SOIL HEALTH CHARACTERIZATION OF AGRICULTURAL LAND IN JHARKHAND, INDIA

A Thesis

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By

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Abstract

Soil health (SH) degradation is primarily the result of degradative anthropogenic activities such as nutrient mining, aggressive tillage, and monocropping, and has over time reduced the capacity of agricultural soil to function. A comprehensive, quantifiable soil health characterization of agronomically important soil functions provides the basis for remedial soil health management. Twenty-nine randomly selected catchments in six districts of Jharkhand, India yielded 133 soil samples used by the Comprehensive Assessment of Soil Health (CASH) framework to establish a holistic understanding of SH beyond nutrient balance and management. Each catchment was stratified into four landscape positions including *uncultivated*, and cultivated *upland*, and terraced *middle*, and *lowland* rice-fallow paddy fields. Textures as well as dynamic physical, biological, and chemical factors were assessed. General nutrient comparisons indicate low to very low P and K values contrasted with high micronutrient levels. A district level ANOVA shows the effects of inherent textural factors and parent material contributing on dynamic physical, biological, and chemical indicators. The degradative influence of management activities such as tillage and insufficient nutrient management on the dynamic soil indicators are seen in landscape position assessment, with the uncultivated soils having higher overall SH scores. Aggressive paddy tillage separated the surface (0 to 15 cm) and subsurface (30 to 40 cm) assessment, with subsurface results showing significantly reduced water holding capacity and less favorable biological indicators. A best subsets regression revealed three indicators as the most predictive in determining SH scores: organic matter content, soil respiration and active carbon, having an R^2-adj = 87%. In conclusion, a first comprehensive assessment of soil health in Jharkhand shows multiple physical, biological and chemical constraints and opportunities for enhanced assessment and management.

BIOGRAPHICAL SKETCH

Phillip S. D. Frost was born in Marondera, Zimbabwe on December 8th 1960 to Desmond and Jay Frost, third child of a group of four siblings. Being raised in a farming environment formed the foundation of an agricultural interest.

Political challenges in Zimbabwe lead to a providential opportunity to attend Cornell in January 2013, to do an MPS in Agriculture and Life Sciences, it was during this period where a discovery of "soil health" took place, this growing understanding of a quantifiable, and measureable soil health captured his mind and energy. He entered an M.S. program in the Department of Soil and Crop Sciences to pursue work in Soil Health under Dr. Harold van Es.

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My wife, foundation, and friend of 25 years, Mandi, my three sons, Murray, Duncan, and Luke, for their willingness to see this move halfway around the world as an adventure to be grasped, and a lesson to be learned…..study while you are young!

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Key words and phrases: Soil health, soil quality, India, landscape positions, physical, chemical and biological indicators, tillage, rice.

1. Introduction to Soil Health in a resource poor, rain-fed subsistence-farming system in Jharkhand India.

This study falls under the scope of the Tata-Cornell Agriculture and Nutrition Initiative (TCi) of Cornell University. TCi, established by the Tata Trust, is a long-term research initiative in India with a view to reducing levels of poverty and malnutrition through rural development. This research is illustrated in Jharkhand by subsistence farmers growing a monocropped, rain-fed transplanted paddy rice crop, middle, and lowland terraced fields. Post harvested grain and straw are removed and transported to the threshing floors, with the grain being family consumed or sold, and the straw used as feed and or bedding for draft animals, commonly penned only during the growing season. The consumption by the animals of the straw enables the recycling of some organic matter and soil carbon through manure. The upland areas are commonly developed for orchards and small home gardens of vegetables for home consumption.

Focusing on agriculture, the primary means of food production that serves not only rural India but also the approximately 1.3 billion people who in 2016 call India home, would be a judicious consideration. There are multiple strategies to appropriately feed a growing population; a few of these may include increasing the area under cultivation, improving crop productivity through plant breeding and genetics, importing food from elsewhere, or intensifying the factor productivity of agricultural inputs that would include soil resources. In a land scarce emerging economy the latter option seems a prudent alternative. For the sustainability of the intensification of existing agricultural resources, the starting point should be on the primary resource and lifeline to the economic advancement of all farmers, their soils. The degradation of soil resources is not a new concern; what is new, are the sustainable remediation options. These received increasing interest in the latter part of the 20th century and continued into the 21st century with 2015 being nominated by the United Nations as the International Year of the Soils in an effort to focus world attention on the importance of this diminishing resource and its importance in food security and the ecosystem. In our assessment of this diminishing resource, where are we to start? Are our soils degraded and if so why? What are the causes of soil degradation beyond the traditionally analyzed topsoil erosion and nutrient balance, and how degraded are our soils? Can the degradation be identified, quantified, and thereafter remediated?

The axiom "Measurement facilitates management" asks a more pressing question; do healthy and or degraded soils have quantifiable attributes (beyond erosion and productivity) that because of their measurement offer appropriate soil management options and remediation? This TCi project is spatially focused, and asks whether selected soils of Jharkhand India can be measured, managed, and mitigated following the Soil Health (SH) framework as benchmarked by the Cornell Assessment of Soil Health (CASH). In other words, can the CASH management framework quantitatively identify and thereafter improve SH and therefore the lives of resource poor, infrastructurally isolated subsistence farmers, (initially in Jharkhand but thereafter in the whole of India)? With that as the background for this paper, I review past and current literature around the concept of SH. Note the progress of assessment protocols and indicator selection that appropriately identify the agronomically important soil functions that require measurement and management for optimum productivity, with the overall goal of reducing levels of poverty and malnutrition through rural development in India. This assessed, quantitative aggradation of SH can directly and indirectly influence equally important issues such as:

- Gender upliftment, as much of agricultural labor is done by women;
- Food security at higher output will reduce the period of food insecurity that households face;
- Improve nutrition as the ability to grow diverse crops in improved soils will add to overall rural intensification and
- Increase the overall productivity in staple food production for food insecure and vulnerable communities.

1.1. What is soil health and is it important for the developing world?

Historically SH was a function of erosion prevention and nutrient management benchmarked on yield. Prevention of erosion through contouring and mechanical barriers was the dominant practice. Nutrient management consisted of chemical analysis carried out by a soil laboratory and consisted generally of pH, macro, and micro nutrient measurement and their balances dependent on crop specific requirements. With the increase in yield indicating an increasing optimization of measured nutrients.

The current attention on SH, galvanized in the 1990's, reflected the "*growing awareness that soil is an essential component of the biosphere*" (Doran and Jones, 1996). The successful green revolution of the mid 20th century brought modern high yielding varieties, initially to rice and wheat, but later to include many other staple crops in the developing world (Eswaran et al., 2005; Lal, 2009). The incorporation of dwarfing genes and input intensification with new high yielding varieties substantially increased harvestable yields, and the resultant per capita caloric intake.

Unfortunately an unintended consequence of the green revolution has been the degradation and decline of natural resources that now warrant a "new revolution", a revolution in responsible intensification, that alongside nutrition outcomes, promotes the building and/or rejuvenation of SH, enhancing the productivity, and sustainability in agricultural food systems. The benefits of a climate smart, responsible intensification of agriculture that promotes the building and/or rejuvenation of SH in the face of climate change and other output reducing effects are increasingly recognized (Hobbs, 2007). Sanchez and Swaminathan (2005), discuss their options to increase the productivity of food insecure farmers and propose that "restoring soil health is often the first entry point". They further note the important link between unhealthy people and unhealthy soils, indicating the wider effects of a degraded soil resource. Others hold this anthropogenic decline in SH to be a global threat as it undermines the productive agricultural ecosystem and affects global climate (Lal, 1990). The prospect of feeding a global population of 9 billion people with a diminishing resource, has drawn wide attention, encouraging scientists, activists and household consumers of agricultural produce in a vigorous multi-sector enquiry, actively seeking sustainably appropriate and holistic solutions (Warkentin, 1995) to this dwindling and fragile natural resource (Carter et al., 1997; Karlen et al., 2003). This was not a new endeavor, as for many centuries there has been an appreciation that classifying and assigning quality to soils is an important prerequisite to the effective management of those same soils. History notes societies that have either flourished or floundered due to their approach to soil conservation (Magdoff and van Es, 2000; Montgomery, 2007).

This growing appreciation and understanding of SH, includes assessment of important soil factors for agronomic practices as well as ecosystem services being relevant in a broad range of agronomic, socio economic, and geographical environments (including rural India; Larkin, 2015) . These factors include both *dynamic* attributes of soil that are easily altered by use and human management over a short period of time, and the *inherent* physical attributes described by (Jenny, 1946), including Parent material, Climate, Biota, Topography and Time. This growing understanding of the complexity of soil and its health has directed leading organizations such as the Soil Science Society of America (SSSA) to examine and redefine SH (Karlen et al., 1997; Wander and Drinkwater, 2000). With the current definition of SH progressing from the historically narrow nutrient and erosion focused explanation (Andrews et al., 2004) to the more comprehensive assessment that includes the evaluation and quantification of Physical, Biological and Chemical attributes of the soil system (Magdoff and van Es, 2000). This quantifiable SH is similar to a human health assessment (Larson and Pierce, 1991), the latter not being a direct or singular measurement. A cursory outward assessment of human health, similarly to SH, is progressively enhanced with easily measured system functions such as blood pressure, body temperature, and pulse rate; these external indicators can be augmented with further assessment of routine but highly informative blood and urine chemistry leading to optimum understanding and therefore optimally appropriate remediation. Similarly, a quantitative soil assessment enhances the utility of the SH concept as well as expanding specific mitigation options of the degradative processes on the basis of an increased understanding of the soil functions that contribute to SH. Fundamentally understanding the impairment is required prior to effective improvement/remediation.

Consequentially, this richer comprehension of soils has resulted in the contemporary holistic definition of SH, described by (Doran and Parkin, 1994) as, "*the capacity of a soil to function within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health*". It includes evaluation of the physical, biological and chemical attributes in a SH assessment providing a holistic range of SH indicators beyond the historical soil nutrient quantities and balance, and allows diagnostic tests to quantify these important dynamic and inherent factors (Doran and Safley, 1997). Another important factor in the appropriate characterization of SH was the shifting of research from the "ethereal" laboratory into the quantifiable domain of the farmer practitioner. The increasing technological capability and general understanding of soils, resulted in the refining of SH concepts and protocols (Warkentin, 1995). Taking SH assessment and management closer to those who affect it has resulted in credible multidisciplinary research seeking to understand the long-term effects of management and farming systems on the soil as opposed to a research focus controlled primarily by protocol and research undertakings (Doran and Zeiss, 2000; Wander and Drinkwater, 2000).

This focus on first identifying the causes of reduced soil productivity as a fundamental SH process is of central importance in the formulation of sustainable solutions. Taking the assessment of the causes beyond the historical nutrient supply and balance offers holistic solutions that include additional benefits such as increased investment and conservation of this natural resource by landowners leading to a revitalization of the primary agricultural resource for smallholder farmers and sustainable intensification. Measurable SH protocols will therefore contribute to improved ecosystem services, reduced soil erosion, degradation, and pollution.

Appropriate indicators of healthy soil, listed by (Magdoff and van Es, 2000; Gugino et al., 2009) include:

- Water dynamics that include infiltration, drainage, and water holding capacity for irregular dry periods.
- Nutrient retention and cycling for food, fiber, and fodder production.
- Biological diversity indicated by:
    - Reduction of plant pests and soil pathogens,
    - Detoxification of harmful chemicals.
    - Sequestration of carbon.

An understanding of SH that targets the monitoring and consequential management of soils has drawn the attention of industrialized countries of the temperate zone (Karlen et al., 2003). These holistic sustainability concerns of research institutions initially in and for the industrialized world's agricultural systems are equally important for the developing world. Unfortunately, in contrast with the trend of the developed world's increasing understanding of holistic SH, the primary effort in the developing world is still narrowly targeted towards the control of erosion and nutrient supply/balance as the measures of SH. Sherwood and Uphoff (2000) discussing sustainability trends in developing nations note with concern the continued narrow focus on the chemical fertility of soils remaining after soil erosion, rather than effective soil health management practices that can have the desired effect on the initial prevention of soil erosion. Looking particularly at India, (Agarwal et al., 2010) overlooking the biological factors confer soil fertility status of soils based on macro and micro nutrient (chemical) reserves of the soil affected by the inherent attributes (physical) of soil forming factors noted by (Jenny, 1946) with solutions including liming, farmyard manure and reducing yield-limiting nutrient imbalances of phosphorus and sulfur. Similarly, defining SH in narrow terms results in descriptions that despite relatively high annual rainfall (>1200mm), crop production on the East India Plateau is locally characterized as "low yielding and drought prone" (Bhattacharyya et al., 2013; Cornish et al., 2015a). This decline in productivity could be due, in part, to the deleterious anthropogenic effects on key dynamic soil functions, such as water holding capacity or nutrient cycling, resulting in this "fatigue" in agricultural soils in India. The result being, the diminishing productivity of small and marginal farmers who comprise 80 % of all rural farmers on 40% of the available land (Bonnerjee, 2010). Reviewing the state of Jharkhand, (Singh et al., 2014) attribute low productivity of the upland province's soils to inherent and dynamic physical and chemical constraints such as coarse texture, low water and nutrient retention capacity, soil acidity, low fertilizer use and deficiencies of Nitrogen, Phosphate, Potassium, Sulfur, and Boron, but unfortunately disregarding the biological indicators.

These constrained views of SH, confirmed in private discussions with development professionals and academics from India indicate a limiting view of SH that focuses on nutrient supply and balance as the primary focus. Precluding essential physical and biological indicators crucial to a holistic understanding of soil and its ability to optimally, "function within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health."

However as a result of increasing population pressure and limited land availability, developing world stakeholders are beginning to adopt practices that enhance the sustainable and holistic health of our limiting and limited soils (Dumanski and Pieri, 2000). This contemporary inclusive and accurate measurement of SH should, as the management axiom implies, lead to effective management preventing further degradation of the primary resource of agricultural land managers.

The literary descriptors soil "health" (SH) and or soil "quality" (SQ) have and still are today used synonymously (Harris and Bezdicek, 1994) . Recently it was suggested that soil "health" was favored by farmers and soil "quality" by scientists (Magdoff and van Es, 2000).

In this paper I have favored the use of Soil Health as a descriptor, as a "healthier soil" should inherently be more productive; the unspoken objective of every sensible farmer and land use manager.

1.2. Soil Health Indicator and assessment criterion

The key soil functions that indicate healthy soil previously noted by (Magdoff and van Es, 2000; Gugino et al., 2009) are incorporated and described in (Table 1) indicating what is required to provide optimum capacity to "function within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health." These indicators of SH incorporated in the 2009 CSHT report when not managed optimally can become constraints (Table 2); these constraints limit SH and reduce agricultural productivity and sustainability.

Table 1: Characteristics and descriptors of a Healthy Soil	
Good soil tilth	Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production
Sufficient depth	Sufficient depth refers to the extent of the soil profile to which roots are able to grow and function. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to extreme fluctuations in the weather, thus predisposing the crop to drought or flooding stress
Sufficient but not excess supply of nutrients	An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. Excess nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.
Small population of plant pathogens and insect pests	In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low and/or inactive. This could result from direct competition from other soil organisms for nutrients or niche habitats, hyper-parasitism, etc. Also, healthy plants are better able to defend themselves against a variety of pests (similar to the human immune system).
Good soil drainage	Even after a heavy rain, a healthy soil will drain more rapidly as a result of good soil structure and an adequate distribution of different size pore spaces, but also retain adequate water for plant uptake.
Large population of beneficial Soil Micro-organisms	Soil microbes are important to the functioning of the soil. They help nutrient cycling, decomposition of organic matter, maintenance of soil structure, biological suppression of plant pests, etc. A healthy soil will have a high and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.
Low weed pressure	Weed pressure is a major constraint in crop production. Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can interfere with stand establishment, block sunlight, interfere with harvest and cultivation operations, and harbor disease causing pathogens and pests.
Free of chemicals and toxins that may harm the crop	Healthy soils are either devoid of harmful chemicals and toxins or can detoxify and/or bind such chemicals making them unavailable for plant uptake due to their richness in stable organic matter and diverse microbial communities.
Resistant to degradation	A healthy, well aggregated soil is more resistant to adverse events including erosion by wind and rain, excess rainfall, extreme drought, vehicle compaction, etc.
Resilience when unfavorable conditions occur	A healthy soil will rebound more quickly after a negative event such as harvesting under wet soil conditions or if land constraints restrict or modify planned rotations.
Source Gugino et al., 2009	

Table 2; Common constraints identified in the Cornell Soil Health Test	
Physical	**Aggregate Stability:** is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing a known weight of soil aggregates between 0.5mm and 2.0mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve determines the percent aggregate stability.
	Available Water Capacity: reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and the wilting point, and is measured using pressure chambers.
	Surface Hardness: is a measure the maximum soil surface (0 to 6 inch depth) penetration resistance (psi) determined using a field penetrometer.
	Subsurface Hardness: is a measure of the maximum resistance (in psi) encountered in the soil at the 6 to 18 inch depth using a field penetrometer.
Biological	**Organic Matter:** is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter consists of both living and dead material, including well decomposed humus. The percent OM is determined by loss on ignition, based on the change in weight after a soil is exposed to approximately 500◦C in a furnace.
	Active Carbon: is a measure of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community (the fuel of the soil food web). Active carbon is a "leading indicator" of soil health response to changes in crop and soil management, usually responding much sooner than total organic matter content. The soil sample is mixed with potassium permanganate (deep purple in color) and as it oxidizes the active carbon, the color (absorbance) is measured using a spectrophotometer.
	Potentially Mineralizable Nitrogen: is the amount of nitrogen that is converted (mineralized) from an organic form to a plant-available inorganic form by the soil microbial community over seven days in an incubator. It is a measure of soil biological activity and an indicator of the amount of nitrogen that is rapidly available to the plant.
	Root Health Rating: is a measure of the quality and function of the roots as indicated by size, color, texture and absence of symptoms and damage by root pathogens such as *Fusarium*, *Pythium*, *Rhizoctonia*, and *Thielaviopsis*. Been seeds are grown in a portion of the soil sample in the greenhouse for four weeks. Low ratings (1 to 3) suggest healthy roots because pathogens are not present at damaging level and /or are being suppressed by the beneficial microorganisms in the soil.
Chemical	**Soil Chemical Composition:** a standard soil test analysis package measures levels of pH, plant nutrients and toxic elements. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

Source: Gugino et al., 2009

(Doran and Zeiss, 2000) further note that for the long term success of SH assessment it must be directed at land managers, as they are ultimately the "judge of which indicators of soil quality are worth measuring," due in part to their constant interaction with the soil and the real world application of the science designed assessment offered. In addition, to be appropriate, the tests, evaluation and quantification of the indicators must be based on high standard assessments that are scientifically defensible (Lal, 1997). This scientific rigor permits assessment over time to be used to quantify change over time in determining the directional impact of soil management practices on sustainability and SH (Karlen et al., 1997; Magdoff and van Es, 2000). Other factors that will encourage the assessments wider adoption and appropriateness will be protocols that require minimal infrastructure that are relatively easy to perform, and affordable to those beyond the research realm (Moebius-Clune, 2010). The development of the Cornell Soil Health Test (CSHT) followed those requirements seeking to:

- Improve the assessment through inclusion of the management-affected dynamic attributes of soil to the inherent attribute found in soil survey data.
- Identify and quantify management options that affect SH over time.
- Offer management options for remediation towards optimum of indicator constraints.

