
Iron, %	1.16	1.15	54

Table 2, depicts the KMO and Bartlett's Test result. KMO and Bartlett's test is used to determine whether our data is suitable to be used in factor reduction or not.KMO value of 0.8 to 0.5 is mediocrely acceptable, while lesser value such as 0 means that there is a widespread correlation.Bartlett's test of Sphericity is used to test whether the variances are equal for all samples of a normally distributed data set. Values from 0.6 to 1 are considered ideal for the null hypothesis.

Table 2: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.665
Bartlett's Test of Sphericity	Approx. Chi-Square	198.05
	Df	45
	Sig.	0

The Component Matrix in Table 3 is made on the basis of loading of parameters into two or more number of components.

Table 3: Component Matrix

Soil Quality Parameters	*Component*	
	1	*2*
Ash content	0.856	-0.331
Aluminum	0.757	0.357
Water holding capacity	0.679	-0.37
Iron	0.581	0.485
Electrical conductivity	-0.572	-0.547
Lead	0.558	0.037
Zinc	-0.399	-0.254
Weight loss after drying	-0.621	0.667
Nitrogen as nitrate	0.047	0.434
pH	-0.225	0.26

The Rotated Component Matrix in Table 4, is made by rotation of a component axis to differentiate between a component with high loading and of low loading. Kaisers Varimax Rotation was implemented for this method. Here we have used a two-component model and grouped the parameters into two groups on the basis of factor loadings. The first component has high loadings of inorganic variables and the second component has a high loading of organic variables. This categorization of physiochemical variables into two components helped in better data interpretation and thus better environmental management.

Table 4: Rotated Component Matrix

Soil Quality Parameters	*Component*	
	1	*2*
Aluminum	0.794	0.265
Electrical Conductivity	-0.792	-0.001
Iron	0.755	0.052
Zinc	-0.464	-0.092
Lead	0.428	0.36
Nitrogen as nitrate	0.334	-0.281
Weight loss after drying	0.013	-0.911
Ash content	0.389	0.831
Water holding capacity	0.234	0.737
pH	0.018	-0.344

In figure 2 we observe the relative positions of various physiochemical parameter variables in a Component Plot with the y-axis as Component 2 and x-axis as Component 1. Component 1 includes potential contamination by inorganic components - Electrical conductivity, aluminum, zinc-lead, and iron. Component2 includes potential organic contaminants – nitrate, the water content in the soil, water holding capacity, ash content, and pH.This grouping of variables helps us to get an accurate idea of the quality of soil in general along the riverine regions of Valsad district. This clear cut demarcation of the two components into organic and inorganic can relate them to pollution or stress factors such as agricultural, industrial or urban waste, etc.

Based on the Component Plot we have ultimately reduced the number of variables by agglomerative clustering to five representative variables

- pH
- aluminum
- nitrate
- water holding capacity
- electrical conductivity

These five marker variables can be utilized to adequately determine the potential contamination of soil or soil quality instead of many parameters used at the beginning of our experiments. The pH, aluminum, nitrate, and EC of soil are dependent upon anthropogenic as well as the environmental cause. So we can control the anthropogenic activities of adversely affected sites only. The reduced number of components is very significant in representing the soil quality monitoring of large areas such as the riverine regions of the whole state or it can be implemented nationally. This five soil quality index will act as a paradigm or standard model for long term soil quality monitoring for agricultural purposes.