- Learn from the process of measurement and management used in various systems and environments.
- Develop a quantifiable system of SH assessment that aids in land valuation of optimally healthy soils (Schindelbeck et al., 2008; Moebius-Clune et al., 2011a) .

The initial selection of 39 indicators (Table 3) derived from a broad range of data spanning 15 years across various geographic locations, diverse farming, and management systems in the northeast of the US were consolidated to a minimum data set of four physical, four biological, and seven standard chemical indicators (Table 4). Table 4 lists soil indicators with relevant soil processes that were validated for use by being useful to practitioners, sensitive to management interventions relevant to functional soil processes, such as aeration, infiltration, root proliferation, N mineralization, toxicity prevention, pest suppression, water, and nutrient retention and were relatively inexpensive to analyze (Doran and Zeiss, 2000; Schindelbeck et al., 2008; Moebius-Clune et al., 2011a; Schindelbeck and Van Es, 2011).

Table 3, Thirty-nine soil health indicators evaluated for the Cornell Soil Health Test in 2003–2005		
Physical indicators	**Biological** indicators	**Chemical** indicators
Bulk density	Root health assessment	pH
Macro-porosity	Organic matter content	Phosphorus
Meso-porosity	Beneficial nematode population	Potassium
Micro-porosity	Parasitic nematode population	Magnesium
Available water capacity	Potentially mineralizable nitrogen	Calcium
Residual porosity	Decomposition rate	Iron
Penetration resistance at 10 kPa	Particulate organic matter	Aluminum
Saturated hydraulic conductivity	Active carbon	Manganese
Dry aggregate size (<0.25 mm)	Weed seed bank	Zinc
Dry aggregate size (0.25–2 mm)	Microbial respiration rate	Copper
Dry aggregate size (2–8 mm)	Soil Proteins	Nitrate Nitrogen
Wet aggregate stability (0.25–2 mm)		Exchangeable acidity
Wet aggregate stability (2–8 mm)		
Surface hardness (penetrometer)		
Subsurface hardness (Penetrometer)		
Field infiltrability		
Source: Moebius-Clune et al.,2011		

Specific Physical tests excluded from the original 39 indicators due to prerequisites of undisturbed samples, such as for bulk density, with long distance transportation an inevitable factor rendering the reliability of such results disputable. Selected Biological indicators were not included due to the high cost of evaluation and variability of results; the chemical indicators included were and still are part of the standard soil nutrient tests carried out in established laboratories (Moebius et al., 2007; Moebius-Clune et al., 2011a).

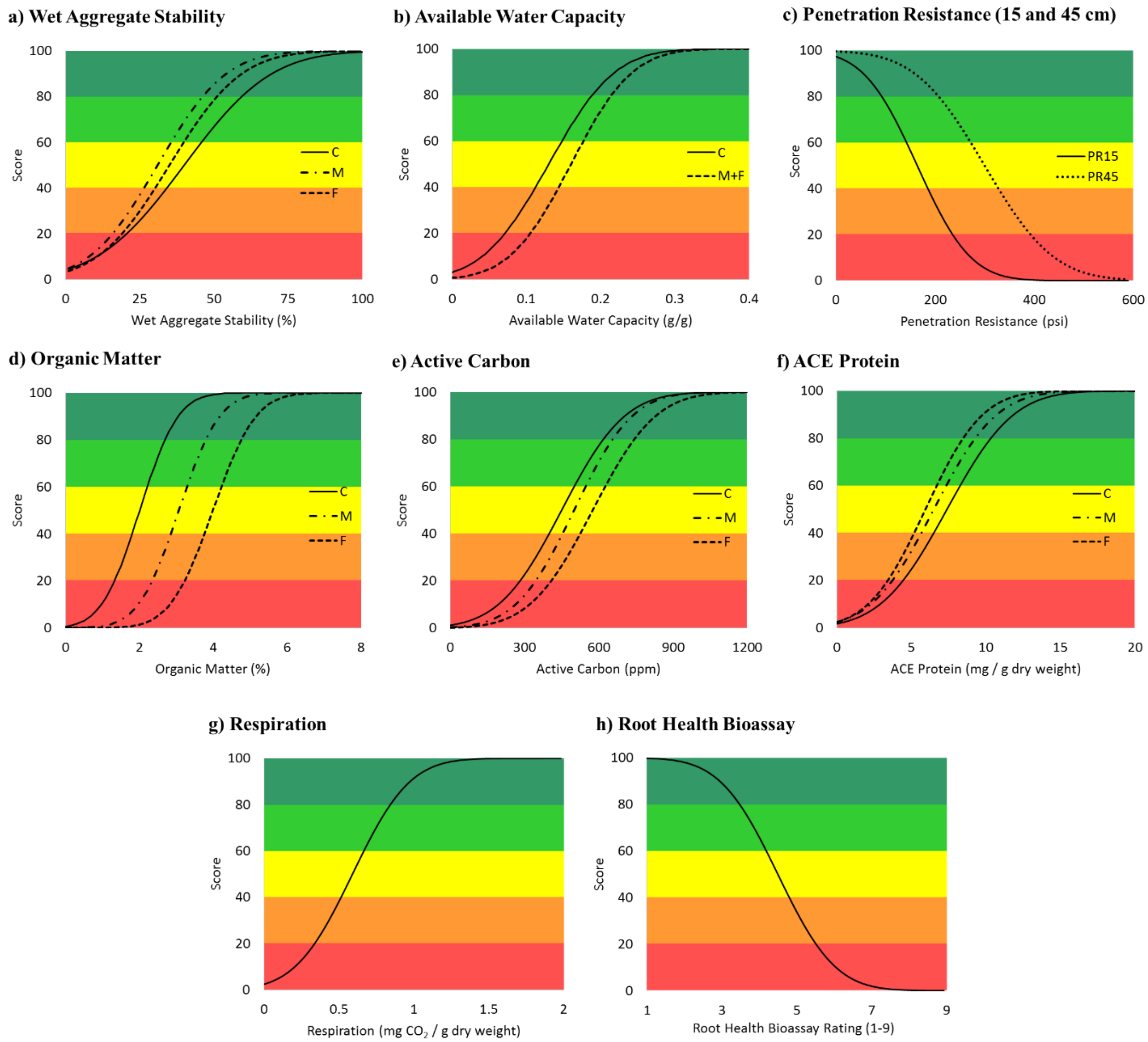
Table 4, Soil quality indicators included in the standard Cornell soil health test, and associated processes	
Soil indicator	Soil process
Physical	
Soil texture	All
Aggregate stability	Aeration, infiltration, shallow rooting, crusting
Available water capacity	Water retention
Surface hardness	Rooting at and in plow layer
Subsurface hardness	Rooting at depth, internal drainage
Biological	
Organic matter content Energy	C storage, water and nutrient retention
Active carbon content	Organic material to support biological functions
Potentially mineralizable nitrogen	Ability to supply N
Root rot rating	Soil-borne pest pressure
Chemical-standard	
pH	Toxicity, nutrient availability
Extractable P	P availability, environmental loss potential
Extractable K	K availability
Minor Element Contents	Micronutrient availability, elemental imbalances, toxicity

Source; Schindelbeck et al., 2008

1.3. **Overview of scoring functions**.

The SH scoring functions permit the high accuracy laboratory assessment of the varied soil health indicators to be converted using a cumulative normal distribution curve to a percentile rating with 100 being a high/good/optimum result and 1 being a low/poor result. In addition to the percentile thresholds ranking, the ratings are allocated an appropriate nominal color rating for ease of identification; these are as follows; very low (score < 20, color red), low (> 20 < 40, color orange), Medium (>40 < 60, color yellow), high (>60 <80, color green), and very high (>80, color dark green) Figure 1. With scoring functions differentiated as **more** is better, **less** is better, and **optimum**. For example figure 1 indicates **more** is better will apply to indicators such as SOM, active Carbon, and aggregate stability; **less** is better will apply to indicators such as surface and subsurface hardness, and indication of root pathogens in the root health assessment. **Optimum** levels will apply for indicators such as pH where a low or high pH is not generally desirable and attract poor scores (Schindelbeck et al., 2008; Gugino et al., 2009; Moebius-Clune et al., 2011a; Schindelbeck and Van Es, 2011).

Figure 1: Score curves indication low, normal, and optimum scores.



Source: Fine et al. 2017.

1.4. **Indicators and assessment methods** are described in materials and methods section 3.

1.5. CSHT management responses to constraints

The CSHT has over the past 15 years gathered data through trial and testing of many remediation options for revealed constraints and progressively developed a broad based management strategy that offers typical solutions to specific constraints. Although there are only a few broad strategies for SH remediation for the physical biological and chemical attributes such as:

- Addition of nutrients and soil amendments such as fertilizers, lime, crop residues, farmyard manures or composts.
- Tillage, of various forms, more, less, deeper, or even none.
- Cover crops
- crop rotations

The options and combinations within the strategies are abundant, with many amendment and tillage and cover crop combinations for specified effects. Remediation options also have temporal options from rapid response such as addition of inorganic fertilizers to longer-term management strategies such as reduced tillage, cover crops crop rotations, and combinations of all of the above.

Table 5, from (Gugino et al., 2009) notes various management practices developed in and primarily but not restricted to the Northeast USA for addressing SH constraints.

Table 5: Management options for treatment of Soil Health Constraints. (Initially developed for North East USA)

	Suggested Management Practices	
	Short term or intermittent	**Long term**
Physical Concerns		
Low aggregate stability	Fresh organic materials (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, surface mulch, rotation with sod crops
Low available water capacity	Stable organic materials (compost, crop residues high in lignin, biochar)	Reduced tillage, rotation with sod crops
High surface density	Limited mechanical soil loosening (e.g. strip tillage, aerators); shallow-rooted cover crops, bio-drilling, fresh organic matter	shallow-rooted cover/rotation crops; avoid traffic on wet soils; controlled traffic
High subsurface density	Targeted deep tillage (zone building, etc.); deep rooted cover crops	Avoid plows/disks that create pans; reduced equipment loads/traffic on wet soils
Biological Concerns		
Low organic matter content	Stable organic matter (compost, crop residues high in lignin, biochar); cover and rotation crops	Reduced tillage, rotation with sod crops
Low active carbon	Fresh organic matter (shallow-rooted cover/ rotation crops, manure, green clippings)	Reduced tillage, rotation
Low mineralizable N (Low PMN)	N-rich organic matter (leguminous cover crops, manure, green clippings)	Cover crops, manure, rotations with forage legume sod crop, reduced tillage
High root rot rating	Disease-suppressive cover crops, disease breaking rotations	Disease-suppressive cover crops, disease breaking rotations, IPM practices
Chemical concerns	See also soil fertility recommendations	
Unfavorable pH	Liming materials or acidifier (such as sulfur)	Repeated applications based on soil tests
Low P, K and Minor elements	Fertilizer, manure, compost, P-mining cover crops, mycorrhizae promotion	Application of P, K materials based on soil tests; increased application of sources of organic matter; reduced tillage
High salinity	Subsurface drainage and leaching	Reduced irrigation rates, low-salinity water source, water table management
High sodium content	Gypsum, subsurface drainage, and leaching	Reduced irrigation rates, water table management

Source: Gugino et al. 2009

2. Soil Health Characterization of Agricultural Land in Jharkhand, India.

Healthy soils are expected to be more productive and resilient to climate shocks than degraded soils. A developing appreciation and understanding of soil health (SH), also termed soil quality, includes a quantifiable assessment of a broad scope of agronomically important soil functions. This richer comprehension of soils has resulted in the widely accepted holistic SH definition:

> "*The capacity of a soil to function within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health*" (Doran and Parkin, 1994).

The objective, routine evaluation of soil health has recently become feasible through the Comprehensive Assessment of Soil Health approach (Moebius-Clune et al., 2016), formerly known as the Cornell Soil Health Test (Gugino et al., 2009). This offers a holistic quantification of SH, as well as remediation options for farmers and land managers that help identify soil constraints that can lead to recommendations to address these problems (Wolfe, 2006; Idowu, 2007; Idowu et al., 2009; Moebius-Clune et al., 2011a; b; Congreves et al., 2015). Soil health assessment includes *dynamic* soil properties that are easily altered through management and *inherent* ones, resulting from long-term pedogenesis (Jenny, 1946). Together these are determinants of *soil functions* that directly affect agronomic and ecosystem services (Larkin, 2015). SH assessment is similar to human health assessment: a quantitative description of key properties, meant to be interpreted for management towards improved health (Larson and Pierce, 1991).

In India, the soil resource is under tremendous pressure to meet societal needs. The large majority (80%) of farmers are classified as small (less than one hectare) and resource poor. As a result of inappropriate management, agricultural land use and productivity are deteriorating (Swaminathan, 2010), resulting in the region having the world's highest per-capita and absolute numbers of hungry and food-insecure persons (Bonnerjee, 2010). While solutions to these problems require multi-faceted interventions, a first step is understanding the status of the soil resource, which is a foundational resource for agriculture. A quantative SH characterization of cultivated agricultural soil would (1) establish the current status of these soils; and (2) help identify remediation strategies to improve agronomically important soil functions, thereby contributing to increased productivity and sound agricultural land use.

India has an active soil health management (SHM) program that

> *… aims at promoting Integrated Nutrient Management (INM) through judicious use of chemical fertilizers including secondary and micro nutrients*

in conjunction with organic manures and bio-fertilizers for improving soil health and its productivity (Ministry of Agriculture & Farmers Welfare, Government of India).

It offers recommendations on soil fertility with NPK fertilizer, micronutrients, organic manure, bio-fertilizer, and lime or gypsum, (Fig, 2 supplementary data). This program is distinct from the CASH approach in that it focuses exclusively on chemical indicators (nutrients and pH), while CASH also measures biological and physical indicators.

This study is spatially concentrated and seeks to understand and assess soil health in representative sites in Jharkhand, India (Fig, 3) following the CASH framework and protocols to identify constraints and causes to inform suitable solutions that lead to improved sustainable management of agricultural land. A second objective is to evaluate the suitability of the CASH approach, including specific indicators and specific scoring functions, to the Jharkhand context, and to identify potential lower-cost alternatives

Figure 3, Map of India and Jharkhand with district boundaries and sample sites.

3. Materials and methods.

3.1. The Comprehensive Assessment of Soil Health framework

The CASH approach offers field-specific information on measured agronomically important, biological, and physical soil properties, combined with characteristic nutrient analysis. It uses interpretive scoring functions to inform management options for remediation of identified constraints linked to past or current management practices, with the intention to promote more holistic and ecological soil and crop management practices (Moebius-Clune et al., 2016).

3.2. Site description

The state of Jharkhand (Fig. 3) in eastern India lies between 21°58’2” to 25˚8’32” North latitude and 83˚19’05” to 87˚55’03” East longitude, with an area of 79,710 km^2 and a population of 33 million, and 22 000 km^2 of cultivated land (World Bank, 2014). The topography is generally undulating with many small catchments dominated by rain-fed farming systems, including terraced and bunded fields for water management in a generally rice *(Oryza sativa)* -fallow rotation.

Pedogenetic factors.

The soil parent material is primarily granite and gneissic metamorphic rocks (State Agricultural Management & Extension Training Institute of Jharkhand), containing around 25% quartz, 65% feldspar with lesser amounts of mica material weathered and locally transported. Depending mostly on the degree of pedogenesis the soils are classified into three orders of US Soil Taxonomy (Staff, 2003): moderately developed Alfisols (54%), slightly developed Inceptisols (24%) and almost undeveloped Entisols (20%; Agarwal et al., 2010).

Topography is largely the undulating peninsular plateau with altitudes from 300 m.a.s.l. to 1350 meter at Mount Shikharji. Mean annual soil temperatures measured at a depth of 50 cm are classified as "hyperthermic" (US Soil Taxonomy), with summer means of $\geq$ 22° C and mean summer and winter temperature differences of >5°C.

The 10 year (1991-2000) mean annual rainfall distribution in the capital Ranchi includes three periods of precipitation (State Agricultural Management & Extension Training Institute of Jharkhand): summer monsoons (*Kharif;* June to October; 1424 mm), winter dry season (*Rabi*; October to March; 178 mm) and a transitional season from March to June with 361 mm. The soil moisture regime is Ustic (US Soil Taxonomy): fewer than 180 cumulative days or 90 consecutive days of the year with a moist control section (Buol et al., 2011).

Cornish et al., (2015a) argues that most soils in Jharkhand, with their felsic parent material, undulating topography, strong seasonal precipitation with warm to hot temperatures, are weathered and infertile. For millennia they have, and continue to be, degraded by anthropogenic agricultural soil practices such as wet tillage and puddling, and so should be classified as Anthroposols.

3.3. *Management systems*

The staple crop in the study area is medium-duration rain-fed, transplanted rice *(Oryza sativa)* on puddled soils in terraced and bunded areas. Despite infertile soils, there is low fertilizer use (mainly compost) with bullock-drawn plows (Image 5) used to puddle soils and create an impervious layer (plow pan) to pond water. (Cornish et al., 2015a; b).

3.4. *Site selection.*

Two approaches were used to select sampling locations. First, two catchments were chosen and opportunistically sampled during an exploratory field trip in February 2015 guided by a local nongovernmental organization (Professional Assistance for Development Action; PRADAN) involved in community development. Subsequently, a stratified random approach was used to select a further 25 catchments within an area of 34,362 km^2 in 6 (Bokaro, Giridih, Gumla, Hazaribagh, West Singhbum and Ranchi) of the 24 districts of Jharkhand, within a 100 km radius of the capital city Ranchi (Fig. 2,). In each district, a grid of 16 equal sized squares was overlaid using the R software (R Core Team, 2015) function `spsample' to ensure a full spread of points. The R function `sample' was then used to randomly select four sites per district (5 in Ranchi) within the overlaid grids, which were located in Google Earth to map their exact position. As the goal of the project was to measure SH in cultivated agricultural soils, the randomly selected positions that were not located on cultivated areas were shifted to the nearest field position where there were terraced and bunded paddy fields.

Fig. 4 shows a section of a catchment stratified into four landscape positions along a transect from generally uncultivated higher elevation to perennially wet bunded or terraced lowland fields, ranging in altitude from 171 to 707 m.a.s.l. The four landscape positions tended to have substantially different land use and management, with uncultivated (forested) lands presumed to have the least impact from anthropogenic soil degradation. The four landscape positions are characterized as follows:

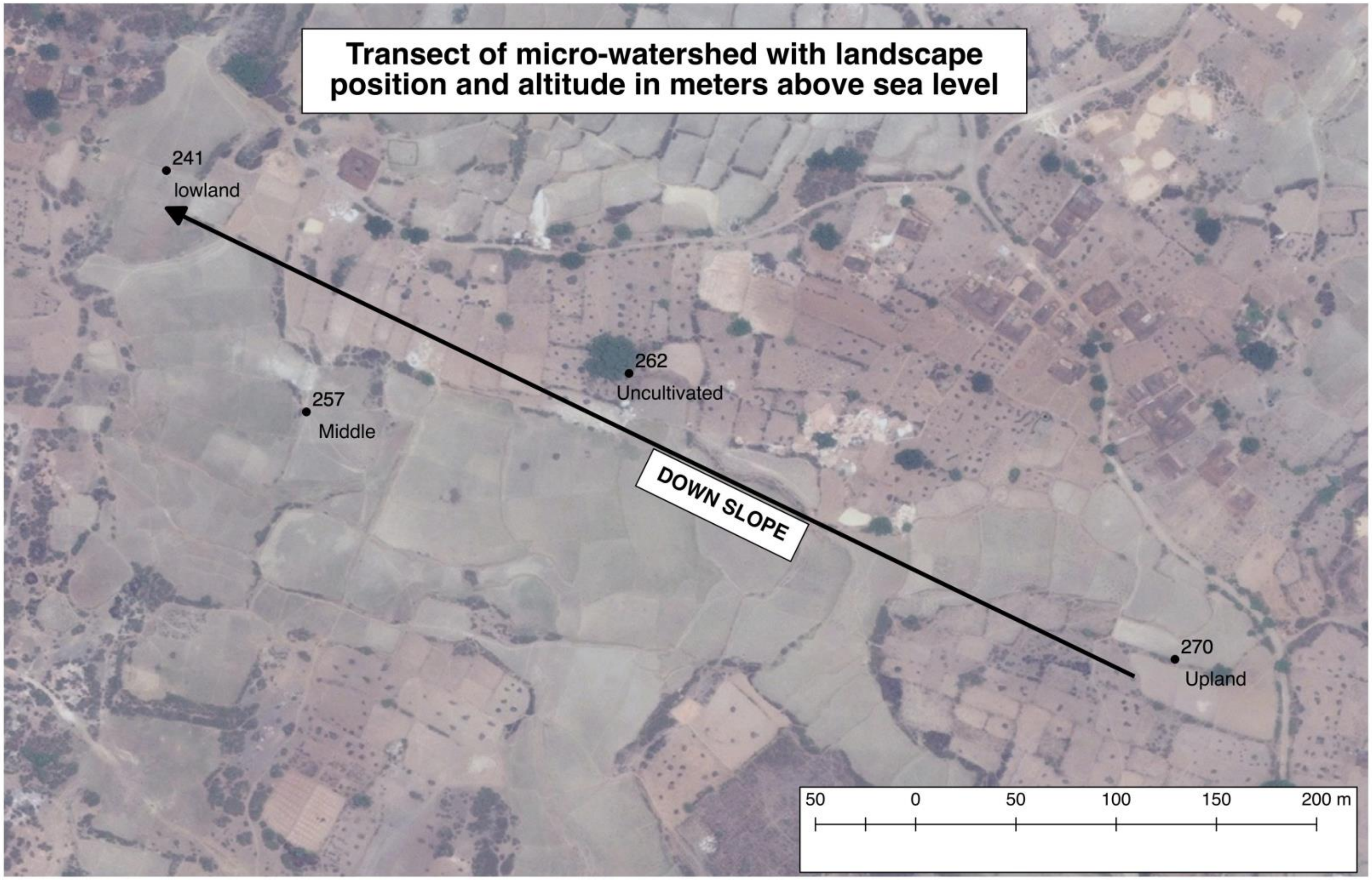


Figure 4. Typical catchment stratified into four landscape positions

Un-cultivated land, located on the upper boundary or side ridges of the catchment characterized by sylviculture and evidence (i.e., large trees) that no cultivation has taken place for some time, if ever. (Image 1, supplementary data)

Upland, non-terraced or bunded cultivated fields adjacent but generally lower in the catchment to the uncultivated land. Uplands are generally managed as small home gardens or orchards, cropped primarily during the seasonally wet monsoon months of June to October, and sometimes irrigated in the dry season. They are generally not terraced or aggressively tilled (Image 2, supplementary data).

Middle, seasonally wet, bunded, or terraced fields, generally in the middle of the catchment profile. They are primarily used for monsoon (*Kharif*) paddy rice cultivation (Image 1, and 6 supplementary data).

Lowland, bunded, or terraced fields part of the lowest profile of the catchment that are often perennially wet, also used for monsoon (*Kharif*) paddy rice cultivation (Image 3, supplementary data).

3.5. *Sample collection*

Using a manual hoe to remove surface residues, 120 disturbed soil samples, (0 to 15 cm depth) were collected. The first 16 samples, taken from the two catchments identified after a guided field trip in February 2015. Metadata included GPS position, altitude, village name, and landscape position. Five samples within a radius of 3 m of the selected position were composited and thoroughly mixed, of which approximately one kg of soil was sampled. The remaining 100 samples from the stratified randomly selected locations were collected in June and July 2015 using the same sampling protocol. All samples were air dried and shipped to Cornell University, Ithaca, NY, USA where they were stored at 4° C until analysis. Three samples were damaged in transit and were unfit for analysis. A total of 113 samples were analyzed.

In November 2015, five previously sampled micro-watershed sites closest to Ranchi were selected for subsoil sampling (30 to 40 cm depth) at each of the four landscape positions, following the earlier established sampling protocols. Concurrently, five penetrometer readings were made from the surface with 10cm depth increments to a maximum of 40 cm, using a Dicky John soil compaction tester (Auburn, Illinois), resulting in a total of 479 data points of soil strength.

3.6. *Laboratory analysis*

The CASH protocol assesses biological, physical and standard chemical analyses described by Wolfe, 2006; Idowu, 2007; Gugino et al., 2009; Moebius-Clune et al., 2011a; b; and Congreves et al., 2015. Samples were air dried in the lab and then passed through a 2 mm sieve before the following assessments:

<u>Physical properties</u>:

- *Texture*: Sand (0.05mm <x<2 mm particles), silt (0.002mm <x<0.05 mm) and clay fractions (<0.002mm) were quantitatively determined using a method developed by (Kettler et al., 2001) where samples are dispersed with a 3% sodium hexametaphosphate ($(NaPO_3)_n$) solution with size fractions separated and measured using a combination of sieving and sedimentation steps.
- *Available water capacity (AWC)*: Capillary hydrated soil moisture was gravimetrically determined as the difference in soil moisture between field capacity at -10kPa and plant wilting point of -1500 kPa using ceramic pressure plate apparatus (Topp et al., 1993).
- *Wet aggregate stability (AgStab)*: measuring the resilience of a known weight, single layer of <2mm air-dried soil aggregates spread on a 0.25mm sieve under a rainfall simulator (Ogden et al., 1997) that delivers 2.5 J of energy over a 300 s time period.

Biological properties:

- *Organic matter (OM)*: content measured by loss on ignition in a muffle furnace for two hours at 500° C.
- *Soil Protein (Prot)*: an extraction with a 0.02 M sodium citrate buffer at pH 7 of soil protein is autoclaved for 30 min at 121° C and 103 kPa (Wright and

Upadhyaya, 1996; Walker, 2009), centrifuged, subsampled and bicinchoninic acid assayed against a bovine serum albumin standard curve for soil protein concentration.

- *Active carbon (ActC)*: a fraction of organic matter that is a ready source of food for soil microbes quantified by potassium permanganate ($KMnO_4$) oxidation measured with a hand held spectrophotometer at 550nm (Weil et al., 2003) .
- *Respiration (Resp)*: a measure of temporal metabolic activity of soil organisms indicated by levels of respired CO_2 in a rewetted soil. (Haney and Haney, 2010),

Chemical properties:

- *pH* was measured in a 1:1water slurry.
- *Soil nutrients* measured using the multi-element Mehlich-3 soil extractant suitable for acid and neutral soils. Phosphorus, potassium, magnesium, iron, manganese, and zinc were assessed in the Cornell Nutrient Analysis Laboratory (CNAL) using a Spectro Arcos axial viewed ICP-OES (2013 model; SPECTRO Analytical Instruments Inc., Kleve Germany).

3.7. *Statistical analysis*

Statistical analysis and graphics were carried out in the R environmental for statistical computing. (R Core Team, 2015). Parameters of the normal distribution for each indicator were determined overall and by landscape position. Values further than two standard deviations from the sample mean were verified against transcription and lab errors. Conservative Shapiro-Wilks tests and less conservative ‘qqnorm’ plots indicated skewed distributions and the rejection of the null hypothesis of normally distributed data for all indicators other than AWC, OM, and pH. Before transformation, all P values were allocated a small value of 0.01 as there were many zero results. Data were transformed using the log10 function for chemical nutrients and square root function for the biological indicators and wet aggregate stability.

Nutrient comparisons for P, K, Mg, Fe, Mn and Zn are based on general sufficiency levels obtained with Mehlich III extractant as found in (Havlin et al., 2005), as assessed soil nutrient concentrations decrease, the required rate of nutrient application required to maximize potential yields increases. High soil nutrient concentrations indicate a 90 to 100 % sufficiency of available nutrients and low concentrations indicate a 50 to 70 % sufficiency of available nutrients. Biological indicators such as Agstab, AWC, OM, actC, Prot, and Resp found in (Moebius-Clune et al., 2016) are based on an estimated cumulative normal distribution of samples in the Cornell Soil Health lab data base using the mean and standard deviation of measured values.

Analysis of variation (ANOVA) was performed to determine variation for each indicator between landscape positions using Tukey's HSD (α=0.05) for multiple pairwise comparisons of means. Due to unequal sample sizes, mean indicator values from 0 to 15 cm (n=113) and 30 to 40 cm depth (n=20) data were evaluated using Welch's t-test.

Correlation analysis was performed to identify and measure associations between pairs of variables. PCA was conducted to evaluate relative redundancies in multivariate data and identify principal factors that incorporate the maximum variation from the original data. Data were standardized with the R formula "scale=TRUE", and Kaiser's rule (Zwick and Velicer, 1986) was applied, which recommends retaining factors with eigenvalues >1.

A best subsets regression (BSR) was performed to determine the best overall SH predictors. First, an overall soil health score was established with thresholds established on local conditions, for each indicator following the CASH protocol (Moebius-Clune et al., 2016) using a Gaussian distribution function,

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(x-\mu)^2}{2\sigma^2}}, -\infty < x < \infty \qquad [1]$$

where μ is the sample mean and σ the standard deviation(s) The CND function is the integral of equation [1] and shows the probability between 0 and 1, of the measured value, that is then normalized by multiplying by 100 to give a standardized scoring between 0 and 100. For each sample, the measured value for an indicator was then scored onto this CND, and the overall soil health score was then determined from the average value of each indicator score. The overall SH score was then predicted using subsets of individual soil health indicator scores, starting with subsets numbers of 1, 2, 3,... This approach evaluates which indicator(s) are most predictive of overall soil health and are most suitable to be included in an abridged and less costly soil health assessment (Fine et al., 2017). It is recognized that the predictor variables are also used to generate the overall SH score and the evaluation is therefore restricted to small subsets (4 or less).

Maps were prepared using QGIS version 2.14.3 (http://qgis.org/en/site/ using the WGS 84 coordinate reference system and Bing Satellite imagery as a background on 94 project layers, with each indicator layer displaying an aggregated value, uncultivated, upland, middle, and lowland layer of data, as well as layers including, country, state and district boundaries, catchment number. (Fig. 5, supplementary material). Political boundaries were obtained as ESRI Shapefiles from ("Global Administrative Areas,") found at www://gadm.org, version 2.8 (November 2015) .

4. Results and discussion

4.1. *Overall*

The 113 surface soils are generally high in sand content (mean of 53%; Table

6) and dominant textural classes are sandy loam (37.2%) and loam (18.6%), in accordance with expectation for soils derived from felsic rock. The mean and standard deviation values for physical indicators (sand, silt, clay, AgStab, AWC) and biological indicators (OM, actC, Resp) are similar for each of the landscape positions (uncultivated, upland, middle and lowland) with Prot showing variance in uncultivated landscape position, but high standard deviations indicate considerable variation among landscape positions. This pattern is also observed for pH, K, Mg, Fe, Mn, and Zn. Conversely, higher differences were observed among landscape positions for P, Table 7, which may be related to variable manure deposition by roaming animals, compost application, and retention of crop residues.

Table 6, Mean, standard deviations, median, inter quartile range and grouping of soil health indicators measured from 29 catchments and four landscape positions.