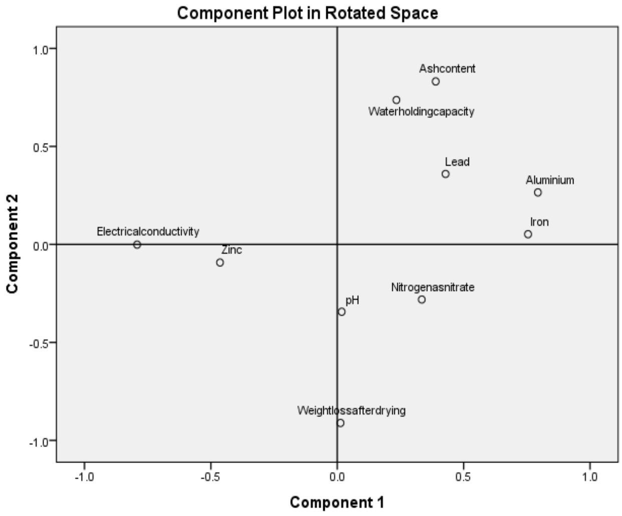

Figure 2: The component plot in rotated space as our reduced factors

The pH of the soil becomes low due to the application of sulfur-based fertilizer, acid rain, air pollutant such as nitrogen oxides and sulfur oxides when precipitate and react with soil water. The temperature of 25 *C to 50*C which is present in Valsad through the year causes a pH of 7 to 6.6. Aluminum is the most abundant metal in earth's crust is not present in the biologically available form under normal pH. Soil acidity makes aluminum available to plants, which in turn shows several mineral deficiency symptoms. Nitrate occurs naturally in the soil can change its concentration due to fertilizer application, climatic reasons, rainfall and type of soil. Water holding capacity depends upon not only soil type but also the land use pattern. Water holding capacity becomes low in acidic soil and soil with a low organic compound. Practices such as tillage reduce the organic matter of the soil. The electrical conductivity of soil is related to temperature and rainfall. Anthropogenic activity such as sewage dumping on the ground can increase soil electrical conductivity. Environmental causesaffecting our soil quality indices cannot be controlled, but we can control anthropogenic activities.

In figure 3 we have placed the various sampling points based on their organic and inorganic component loadings. The x is our first component is inorganic and the y-axis shows component two that is organic parameters. Thus we can easily observe that which point along the riverine region has what type of pollutants.

Kolak riverside soil has co-dominance of both organic and inorganic factors in its upper reach sampling site, while it is mainly inorganic at the middleand lower reaches. This is quite normal as every river bank has more organic matter in its upper reach whereas in lower reach we get more inorganic components like high EC and TDS of soil due to ingression of saline water.Kolak River has its upper reach in a rural area with an agricultural field surrounding the river course. So practically it is getting polluted right from its origin. In the middle and lower reach it if facing stress due to industrial effluent and urban sewage stress, which affects the surrounding soil of its bank.

Damanganga has more inorganic load dominant at its all three sampling points – in the upper, middle and lower reach. Damanganga has many stone quarrying and bricks laying areas in its upper reach. During the monsoon,this mineral-rich water from the stone quarrying gets drained to the river. Damanganga at its middle sites is situated near CETP treatment plant and core industrial area. Naturally, the soil will have more salinity and more inorganic load. In the lower reach it if facing heavy stress due to the high-density urban population.

Par riverside soil has co-dominance of organic and inorganic factor loading at its upper from agricultural runoff and household wastes. Organic factor dominates the soil in its middle reach, which is much of a protected area having mango and sapodilla plantation under the local public. Lower reach soil also has co-dominance of organic and inorganic parameters. This knowledge of the spatial variation of soil indices helps in site-specific reclamation of soil and cultivation of those crops that are suitable for that particular soil.

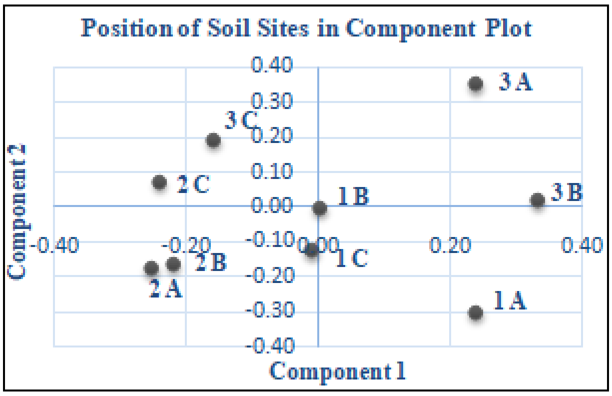

Figure 3: Component plot indicating the factor loading at various sampling sites

Kolak River sampling sites – 1A (Upper reach, Salvav village), 1B (Middle reach, Tukawara village), 1C (Lower reach, Vatar village); Damanganga River sampling sites – 2A (Upper reach, Chanod village), 2B (Middle reach, Namdha village), 2C (Lower reach, Zari village); Par River sampling sites – 3A (Upper reach, Bhilwara village), 3B (Middle reach, Atul village), 3C (Lower reach, Umarsadi village)

4. Conclusion

From our study of various physiochemical parameters of the soil of various sites of the riverbank, we can conclude that anthropogenic activities happening upstream of the river not only affect river water but also the soil quality of the downstream areas. PCA simplifies our work identifying stochastic parameters that can act as representative parameters for site-specific management of soil. The reduced parameters that will be used for long term agricultural management are – pH, aluminum, nitrate, water holding capacity, electrical conductivity. Based on PCA we caneasily identifythe most potent stress factors or pollution sources and treat the pollution source before being dumped. With such simplification of environmental monitoring, we can increase our area of work by setting up a network of monitoring stations throughout the country. To restore soil fertility this method of studying a reduced number of parameters is very efficient and time-saving technique. We can do precision farming where fertilizers are added only where it is needed and the soil is reclaimed only where it is needed. Thus minimizing the cost of fertilization and reclamation. Such precision farming is already done in European and Americancountries, can be started in south Gujarat also. We can also create soil database and soil map for various parameters easily from such a study.

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