	Aggregated[1to4]				Un-cultivated[1]					Upland[2]					Middle[3]					Lowland[4]				
Indicator	Mean	Std dev	Median	IQR	Mean		Std dev	Median	IQR	Mean		Std dev	Median	IQR	Mean		Std dev	Median	IQR	Mean		Std dev	Median	IQR
Sand (%)	53.00	21.85	54.51	29.89	55.66	a	15.63	57.36	19.48	55.67	a	20.13	56.20	27.11	51.97	a	22.02	50.23	31.59	49.19	a	27.51	50.38	47.76
Silt (%)	28.70	15.29	26.55	19.98	26.24	a	11.20	26.31	12.62	27.21	a	14.04	23.81	19.31	29.04	a	15.49	30.00	20.37	31.90	a	18.99	27.13	30.72
Clay (%)	18.29	9.18	17.70	11.65	18.10	a	7.28	15.61	8.31	17.12	a	8.91	15.74	10.47	18.99	a	9.68	17.21	15.32	18.91	a	10.66	18.97	12.64
Agstab[a] (%)	17.02	12.36	13.94	14.15	21.70	a	16.53	18.50	22.10	15.71	a	10.42	12.29	13.23	15.16	a	9.42	11.77	12.80	15.75	a	11.54	10.42	12.53
AWC[b] (m3 /m-3)	0.20	0.05	0.19	0.07	0.19	a	0.05	0.19	0.06	0.19	a	0.06	0.19	0.08	0.20	a	0.05	0.21	0.05	0.20	a	0.05	0.20	0.07
OM[c] (g/kg-1)	1.79	0.84	1.72	1.07	2.01	a	0.74	1.99	1.18	1.62	a	0.88	1.41	0.80	1.87	a	0.96	1.93	1.04	1.67	a	0.74	1.75	1.21
actC[d] (mg/kg -1)	152.15	111.29	119.19	143.77	184.05	a	126.72	163.49	107.69	110.66	a	94.14	101.80	111.38	133.39	a	89.86	125.92	116.11	178.18	a	117.51	176.32	213.65
Prot[e] (mg/g)	2.17	1.09	1.89	1.06	2.88	b	1.42	2.49	1.04	1.99	a	0.77	1.85	0.89	1.96	a	0.81	1.91	1.02	1.91	a	0.99	1.80	0.97
Resp[f] (mg/g)	0.14	0.08	0.12	0.08	0.17	b	0.08	0.15	0.09	0.10	a	0.07	0.08	0.09	0.12	ab	0.06	0.10	0.10	0.16	ab	0.10	0.15	0.08
pH	5.83	0.75	5.97	1.10	5.85	a	0.67	5.89	0.45	5.60	a	0.67	5.52	0.94	5.86	a	0.76	5.82	0.90	6.00	a	0.85	6.04	1.49
P (ppm)	4.29	8.38	1.13	2.23	6.77	a	11.19	1.72	11.59	5.65	a	9.28	1.02	4.09	1.21	a	1.64	0.87	1.96	3.59	a	7.59	1.00	2.64
K (ppm)	93.77	136.27	66.57	58.86	158.18	b	261.27	93.11	86.57	74.49	ab	38.78	67.82	38.86	64.81	a	35.41	62.06	55.96	80.31	ab	51.92	66.67	58.48
Mg (ppm)	223.70	174.41	175.06	221.84	198.47	a	105.89	201.68	143.25	156.82	a	119.67	138.45	141.34	236.56	a	179.86	176.06	263.27	294.87	a	229.76	272.55	303.67
Fe (ppm)	243.22	260.54	175.44	106.73	173.77	a	94.57	152.17	83.80	182.11	a	110.54	149.34	98.97	233.87	ab	175.13	185.98	106.08	367.05	b	429.36	198.14	198.03
Mn(ppm)	145.99	101.98	136.24	154.31	165.07	a	100.06	152.13	95.76	147.56	a	95.26	149.69	159.34	154.36	a	120.06	139.23	227.87	120.65	a	91.83	109.75	131.51
Zn (ppm)	1.84	3.72	1.15	1.04	1.71	a	1.26	1.19	1.09	1.33	a	0.84	1.18	0.85	1.37	a	0.70	1.45	1.12	2.81	a	6.92	1.33	0.98

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

Table 7. ANOVA for Landscape positions with catchment as the random variable, and district. n=133

	District		**Landscape Position**		**Landscape position* District**	
Indicator	**df**	**p-value**	**df**	**p-value**	**df**	**p-value**
Sand	5	**0.0006747 *** **	3	0.89500	15	**0.005763 ** **
Silt	5	**0.005065 ** **	3	0.58970	15	**0.01801 ***
Clay	5	**0.0003156 *** **	3	0.96500	15	**0.02179 ***
Agstab[a]	5	0.07916	3	**0.03425 ***	15	0.15
AWC[b]	5	0.2321	3	0.71090	15	0.07999
OM[c]	5	**0.002783 ** **	3	**0.02645 ***	15	0.120865
actC[d]	5	**0.0005865 *** **	3	**0.01169 ***	15	0.10579
Prot[e]	5	0.07442	3	**0.0005572 *** **	15	**0.002341 ** **
Resp[f]	5	**0.01413 ***	3	**9.727e-06 *** **	15	0.4602
pH	5	**0.002171 ** **	3	0.20010	15	0.4934
P	5	0.3604	3	**0.0469 ***	15	0.41939
K	5	0.5156	3	**0.02852 ***	15	0.9614
Mg	5	**0.04185 ***	3	0.18920	15	**0.005009 ** **
Fe	5	0.1057	3	**0.006292 ** **	15	0.5735
Mn	5	**0.04005 ***	3	0.49120	15	0.4619
Zn	5	0.06973	3	0.23500	15	0.7668

Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 ' .', 0.1 ' '

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

4.2. *Variations among districts*

The six districts selected for sampling comprise an area of 34,362 km^2 stretching 300 km north to south and 250 km east to west and between 170 and 707 m above sea level. The variance in parent material and other soil forming factors such as altitude and climate suggest SH variations among districts.

A one-way ANOVA among districts (assuming random catchments) shows significance (α=0.05) for the inherent soil indicators sand, silt, and clay, suggesting regional variations in parent material (Table 7). These are primarily reflected in differences between the West Singhbhum district and the others, where the former has soils with lower sand contents and higher clay and silt contents. (Table 8) The textural differences are also associated with significant differences (Tukey HSD pairwise comparisons; α=0.05) for several other SH indicators, including OM, ActC, Resp, pH, Mg and Mn (Table 7). These finer textured soils in West Singhbhum presumably have stronger bonds with organic compounds that are able to hold higher levels of OM and ActC, the primary food source for soil microbes. The only other district-level SH differences were for Giridih, which was had significantly higher ActC than Gumla and higher pH than Ranchi.

Table 8 , Mean, standard deviations, median,interquartile range and grouping of soil health indicators measured from 6 districts.

	Bokaro			Giridih			Gumla			Hazaribagh			Ranchi			West Singhbhum		
Indicator	Mean		Std dev	Mean		Std dev	Mean		Std dev	Mean		Std dev	Mean		Std dev	Mean		Std dev
Sand (%)	65.90	b	17.51	64.59	b	16.85	52.89	ab	20.15	50.54	ab	18.70	50.71	ab	23.31	34.16	a	23.94
Silt (%)	20.31	a	12.17	20.73	a	11.60	26.13	ab	10.79	30.49	ab	14.73	31.50	ab	17.74	37.39	b	13.51
Clay (%)	13.79	a	6.97	14.68	a	8.15	20.98	ab	10.62	18.97	a	6.93	17.79	a	8.76	28.45	b	12.12
Agstab[a] (%)	13.84	a	9.67	11.29	a	5.93	21.19	a	15.34	15.63	a	11.09	19.31	a	12.71	20.62	a	14.88
AWC[b] (m3 /m-3)	0.19	a	0.04	0.19	a	0.04	0.18	a	0.04	0.19	a	0.05	0.19	a	0.07	0.23	a	0.05
OM[c] (g/kg-1)	1.64	a	0.88	1.44	a	0.87	1.60	a	0.72	1.83	a	0.64	1.71	a	0.75	2.63	b	1.08
actC[d] (mg/kg -1)	122.80	ab	56.77	190.08	b	114.67	77.06	a	53.82	145.37	ab	101.36	131.20	ab	121.62	228.22	b	143.28
Prot[e] (mg/g)	1.58	a	0.53	1.98	a	1.80	1.77	a	0.70	2.26	a	0.95	2.09	a	0.83	2.64	a	1.52
Resp[f] (mg/g)	0.11	ab	0.06	0.11	ab	0.08	0.10	a	0.06	0.17	b	0.09	0.13	ab	0.08	0.16	ab	0.06
pH	6.00	ab	0.62	6.37	b	0.69	5.79	ab	0.74	6.06	ab	0.86	5.60	a	0.63	6.48	b	0.75
P (ppm)	2.31	a	4.42	5.56	a	12.20	2.60	a	3.66	3.16	a	6.47	6.34	a	10.36	2.74	a	5.99
K (ppm)	54.13	ab	26.80	91.20	a	79.40	86.43	a	56.65	116.57	a	227.64	69.25	a	53.44	120.29	a	57.63
Mg (ppm)	228.57	ab	154.80	249.86	ab	151.00	202.13	a	191.65	231.49	ab	167.43	183.78	a	156.56	386.68	b	277.59
Fe (ppm)	161.44	a	79.74	183.32	a	55.26	214.69	a	242.65	343.54	a	404.55	226.67	a	155.43	191.80	a	62.95
Mn(ppm)	162.64	ab	105.27	165.02	ab	125.07	121.27	a	78.43	137.59	ab	93.45	122.35	a	87.76	224.20	b	127.23
Zn (ppm)	1.41	a	0.73	1.56	a	1.02	0.87	a	0.41	1.58	a	1.11	1.49	a	1.26	1.72	a	0.82

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

4.3. *Variations among landscape positions*

A one-way ANOVA among landscape positions (assuming random catchments) did not show significant effects (α=0.05) for sand, silt, and clay (Table 7), in part due to high variability in sand contents among districts (Table 8) There is a slight trend, however, for lower sand contents and higher silt contents from upland to lowland positions, suggesting effects of erosion and deposition (Table 6) (Fig. 11 supplementary data).

Landscape position effects were significant (α=0.05) for Agstab and the biologically aligned indicators OM, actC, Prot, Resp, and the chemical indicators P, K, and Fe (Table 7). In TukeyHSD pairwise comparisons soil health indicators primarily showed significant landscape position effects as it relates to anthropogenic disturbance (i.e., uncultivated vs. the cultivated upland, middle, lowland for Prot; uncultivated vs. upland for Resp; and uncultivated vs. middle for K; (Table 9).

Table 9, TukeyHSD landscape position pairwise comparisons

Indicator	landscape position	p-value, adjusted	
Protein	**Uncultivated**>Lowland	**0.0084638**	**
	Uncultivated> Middle	**0.0325279**	*
	Uncultivated>Upland	**0.006946**	**
Respiration	**Uncultivated**>Upland	**0.0038461**	**
K	**Uncultivated**>Middle	**0.0477775**	*
Fe	**Lowland**>Uncultivated	**0.0130224**	*
	Lowland>Upland	**0.0106035**	*

Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 ' . ', 0.1 ' '

These show the uncultivated lands with the highest indicator mean values, and suggest that the primary and dominant management disturbances of tillage, (or lack of), nutrient management and low above ground biomass diversity have influence on the below-ground biological functions.

It was anticipated that the long-term management impacts of tillage, application (or not) of crop nutrients and soil amendments, crop rotations, profile inversion through terracing and bunding for rice paddy systems, and its interaction with changes in seasonal soil wetness (especially in the upland vs. lowland comparisons) would result in more significant variability in the dynamic SH indicators. Our results suggest that such patterns are present in some cases, but high variability among landscape position or (unknown) field-specific management practices prevent statistically significant effects. For example, soil P contents are strongly influenced by animal manure or compost applications. These are either collected from penned animals and unevenly spread on cropped fields or deposited by free grazing animals, resulting in patches of high and low concentrations within fields. In our study, 21% of sample values tested with undetectable amounts of P, while overall mean and standard deviation were 4.29 and 8.38 ppm, respectively (Table 6; Table. 7). Higher K contents between uncultivated and cultivated areas could be due to K mining, with the removal of straw and crop residues for off-site fodder.

Only Fe was related to landscape position in that the middle and lowland areas had higher values than upland and uncultivated, presumably associated with variations in the redox regime (Table 6), i.e., longer anaerobic periods leading to higher Fe solubility (Havlin et al., 2005).

The highest and lowest measured mean indicator values according to landscape position (Table 10 shows that uncultivated positions generally measured the highest values for Agstab, all biological indicators (OM, actC, Prot, Resp.) and macronutrients (P and K), with lowland areas showing highest values for pH, Mg, Fe, and Zn, as well as clay, silt, and AWC, presumably due to the depositional effects and low redox environments.

Table 10, Highest and lowest mean indicator values according to landscape positions

Landscape position	Uncultivated		Upland		Middle		lowland	
Indicator	Highest	lowest	Highest	lowest	Highest	lowest	Highest	lowest
Sand (%)			85.31					5.69
Silt (%)		8.28					70.1	
Clay (%)		5.32			39.8			
Agstab[a] (%)	58.61					5.72		
AWC[b] (m^3/m^{-3})				0.07	0.32			
OM[c] (g/kg^{-1})	4.01			0.24				
actC[d] (mg/kg^{-1})	498.75			2.48				
Prot[e] (mg/g)	8.1							0.24
Resp[f] (mg/g)	0.34			0.02				
pH				4.57			7.74	
P (ppm)	47.62					0		
K (ppm)	1406.4					19.12		
Mg (ppm)				20.08			1070.8	
Fe (ppm)		68.05					1927.8	
Mn(ppm)	414.4							2
Zn (ppm)				0.48			39.6	

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

4.4. *Interactions*

Significant interactions between districts and landscape positions suggest that effects of cultivation or position in the catchment are variable among the districts. This appeared primarily the case for the textural separates (sand, silt, clay; Table 8), presumably influenced by the difference between West Singhbhum and other districts. Otherwise, only Prot and Mg showed significant interactions, with the latter presumably influenced by outlier values.

4.5. *Least square means*

SH indicators and district least square means show minimal grouping (Fig.14 supplementary data), with management effected dynamic indicators of wet aggregate stability, available water capacity, organic matter, and protein having single grouping due to many years of comparable management impacts along with P, K, Fe, and Zn having a single grouping, and the inherent textural indicators showing more variance with two groupings.

4.6. *Soil health interpretations*

The CND indicator scores for the physical and biological indicators according to landscape position color coded for ease of reading with red indicating low scores yellow indicating medium and green high (Fig 1, Table 11), show Uncultivated positions with generally high scores for all indicators except AWC, these high scores reflect the reduced effects of agricultural management such as tillage, nutrient mining, and monocropping on physical soil structure and the consequential biological indicators. Upland biological indicator scores are lowest followed by middle and then lowland scores, possibly due to increased crop and root residues found in terraced paddy fields. The middle and lowlands show increased levels of

OM and actC, probably due to crop and root residue that also positively influences AWC and biological community respiration.

General comparisons of nutrient values with Mehlich III extractions (Havlin et al., 2005; (Table 11) indicate very low P values for all landscape positions, low K values apart from Uncultivated land that has a high value indicating that in the cropped area significant extraction with little or no replacement through fertilizer application. Micro nutrient levels all indicate very high levels. Soil respiration mean values are a prime indicator of biological activity in soils (Moebius-Clune et al., 2016) and comparisons from various landscape positions from Arunachal Pradesh, India (Arunachalam et al.,) show values 3.6 times higher than the sampled Jharkhand soil.

Table 11, Physical and biological indicators scored with CND, nutrients scored with sufficiency levels.

Indicator	scoring mechanism	Aggregated[1to4]	Un-cultivated[1]	Upland[2]	Middle[3]	Lowland[4]
Agstab[a] (%)	CND	0.468	0.563	0.480	0.421	0.414
AWC[b] (m3 /m	CND	0.480	0.439	0.466	0.514	0.498
OM[c] (g/kg-1)	CND	0.484	0.573	0.439	0.498	0.434
actC[d] (mg/kg ·	CND	0.443	0.504	0.337	0.416	0.509
Prot[e] (mg/g)	CND	0.443	0.574	0.387	0.426	0.394
Resp[f] (mg/g)	CND	0.454	0.575	0.347	0.409	0.485
pH		5.977	5.891	5.878	5.928	6.187
P (ppm)	Sufficiency	4.290	6.770	5.650	1.210	3.590
K (ppm)	Sufficiency	93.770	158.180	74.490	64.810	80.310
Mg (ppm)	Sufficiency	223.700	198.470	156.820	236.560	294.870
Fe (ppm)	Sufficiency	243.220	173.770	182.110	233.870	367.050
Mn(ppm)	Sufficiency	145.990	165.070	147.560	154.360	120.650
Zn (ppm)	Sufficiency	1.840	1.710	1.330	1.370	2.810

CND = Cumulative Normal Distribution

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

Sufficiency levels	P (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	Zn(ppm)	Mn(ppm)
V low	<7	<40	<8			
low	8 to 14	41 to 80	8 to 16	0 to 2.5	0 to 0.5	<1
med	15to28	81 to 120	17 to 24	2.6 to 4.5	0.6 to 1.0	
high	29to50	121 to 160	25 to 32	> 4.5	>1	>1
V high	>50	>160	>32			

4.7. *Correlations*

Pearson correlations values >0.50 between physical, biological and chemical indicators (Table 12) show most indicators negatively correlated with sand and positively with silt and clay, as expected and compared with Fine et al 2017 who assesses the USA focused CASH data base looking generally at the corn soya growing regions of the north east and Midwest. Biological indicators (OM, actC, Prot, and Resp) show correlation coefficients between 0.47 and 0.64, suggesting that biological processes tend to be jointly enhanced, but individually may still be differently expressed, the CASH trends are broader and higher with correlation coefficients between 0.027 and 0.78. Zn showed strong correlations with all biological indicators (OM, ActC, Prot, Resp) which can be explained by chelation and possible effects of outliers. Mg is strongly correlated with clay and pH. and respiration with zinc.

Table 12, Correlation data for Soil Health indicators

	sand	silt	clay	agstab	AWC	OM	actC	prot	resp	pH	P	K	Mg	Fe	Mn	Zn
sand	**-1.00**															
silt	**-0.93**	**1.00**														
clay	**-0.83**	**0.57**	**1.00**													
agstab	-0.14	0.02	0.35	**1.00**												
AWC	**-0.76**	**0.77**	**0.53**	-0.15	**1.00**											
OM	**-0.77**	**0.67**	**0.72**	0.11	**0.75**	**1.00**										
actC	-0.33	0.36	0.20	-0.20	0.47	0.47	**1.00**									
prot	-0.38	0.45	0.15	-0.09	0.49	**0.56**	**0.59**	**1.00**								
resp	-0.39	0.43	0.21	0.15	0.43	**0.52**	**0.52**	**0.64**	**1.00**							
pH	-0.20	0.10	0.29	0.01	0.18	0.21	0.32	-0.02	0.23	**1.00**						
P	0.05	-0.04	0.19	-0.14	-0.01	0.02	0.20	0.29	0.21	-0.03	**1.00**					
K	-0.17	0.15	0.15	0.00	0.05	0.18	0.23	0.26	0.33	0.10	0.27	**1.00**				
Mg	**-0.52**	0.35	**0.65**	0.21	0.47	**0.53**	0.27	0.01	0.19	**0.59**	-0.17	0.12	**1.00**			
Fe	-0.24	0.35	0.00	-0.20	0.28	0.18	0.35	0.31	0.45	-0.04	0.06	-0.01	-0.03	**1.00**		
Mn	-0.24	0.19	0.26	-0.03	0.26	0.35	0.19	0.29	0.08	0.28	-0.06	0.08	0.27	-0.12	**1.00**	
Zn	-0.33	0.42	0.09	-0.16	0.48	0.49	**0.53**	0.52	**0.60**	0.15	0.46	0.17	0.19	**0.51**	0.19	**1.00**

Abbreviations: agstab(Wet Aggregate Stability), AWC (Avaliable Water Capacity), OM (Organic Matter), actC (Active Carbon), prot (ACE protein Index), resp (Soil Respiration), P (Phosphorus), K (Potassium), Mg (Magnesium), Fe (Iron), Mn (Manganese), Zn (Z

Table 16, (a) (b) (c) "Heat bars" (supplementary data) offer a visual correlation of n=116 SH indicators, it demonstrates the broad correlation of overall SH (indicated by the correlation of high/green scores) with selected indicators OM (sorted from low to high scoring) then active carbon and then contrasted with high levels of sand indicating low SH scores.

4.8. *Surface vs. subsurface soil health*

Samples from surface (0-to-15 cm) and subsurface (15-to-30 cm) soil on average had similar textures (Table 13) (Fig.12 supplementary data). Biological indicators were higher for the surface horizon, with significant effects for actC, Prot, and Resp, but OM contents were relatively similar. Notably, ActC levels averaged 2.23 times higher, while the OM content was only 1.10 times higher, suggesting that organic matter in the surface layer is biologically more active. In terms of nutrients, extractable P contents were 2.6 times higher in the surface horizon that the subsurface, presumably due to manure and compost additions. Other nutrients contents were similar among the layers. Zn had higher values in the 0 to 15 cm layer mostly associated with outlier values that could be related to localized depositions. AWC was slightly higher in the subsurface, presumably associated with somewhat higher silt contents. Soil strength indicated by penetrometer resistance, separated into 10 to 20 cm depth and 30 to 40 cm depth due to calibration of the tool. With 30 to 40 cm depth soil resistance increasing by nearly 22%, this could be due to a tillage induced compaction layer or reduced moisture at lower soil depth from the layer of compaction.

Table 13, Welch two sample t-test, 0 to 15 and 30 to 40 cm depth

				Means		
Indicator	df	p-value		0 to 15cm	30 to 40cm	% variance
Sand (%)	27	0.9205		53.00	53.51	0.95%
Silt (%)	34	0.1800		28.70	24.80	-13.61%
Clay (%)	24	0.1909		18.29	21.70	18.59%
Soil Strength [g] (kpa)	343	**0.000352**	***	1470.29	1791.81	21.87%
Agstab [a] (%)	26	0.7119		17.02	18.17	6.74%
AWC [b] (m3 /m-3)	25	**0.0428**	*	0.20	0.17	-14.05%
OM [c] (g/kg-1)	28	0.3953		1.79	1.63	-9.00%
actC [d] (mg/kg -1)	68	**2.45E-07**	***	152.15	68.56	-54.94%
Prot [e] (mg/g)	44	**0.00001945**	***	2.17	1.35	-37.85%
Resp [f] (mg/g)	69	**0.0035**	**	0.14	0.11	-23.66%
pH	25	0.1086		5.93	6.26	5.70%
P (ppm)	125	**0.0016**	**	4.29	1.65	-61.53%
K (ppm)	86	0.1736		93.77	71.08	-24.20%
Mg (ppm)	23	0.3497		223.70	275.12	22.99%
Fe (ppm)	31	0.5897		243.22	214.92	-11.64%
Mn(ppm)	26	0.8584		145.99	141.59	-3.01%
Zn (ppm)	127	**0.0068**	**	1.84	0.83	-54.69%

Significance codes:0 '***', 0.001 '**', 0.01 '*', 0.05 ' . ', 0.1 ' '

[a] Agstab = wet aggregate stability

[b] AWC = available water capacity

[c] OM = Total Organic matter by loss on ignition at 500 °C

[d] actC = permanganate –oxidizable, biologically active carbon

[e] Prot = Citrate buffer extracted Soil Protein.

[f] Resp = Soil respiration measure of CO_2 in rewetted soils.

[g] Soil Strength = 10 to 20 cm and 30 to 40 cm depth

4.9. Soil Strength

Penetrometer data from 479 points were separated into landscape positions. Of these data values, 97, or 20.2% reached ≥ 3500 kilopascals (kPa) the maximum output of the penetrometer (Fig. 8). These maximum values are disproportionately spread among landscape positions, with 17 in the uncultivated, 33 in upland, 22 in middle and 25 in lowland. Linear regressions show that depth is a significant factor for penetration resistance reaching 3500 kPa, with each 10cm increase in depth increasing the count of ≥ 3500 kPa by 0.111. No significance was found in regression analysis between soil strength ≥ 3500 kPa and landscape position, nor any interaction between landscape position and depth. These maximum value data points (≥ 3500 kPa) were therefore removed before plotting (Fig. 8).

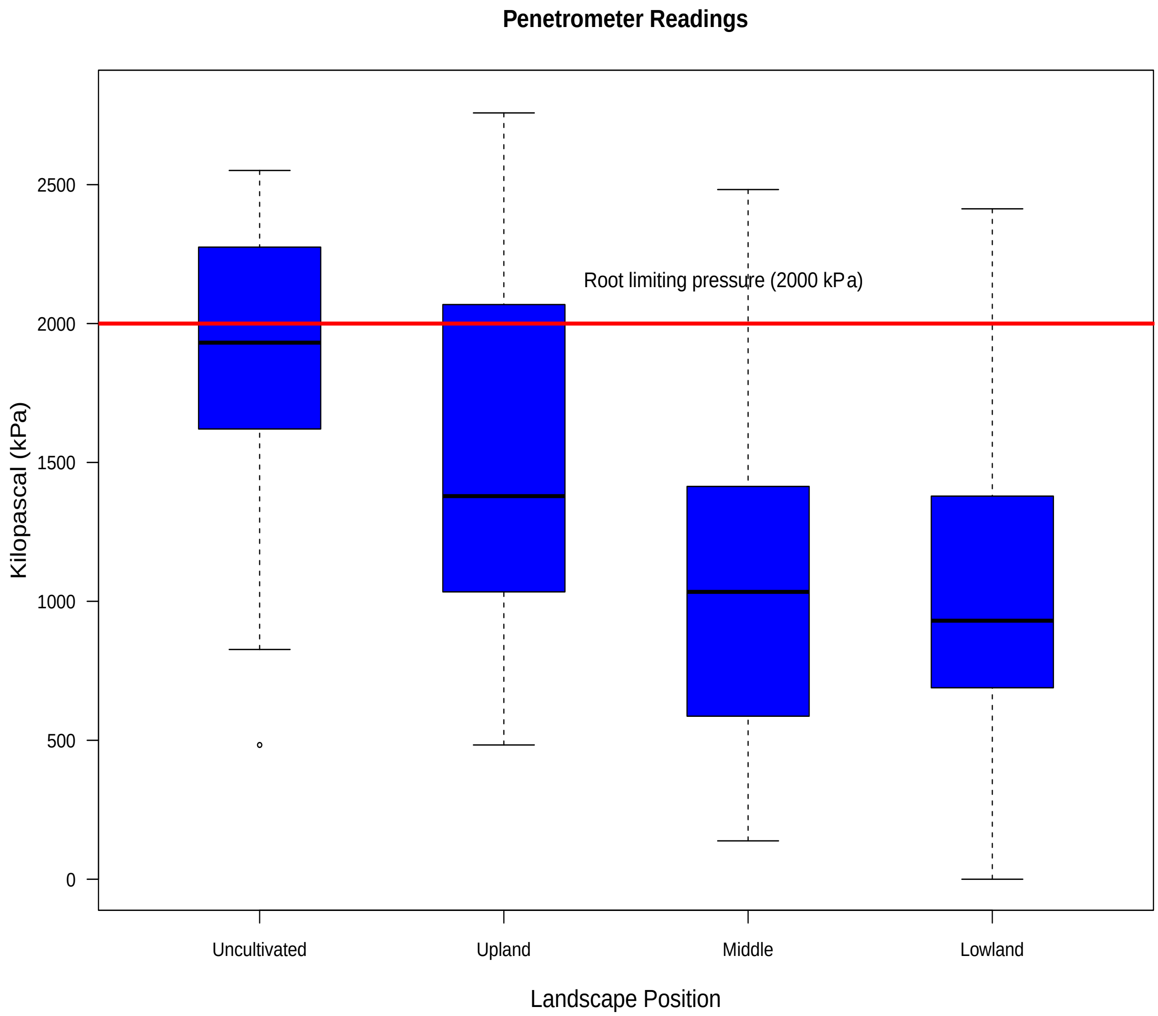


Figure 8. Penetrometer reading according to landscape position

Penetrometer readings were taken subsequent to the start of the *Kharif* summer monsoons when many of the lower lying bunded terraced landscape positions, middle and lowland, were very wet as compared to the non-bunded or terraced dryer upland and uncultivated landscape positions. This is reflected in lower landscape positions having lower mean values compared to higher landscape positions. Field preparation for paddy production was in progress when measurements were made in the middle and lowland sites, resulting in lower surface readings with higher subsurface readings indicating the deliberate lower dense layer for paddy rice cultivation.

Retaining the maximum value data points of ($\geq$ 3500 kPa) for comparison of mean pressure values between landscape position and depth shows that there is an increase in mean pressure for all landscape positions from the upper to the lower 30 to 40 cm depths, 24% for uncultivated, 24% for upland, 45% for middle and 26% for lowland landscape positions, these increases indicate a shallow layer of compaction probably cause by tillage, or reduced soil moisture in the non terraced landscape positions.

4.10. *Principal Component Analysis.*

The first 5 principal components of the 16 transformed and standardized soil properties explained a combined 82% of the total variance (Table 14) (Fig. 13 supplementary data) as compared to 6 PC's and 74% explained variance with Fine et al 2017 and the CASH data base. PC1 explained 40% of the variance with strong positive loading and correlation on AWC, biological indicators (OM, Prot, Resp) again comparably to Fine 2017, K, Zn and to a lesser extend other micro-nutrients. PC2 added 17% variance explanation, with positive loadings from pH, Mg, and Mn, and strong negative loadings from P and Fe, two indicators that have influential outliers. PC3 and PC4 added a combined 19% variance and showed limited directional loadings (Fig. 10). Overall, this analysis showed PC1 in the biological SH category and PC2 generally in the chemical or nutrient category. (Fig.9 Scree plot, supplementary data) indicate the importance of the first 4 principal components in the explanation of the variance.

Table 14, Eigenvectors from a principal component analysis of standardized and transformed SH attributes.

Proportion of Variance %	40%	17%	12%	7%	6%
Cumulative Proportion %	40%	57%	68%	76%	82%
Principal components	PC1	PC2	PC3	PC4	PC5
Eigenvectors					
Agstab[a] (%)	-0.0286	0.2033	**-0.6654**	0.1964	**-0.3876**
AWC[b] (m3 /m-3)	**0.3487**	-0.0306	0.1006	0.2458	**0.3734**
OM[c] (g/kg-1)	**0.3737**	0.0252	-0.1504	0.1583	0.1960
actC[d] (mg/kg -1)	0.2860	-0.0562	**0.3441**	-0.0701	**-0.3944**
Prot[e] (mg/g)	**0.3308**	-0.2285	-0.2202	-0.1872	0.1472
Resp[f] (mg/g)	**0.3148**	-0.1687	-0.2302	0.0897	**-0.4773**
pH	0.1658	**0.3821**	**0.4053**	-0.2744	**-0.3480**
P (ppm)	-0.0648	**-0.5084**	-0.0279	**-0.5472**	-0.0686
K (ppm)	**0.3191**	0.0788	-0.2739	**-0.3735**	0.0275
Mg (ppm)	0.2982	**0.3775**	0.1286	0.1663	-0.0512
Fe (ppm)	0.2069	**-0.4118**	0.1504	**0.4108**	0.0081
Mn(ppm)	0.2530	**0.3165**	-0.1312	**-0.3422**	**0.3585**
Zn (ppm)	**0.3440**	-0.2243	0.0903	-0.0124	-0.0954

[a] Agstab = wet aggregate stability
[b] AWC = available water capacity
[c] OM = Total Organic matter by loss on ignition at 500 °C
[d] actC = permanganate –oxidizable, biologically active carbon
[e] Prot = Citrate buffer extracted Soil Protein.
[f]Resp = Soil respiration measure of CO_2 in rewetted soils.

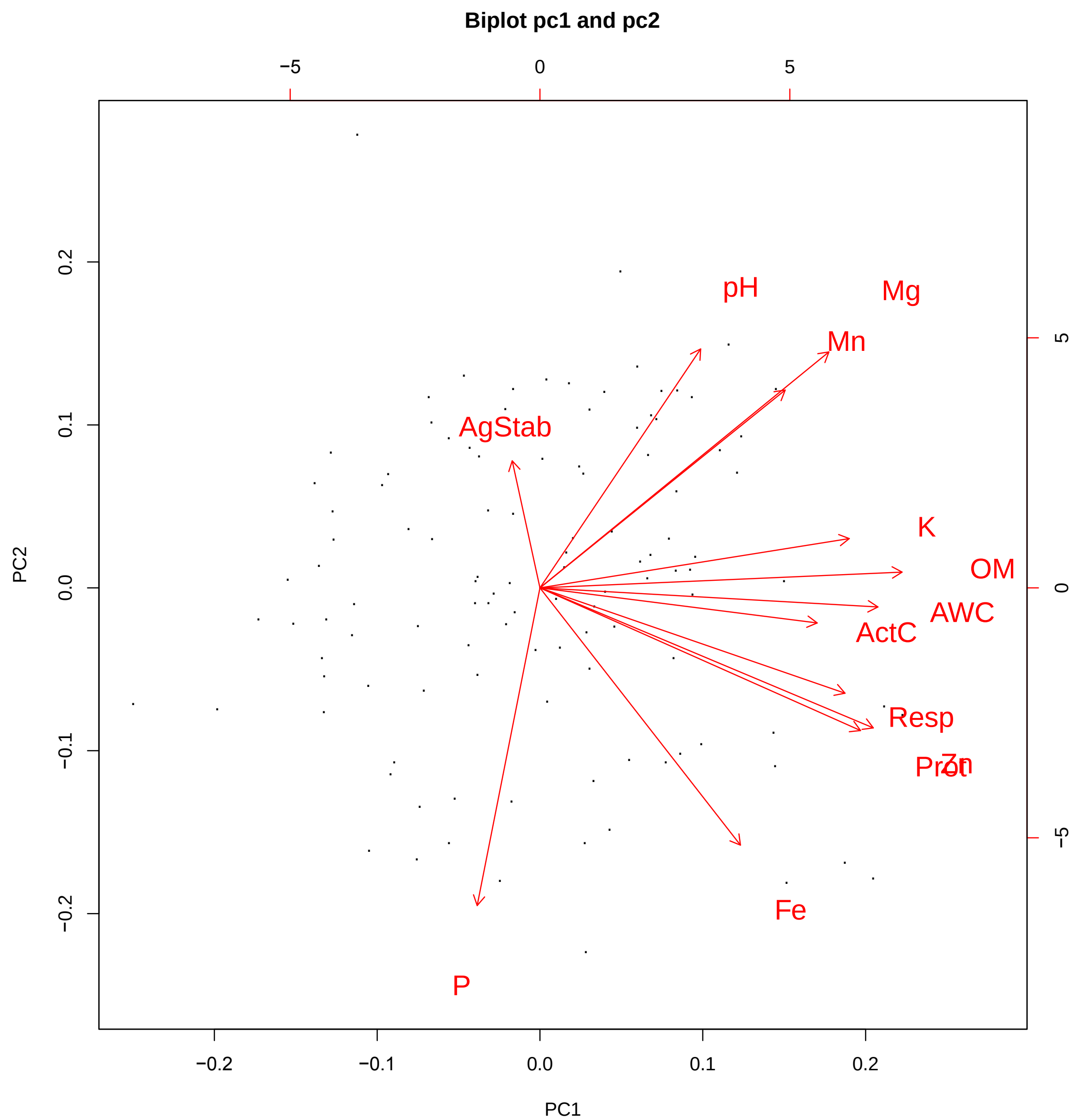


Figure 10. Biplots graphically show the directional loading of variables in PC1 to PC4

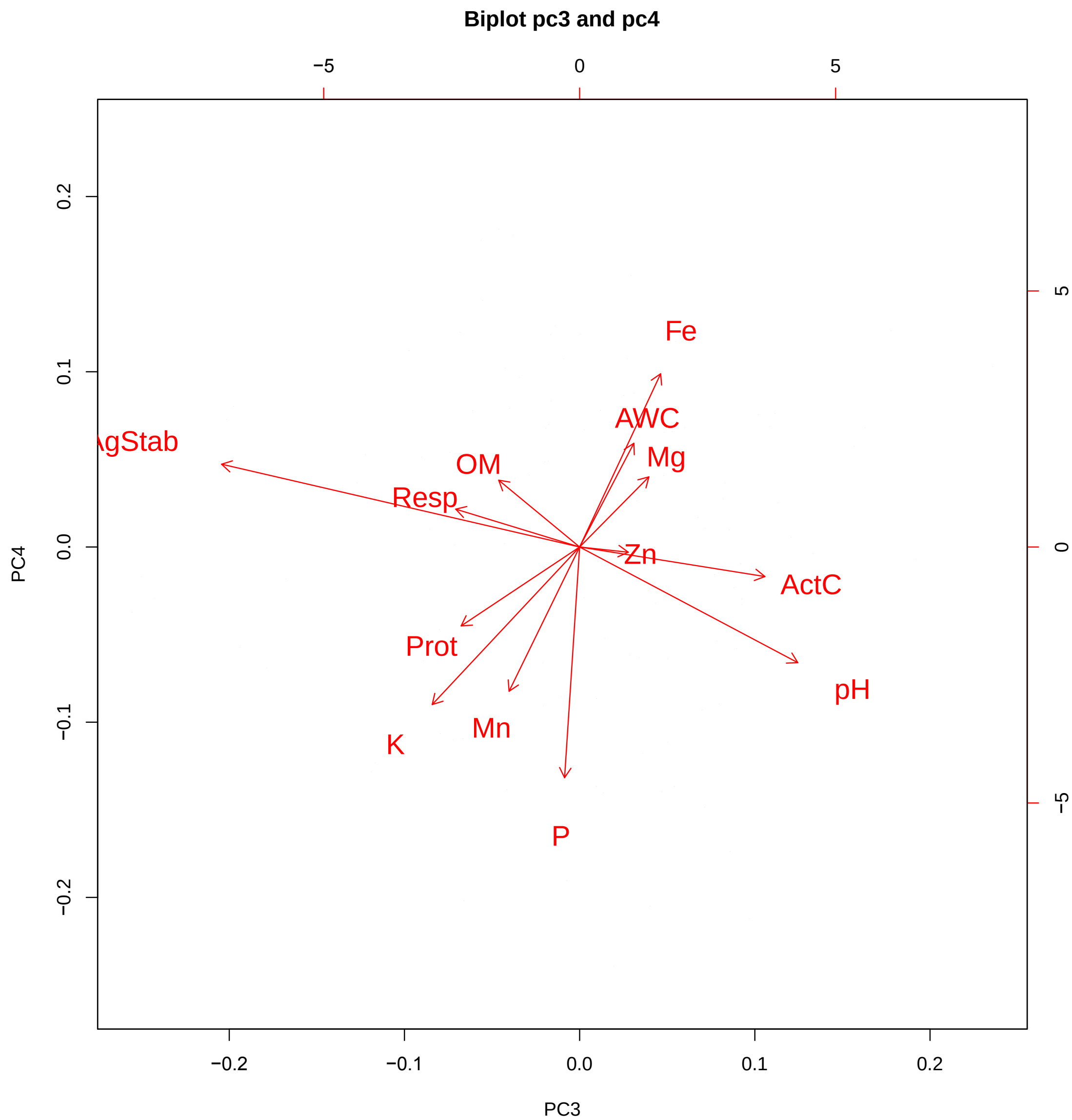


Figure 10. (continued) Biplots graphically show the directional loading of variables in PC1 to PC4.

4.11. *Best subsets*

The Best Subsets regression analysis allows for the evaluation of the relative predictability of overall soil health by subsets of individual indicators. When considering a single predictor, OM predicts two-thirds of the variability in overall soil health (R^2-adj = 68%; Table 15), indicating that the single measurement of OM offers considerable soil health information. Resp was second with R^2-adj = 0.55. Combined, OM and Resp explain 82% of the variability in soil health, similar to OM and actC (80%). OM, Resp, and actC combined have an R^2-adj of 87%. This suggests that a soil health test can be simplified by measuring a limited number of SH indicators at lower cost.

Table 15. Results of Best Subset Regression identifying the best-fitting regression models using Soil Health indicators as predictors (n = 133). Vars is the number of variables included in each model, R-sq (adj) is adjusted coefficient of determination.

Vars	R-sq(adj)	agstab	AWC	OM	actC	prot	resp	pH	P	K	Mg	Fe	Mn	Zn
1	0.68			*										
1	0.55						*							
2	0.82			*			*							
2	0.80			*	*									
3	0.87			*	*		*							
3	0.87			*			*						*	
4	0.92			*	*		*						*	
4	0.90			*	*		*				*			

Abbreviations: agstab(Wet Aggregate Stability), AWC (Avaliable Water Capacity), OM (Organic Matter), actC (Active Carbon), prot (ACE protein Index), resp (Soil Respiration), P (Phosphorus), K (Potassium), Mg (Magnesium), Fe (Iron), Mn (Manganese), Zn (Z

5. Conclusion

Soil health degradation is often the result of poor farmer resource management such as nutrient mining, removal of biomass, aggressive tillage, and monocropping. Therefore, a holistic approach to a comprehensive assessment needs to be adopted beyond nutrient management. Results indicate the degradative effects in the dynamic, management influenced, agronomically important soil functions, used by the CASH framework to indicate soil health, with district wise ANOVA indicating the effects of inherent textural indicators, with finer textured soils in West Singhbhum district having enhanced dynamic indicator's, OM, active carbon, Mg, and Mn.

The within-catchment focused assessment of landscape position, statistically significant differences between mean values indicated less managed, uncultivated lands having quantifiably higher soil health values in the dynamic biological indicators of respiration and protein, than the remaining management impacted seasonally cultivated upland, terraced and puddled rice-fallow middle and lowlands.

The effects of aggressive tillage and management, evident in the statistically significant variance between surface (0 to 15cm) and subsurface (30 to 40cm) soil horizons, with the subsurface tillage induced compaction layer in paddy tilled middle and lowlands significantly reducing available water holding capacity, active carbon the primary food source of soil microbes resulting in reduced biological activity signaled by protein and respiration levels, as well as reduced phosphate and zinc. Soil strength increased by an average of 25% between surface and subsurface in all landscape positions except for middle lands where an increase in 45% was measured. This shows the added effects of seasonal drying of puddled soils.

Where management has not been applied, statistically significant, beneficial variance is found in dynamic biological indicators and generally, where increased management had been applied, this variability has been reduced. Measurement of overall SH with reduced resources as indicated by PCA and best subsets regression, could be focused on three dynamic indicators that offer an 87% coefficient of determination of soil health in terms of OM, active carbon, and respiration.

This study presents data on the overall SH of representative sites in Jharkhand India, an area characterized by small subsistence farmers. In order to increase resource utilization and resource intensification, the assessment of SH must be related to yield outcomes. Without an obvious outcome in yield benefit, any programs endeavoring to influence SH will be rejected. The probability of increased yield response to simply improved nutrient management is highly probable, however to achieve optimum response to nutrient management, attention to biological and the other dynamic agronomically important indicators need to be simultaneously pursued, therefore future researchable issues could include:

Nutrient response trials to demonstrate the positive yield and over all SH score response of appropriate nutrient application due to the extractive nature of prior management.

Tillage trials to demonstrate the benefit of less aggressive tillage on soil aggregates, reduced surface and subsurface layers of compaction, an increased rooting depth, moisture availability and nutrient extraction zone via permanent beds, deep tillage to reduce and remove the compaction layer, or non mechanical deep rooting regionally appropriate cover crops.

Crop rotations and *cover crops* to develop diverse and stable soil biology

OM and carbon sequestration, through retention of crop residues and rotational grazing of animals, to allow accumulation of manures.

Micro-dosing of scarce nutrients and bio amendments into permanent placement plots to allow for annual accumulation of accurate repeated placement. This could then lead into the development of appropriate scoring curves based on local conditions, cropping system and optimum yield response.

The goal is to holistically remediate SH to attain optimum yield response, an intensification of resource management, improved nutrition and the sustainability of soil resources.

6. Future focus for remediation.

The degradation of our soils has, in the most part, been ongoing for many years, and to expect a remediation strategy to shows immediate results is imprudent, as SH improvement will generally take time. When seeking appropriate management options, there are invariably more than one opportunity and multiple combinations, i.e. reduced tillage with cover crops during the non traditional cropping season to capture nitrogen or provide “bio pores” from deep penetrating roots to allow rapid water infiltration and penetration of subsoil compaction layer from long term moldboard plowing. This example indicates that the considered combination of various options will be more effective when taken in context with the economic and other circumstances that are found, remembering that not all suggestions are for every farm, or farming system. With the economic bottom line very important, it is no use “being green when you are in the red”; yet, improved soil health should result in higher yield quality quantity and stability, showing increased resilience during climate shocks.

General approaches to SH noted in (Magdoff and van Es, 2000) include some of the following:

Reducing tillage to retain biological activity and organic matter near the surface, maintain soil structure facilitating rapid water infiltration and storage.

Reducing surface and subsurface compaction, to enhance root penetration, water infiltration, and soil structure.

Growing cover crops to capture residual nutrients, prevent erosion, sequester carbon in plant roots, increase biological diversity, keep the soil covered, provide seasonal forage crops.

Using better crop rotations to enhance nitrogen fixation through legumes, reduce mono-cropping disease pressure with non-host crops, alternating organic matter residues to build microbial diversity.

Applying organic amendments such as manures and composts to enhance labile and stable carbon stores. The "living dead and very dead" carbon sources.

Applying inorganic amendments such as lime and fertilizers, to rapidly correct crop specific nutrient imbalances and deficiencies.

The measurement and management of SH over time, will support farmer production to and from sufficiency to surplus to profit, encouraging diet diversity and nutrition enhancement. It will also enhance the evaluation of practices revealing the SH trend and effectiveness of the management options employed and allow appropriate changes to enhance effectiveness summarized as follows;

> *"Whatever crops you grow, when you creatively combine a reasonable number of practices that promote high-quality soils, most of your farms soil health problems should be solved along the way, and the yield of your crops should*

improve. The soil will have more available nutrients, more water for plants to use and better tilth. There should be fewer problems with diseases, nematodes, and insects, all resulting in reduced use of expensive inputs. By concentrating on the practices that build high-quality soils, you will leave a legacy of land stewardship for your children and their children to inherit and follow" (Magdoff and van Es, 2000).

Sanchez and Swaminathan (2005) note that the green revolution of India, initiated with high yielding varieties of wheat and rice, was supported by increased use of crop inputs, irrigation and enabling government policies. Recalling the US agricultural innovative approaches experience (Lal, 2001) adds:

"In the past 50 years, the number of people fed by a single farmer has increased from 19 to 129 through adoption of recommended agricultural practices. Such practices include, use of conservation tillage, growing cover crops, using biosolids and amendments, enhancing soil fertility through the judicial use of fertilizers and adopting precision farming, water conservation and improving methods of irrigation and use of improved genetics and varieties."

6.1. *Results indicate*

The *between district* view indicated the inherent textural factors are highly significant and influential on the dynamic biological and nutrient indicators (Table 2). Remediation options that affect the scope of districts include a focus on preventing erosion of the generally finer textured topsoil. This will, over time, improve sustainability, enhance soil health, increase resource utilization and ultimately the development of the vulnerable farming community.

The *between catchment* least mean squares assessments, not considered for the thesis, as catchments are the random variable, showed little variability in all the dynamic indicators presenting one or two groupings apart from Zn with 4 groupings.

Within catchment assessment, looking at variation *between the four landscape positions* (Table 2) reveals that dynamic indicators in uncultivated landscape positions have very significant variance and higher SH scores showing the deleterious effects of management. The influential management options probably include, paddy tillage, lack of organic matter management, nutrient extraction without replacement that all affect the biological stability and diversity. In the same way, within the four landscape positions is the *surface*, *subsurface* comparisons, (Table 8) that show significant variance in physical, biological, and nutrient indicators, with the primary influence being paddy tillage for traditional rice cultivation.

This millennia applied production system (paddy rice) reduces the spatial options for second or other/cover crop production. More effective rice production, on perennially wet lowlands with post-rice-harvest second crop options for use of residual moisture and increased resource utilization would be of economic and nutritional benefit. Crops could include, legumes for nitrogen fixation, or mixed crops for food, fodder, and OM, the prime indicator of soil health (Table 10), recycling and incorporation of crop residues would additionally enhance biological stability and diversity.

In addition to, and in conjunction with reducing traditional paddy rice production to smaller and specific perennially wet landscape positions, could be the cultivation of direct seeded rice (DSR) in, non puddled, seasonally moist middle and uplands, with post-rice-harvest secondary crop production on residual moisture, offering economic benefit as well as enhanced human nutrition through SH enhancing cover crops, inter-seeded with food crops that are harvested prior to targeted grazing or incorporation.

Additional remediation appropriate for resource poor farmers could include chemical/nutrient intervention, specific crop rotations including winter fodder crops to “move carbon back to it source” in the landscape position, increased aboveground and below ground biodiversity for bio-stability and increased control of soil borne diseases, deep tillage (organic and mechanical) for compaction remediation.

Permanent station/beds with micro dosing of limited farm yard manure/compost and other plant nutrients including lime allowing for maximum resource utilization with incremental temporal and spatial build up of residual amendments applied. This is in contrast to the broadcasting of amendments that reduces the efficiency of the scarce resource. Retention of crop residues including roots will improve macro-pores enabling increased water infiltration and buildup of carbon. Reduced tillage positively affects multiple factors such as soil aggregation, compaction, reducing time and energy constraints that enable multiple cropping per season.

The combination of all of these things will lead to the development of a regional appropriate score curve based on yield response.

6.2.*Lab in a box*

The PCA and best subsets regression (Table 14 and 15) indicate that the focus of a rapid assessment tool, or "lab in a box", for simple, quick, appropriately accurate and cost effective indicator tests for farmers, could be on three dynamic indicators that offer an 87% coefficient of determination of soil health in terms of OM, active carbon, and respiration. The Soil Doc, is a self contained lab in a box, developed in conjunction with Alliance for a green revolution in Africa (AGRA) and Columbia University, with the aid of battery powered miniaturized equipment measures various soil health indicators that include soil pH, active carbon, electrical conductivity, and macro-nutrients (nitrate-N, sulfate-S, phosphate-P, and potassium-K). The kit also includes tools to measure soil physical properties such as a penetrometer for surface sealing strength and compaction, and filters to assess wet aggregate stability. These rapid in-field assessments of key soil processes can reveal constraints directly to the farmer.

6.3. *Collaboration*

Many of the remediation options indicated in section 6 have or are currently being further developed by PRADAN, the BIRSA Agricultural University in Ranchi or the Borlaug Institute of South Asia who have centers in Ludhiana, Punjab, Jabalpur, Madhya Pradesh, and Pusa, Bihar. Their links and continued collaboration with farmers and other stakeholders will ensure that the research and trials are not set in theory alone.

6.4. *Micro-farming*

Farmer based trials incorporating diverse remediation options can be combined into micro-farming, a system that considers the remediation of SH in conjunction with equally important development issues of gender upliftment, food security, nutrition, agricultural intensification, and increase productivity in staple food production for vulnerable communities. Micro-farming comprises three interdependent principles of **Micro-size**, **Micro-dosing**, **and Micro-management.**

6.4.1. Micro-size

Micro-size is based on one of often competing explanations of the inverse farm size and productivity relationship, here assuming inherently greater efficiency of small farms (Barrett, 1996) for the focus of primary staple food production. The key principle is to ensure that the area cultivated is well within the physical means of the family unit to cultivate and manage throughout the duration of the season, hence preventing excess drudgery but ensuring all activities are performed to a high level, whilst offering time and energy for other important family activities.

Utilizing a permanent position/planting station offers temporal incremental benefit from each management operation such as, tillage (Two wheel tractor, Four Wheel tractor, or hand, (animal draft is not encouraged due to inconsistency of precision)), planting, pest management (IPM), weed control, mulching and supplementary irrigation.

6.4.2. Micro-dose

Micro-dosing with appropriately accurate applicators/measuring devices and nutrient, as opposed to broadcasting, ensures maximum resource utilization for resource poor farmers. Accurate, site specific (permanent station) placement of limited nutrients such as dolomitic lime and or gypsum, NPK blend, farm yard manure /compost in shallow trenches or planting station, determined on a crop by crop basis will over time accumulate residual nutrients, root residues, manure and other soil amendments.

6.4.3. Micro-management

Micro-management follows the precision agriculture principles noted in Lal 2001, which have enabled many developed worlds famers to feed more and more people per capita. Precise management requires that every planting station/plant is precisely considered and managed. Pre-plant tillage should be at a consistent depth to allow for precise and uniform seed and nutrient placement, promoting uniform emergence, canopy development, and optimum resource utilization. Precise crop hygiene activities on the micro size field, such as scouting for disease or pests, periodical weeded and or mulching to increase water infiltration and retention, shade out weeds, and increase OM to provide above and below ground habitat for beneficial organisms, all add to the soils overall SH whilst optimizing resources and yield.

Micro-farming is climate smart, precise agriculture, that plant-by-plant seeks the optimum yield, via optimum SH, adding to food security. After success in trials near the homestead, this system can be moved to the fields or implemented in the urban environment as it is a resource maximizer and requires small areas of land that can be alternately used as kitchen gardens to diversify crop/nutrient supply.

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8. Supplimentary Materials

Table 16(a), n=116 SH indicator scores sorted on OM, to indicate the correlation of overall SH to various indicators.

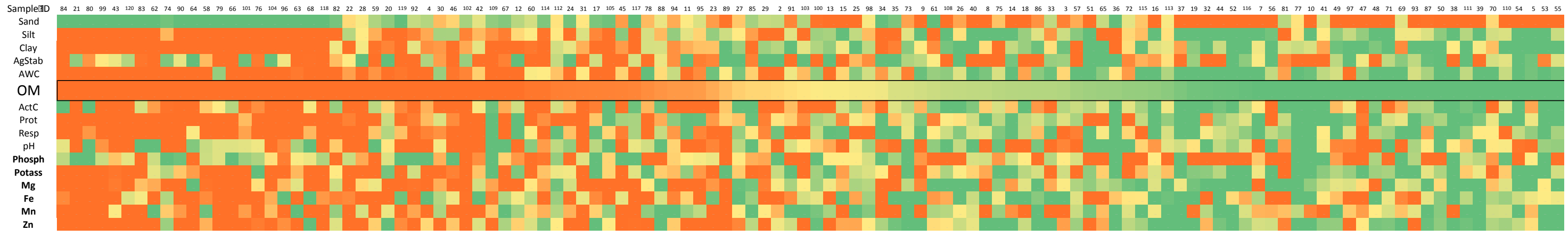


Table 16 (b) n=116 SH indicator scores sorted on Active carbon, to indicate the correlation of overall SH to various indicators.

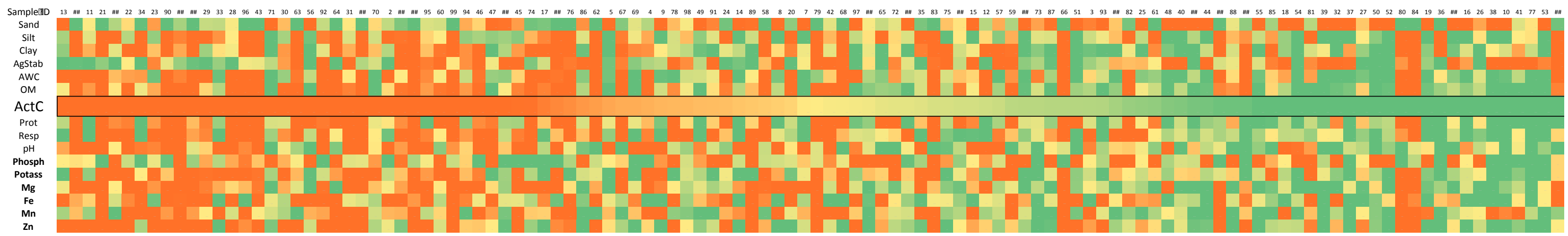
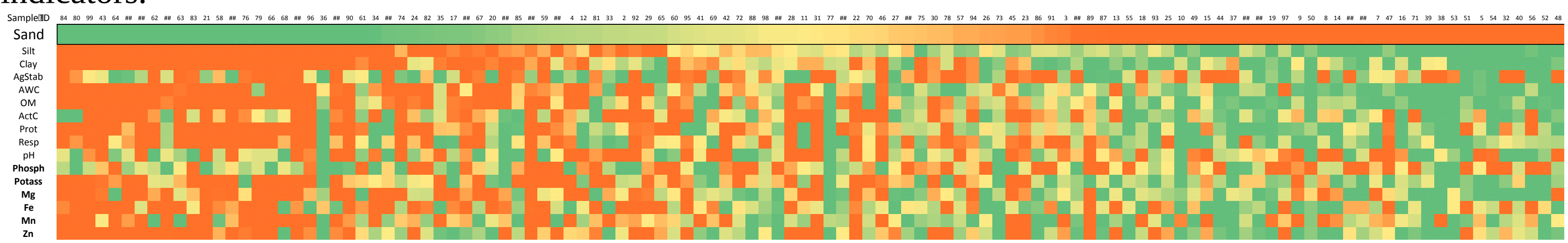
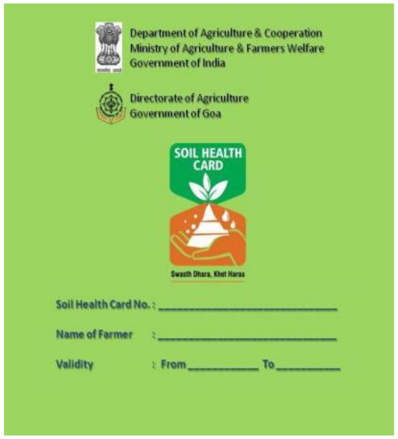


Table 16 (c) n=116 SH indicator scores sorted on Sand, to indicate the correlation of overall SH to various indicators.





SOIL HEALTH CARD		
Farmer's Details		
Name		
Address		
Village		
Sub-District		
District		
PIN		
Aadhaar Number		
Mobile Number		
Soil Sample Details		
Soil Sample Number		
Sample Collected on		
Survey No.		
Khasra No. / Dag No.		
Farm Size		
Geo Position (GPS)	Latitude:	Longitude:
Irrigated / Rainfed		

Name of Laboratory				
SOIL TEST RESULTS				
S. No.	Parameter	Test Value	Unit	Rating
1	pH			
2	EC			
3	Organic Carbon (OC)			
4	Available Nitrogen (N)			
5	Available Phosphorus (P)			
6	Available Potassium (K)			
7	Available Sulphur (S)			
8	Available Zinc (Zn)			
9	Available Boron (B)			
10	Available Iron (Fe)			
11	Available Manganese (Mn)			
12	Available Copper (Cu)			

Secondary & Micro Nutrients Recommendations		
Sl. No.	Parameter	Recommendations for Soil Applications
1	Sulphur (S)	
2	Zinc (Zn)	
3	Boron (B)	
4	Iron (Fe)	
5	Manganese (Mn)	
6	Copper (Cu)	
General Recommendations		
1	Organic Manure	
2	Biofertiliser	
3	Lime / Gypsum	
International Year of Soils 2015		**Healthy Soils for a Healthy Life**

Fertilizer Recommendations for Reference Yield (with Organic Manure)						
Sl. No.	**Crop & Variety**	**Reference Yield**	**Fertilizer Combination-1 for N P K**		**Fertilizer Combination-2 for N P K**	
1	Paddy (Dhaan)					
2						
3						
4						
5						
6						

Figure 2, Soil Health card of India , English version

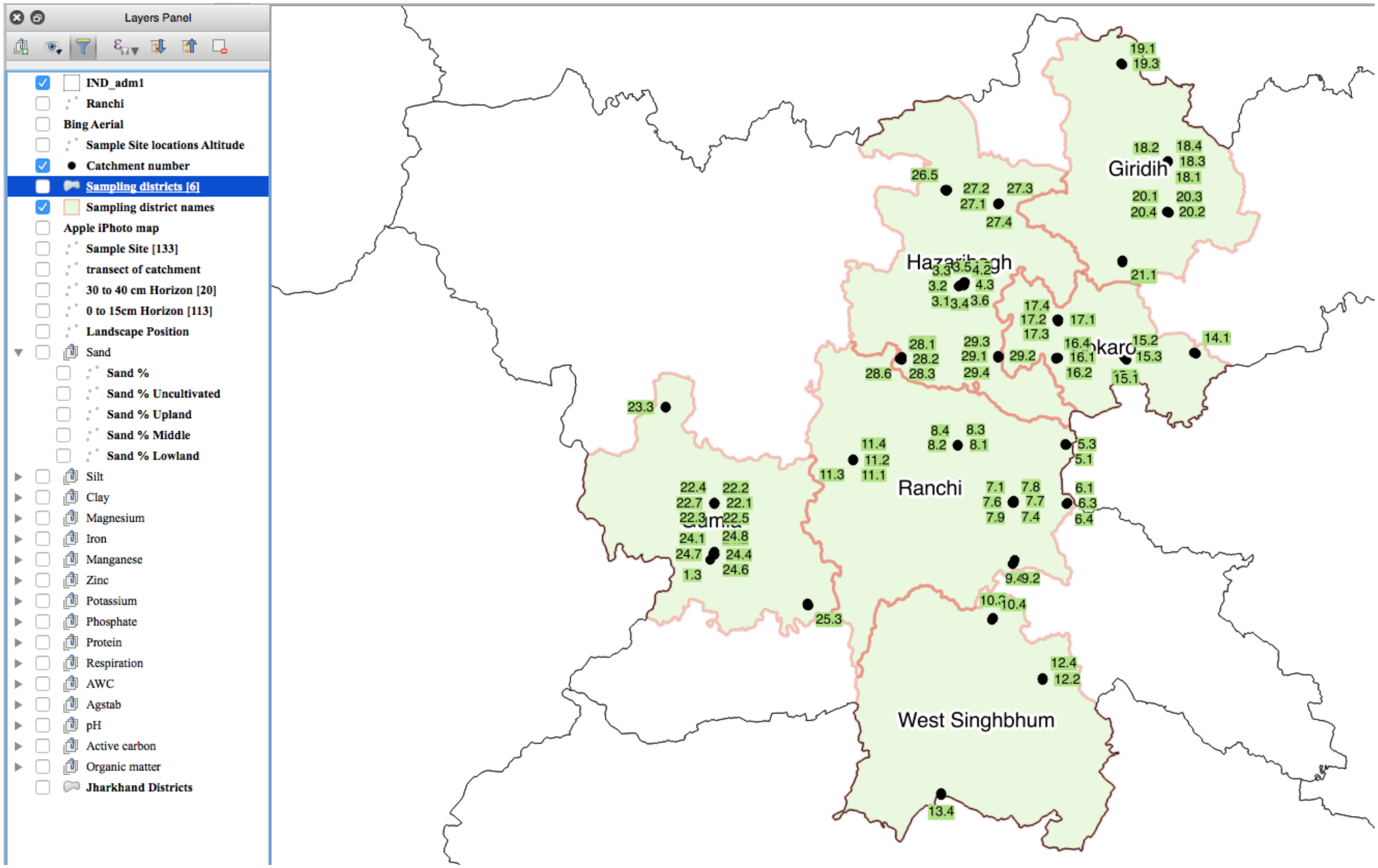


Figure 5, SH Indicator Layers within QGIS map

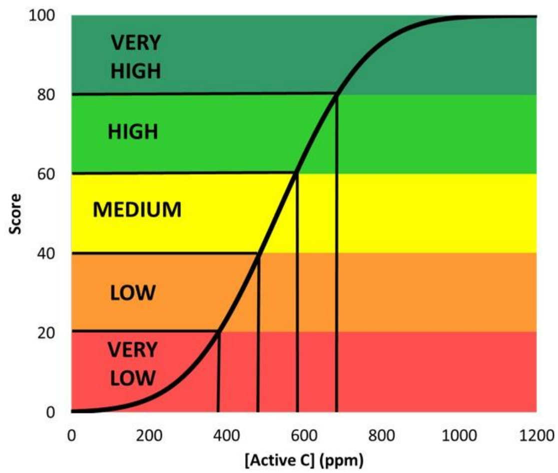


Figure 6. Cumulative normal distribution curve for Active Carbon in silt soils indicate levels between 500 and 600 ppm with a medium score. (Source: Moebius-Clune et al 2016)

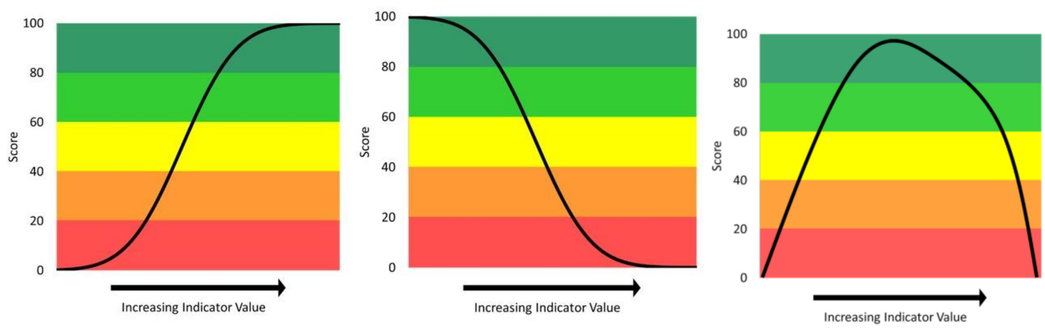


Figure 7. Variations in scoring functions, with more is better, less is better and optimum level score curves. (Source: Moebius-Clune et al 2016)

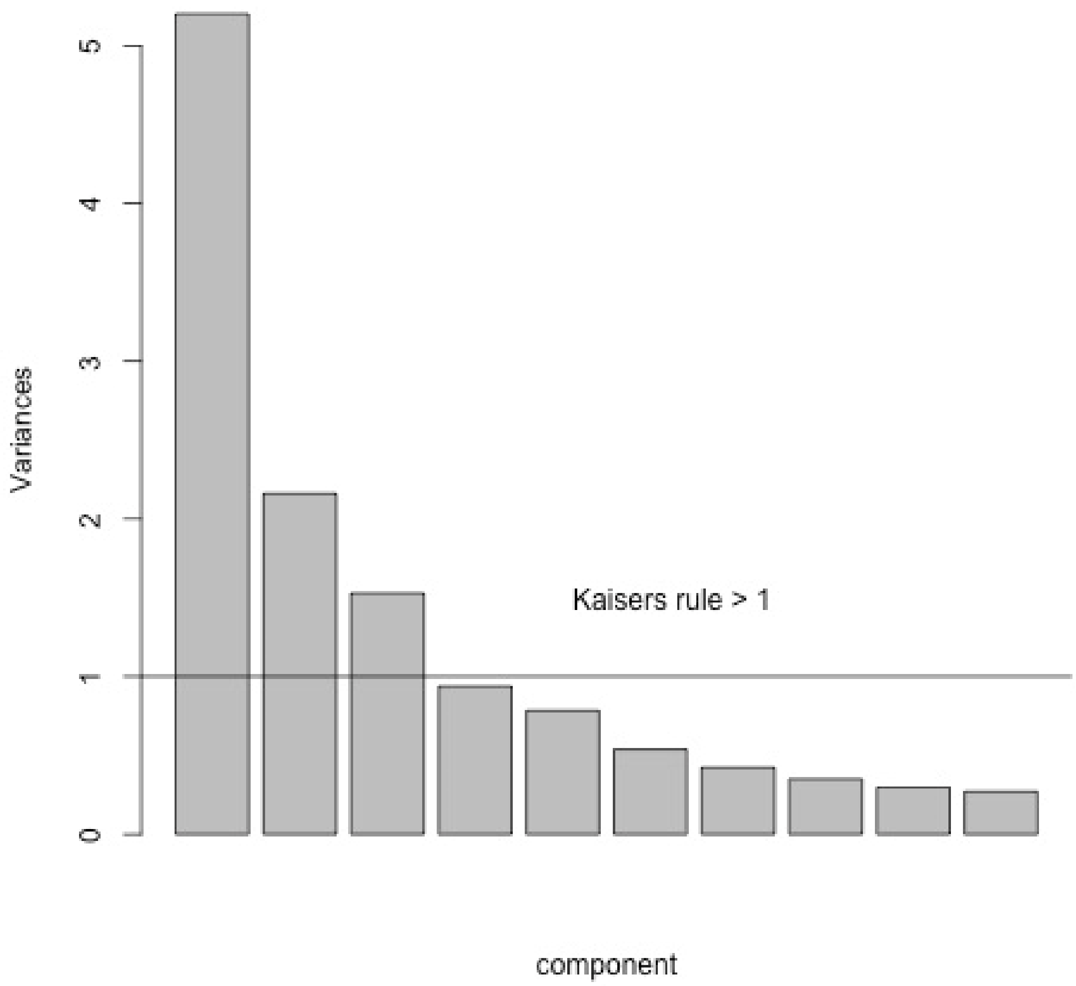


Figure 9. Scree plot of variances after PCA

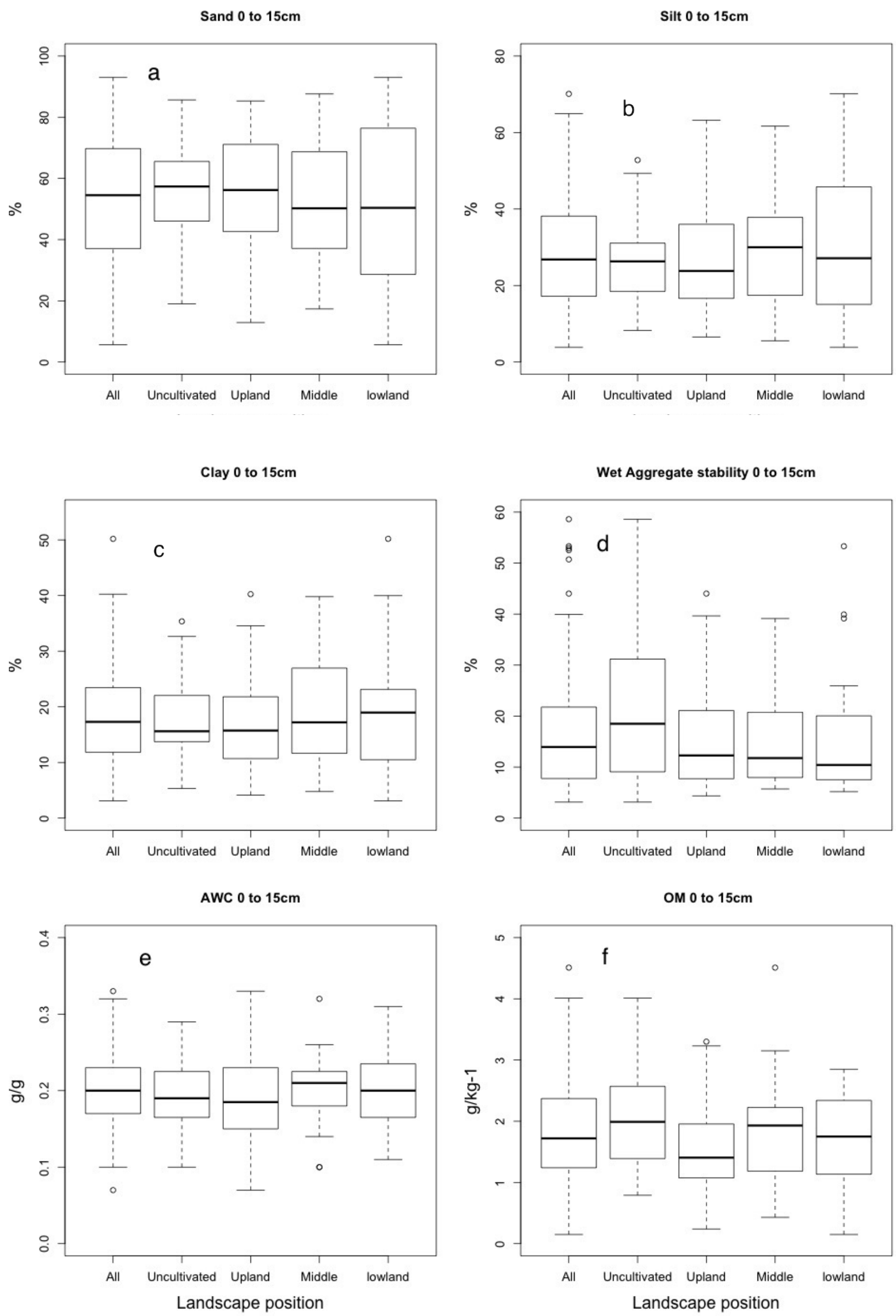


Figure 11 (a) to (p) Landscape position indicator boxplots (outlier values denoted by "o" above or below quartile ranges)

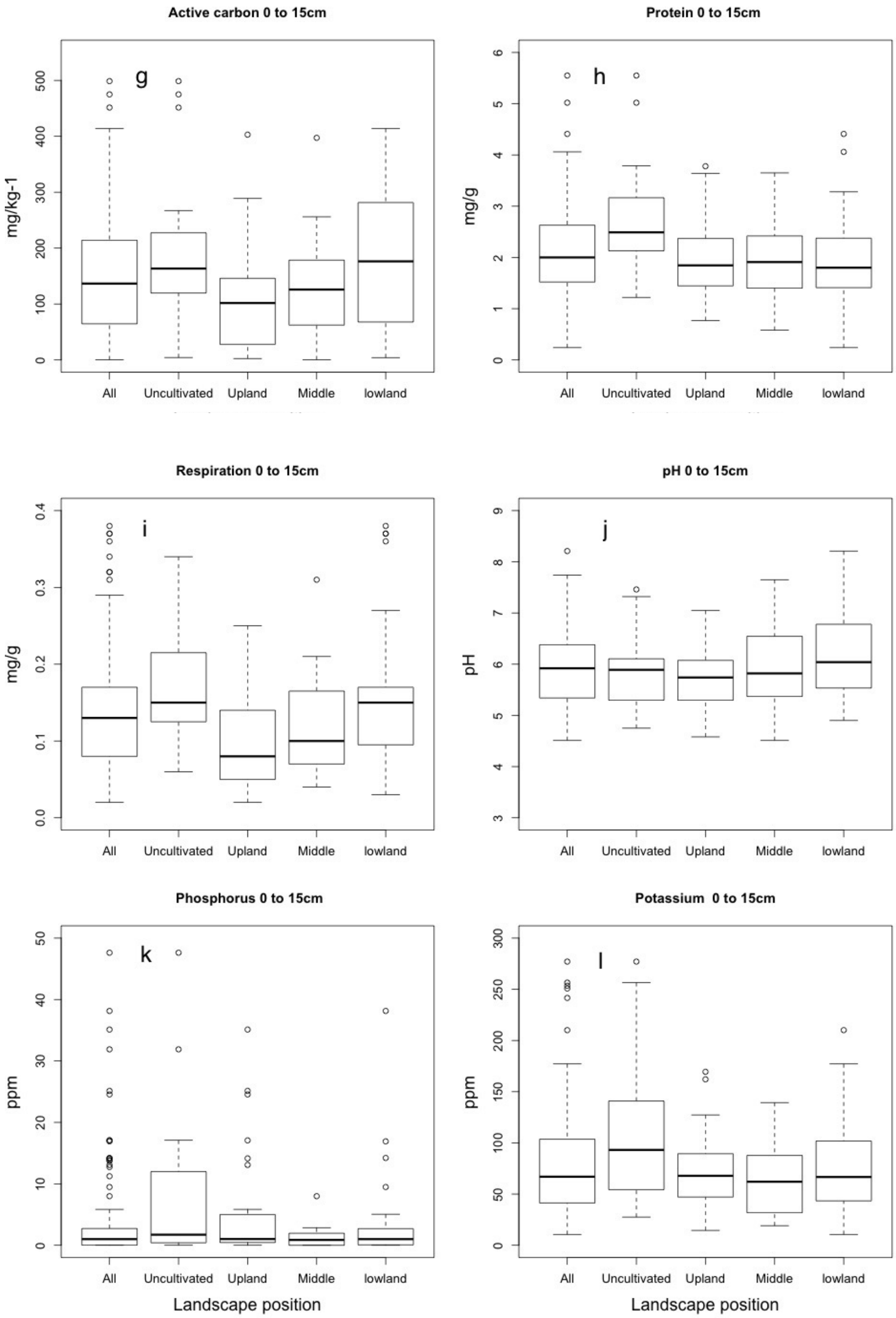


Figure 11 “a” to “p”(Continued). Landscape position indicator boxplots (outlier values denoted by "o" above or below quartile ranges)

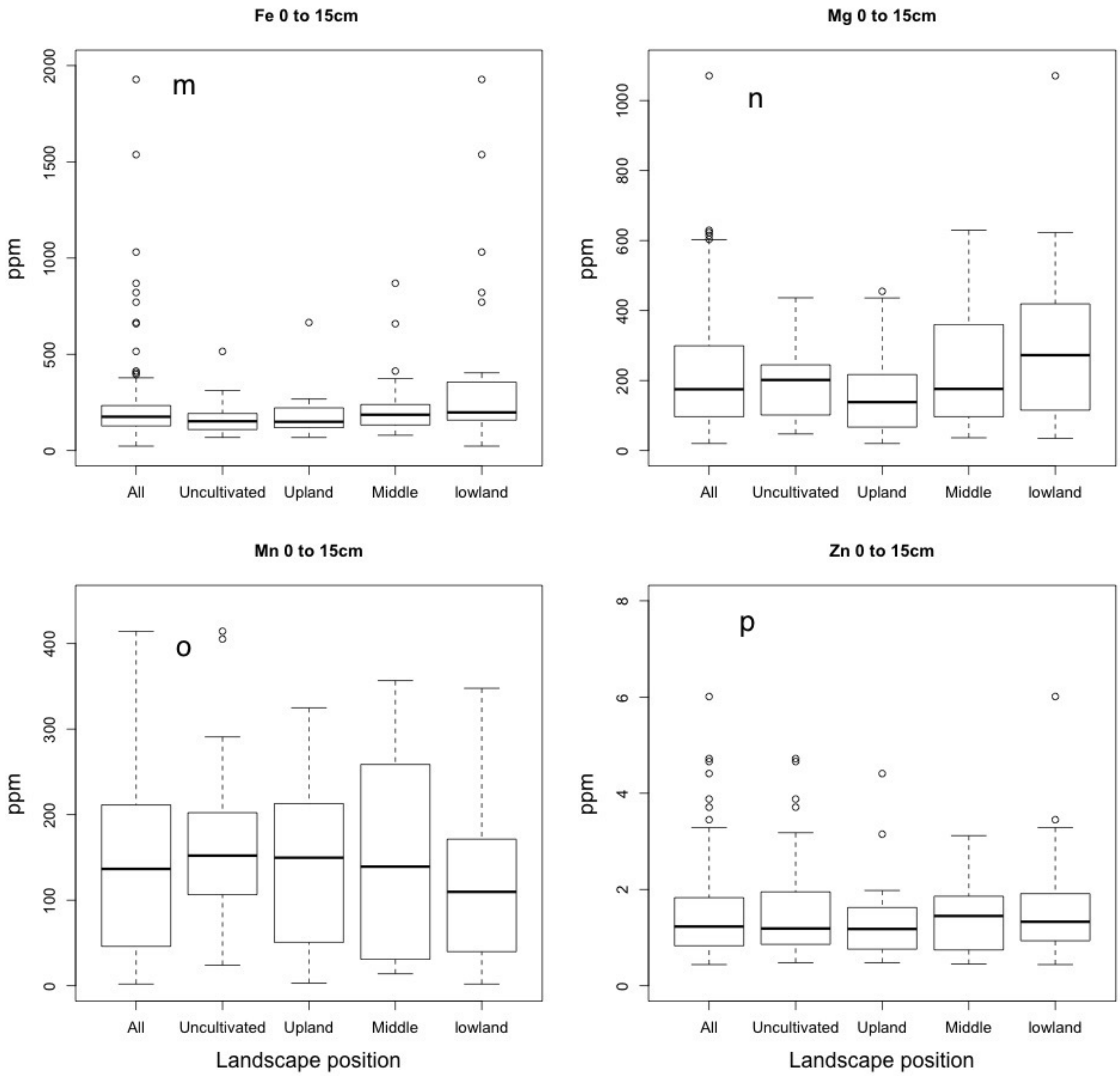


Figure 11 “a” to “p”(Continued**).** Landscape position indicator boxplots (outlier values denoted by "o" above or below quartile ranges)

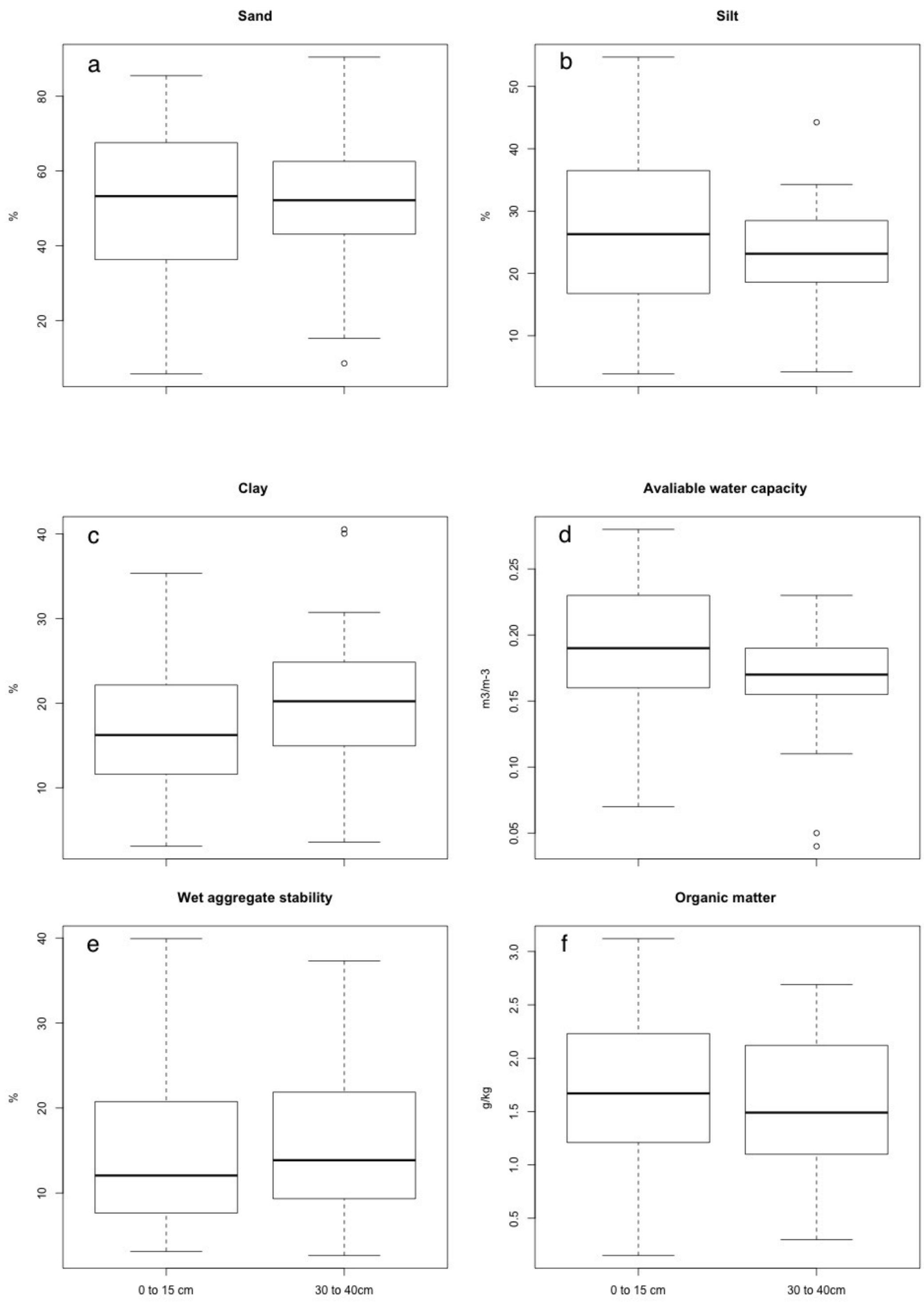


Figure 12. ‘a’ to ‘p’. Box plots of quartile variance indicator values from 0 to 15 cm and 30 to 40 cm sample horizons ('o' denoted outlier values)

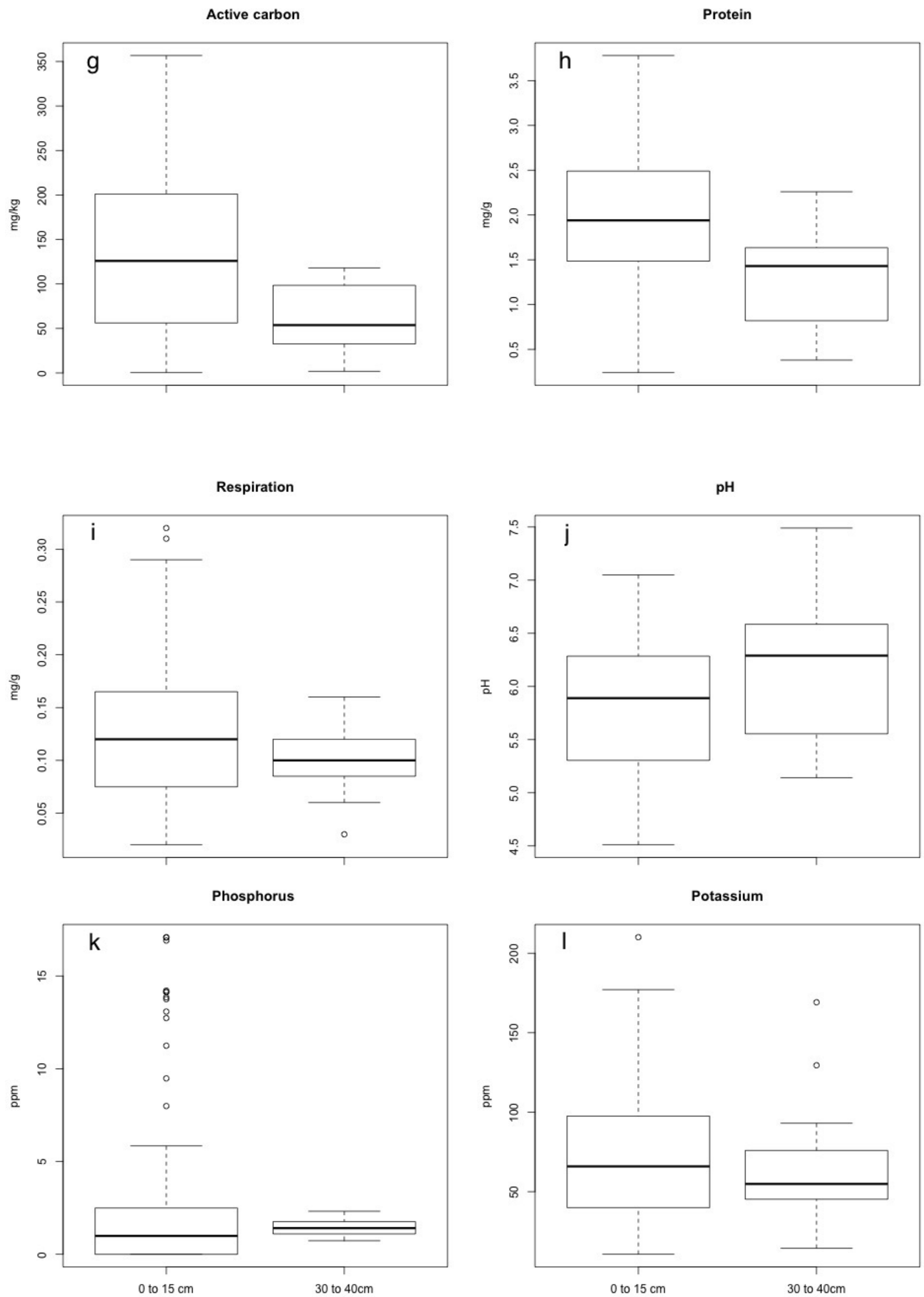


Figure 12. ‘a’ to ‘p’ (continued). Box plots of quartile variance indicator values from 0 to 15 cm and 30 to 40 cm sample horizons ('o' denoted outlier values)

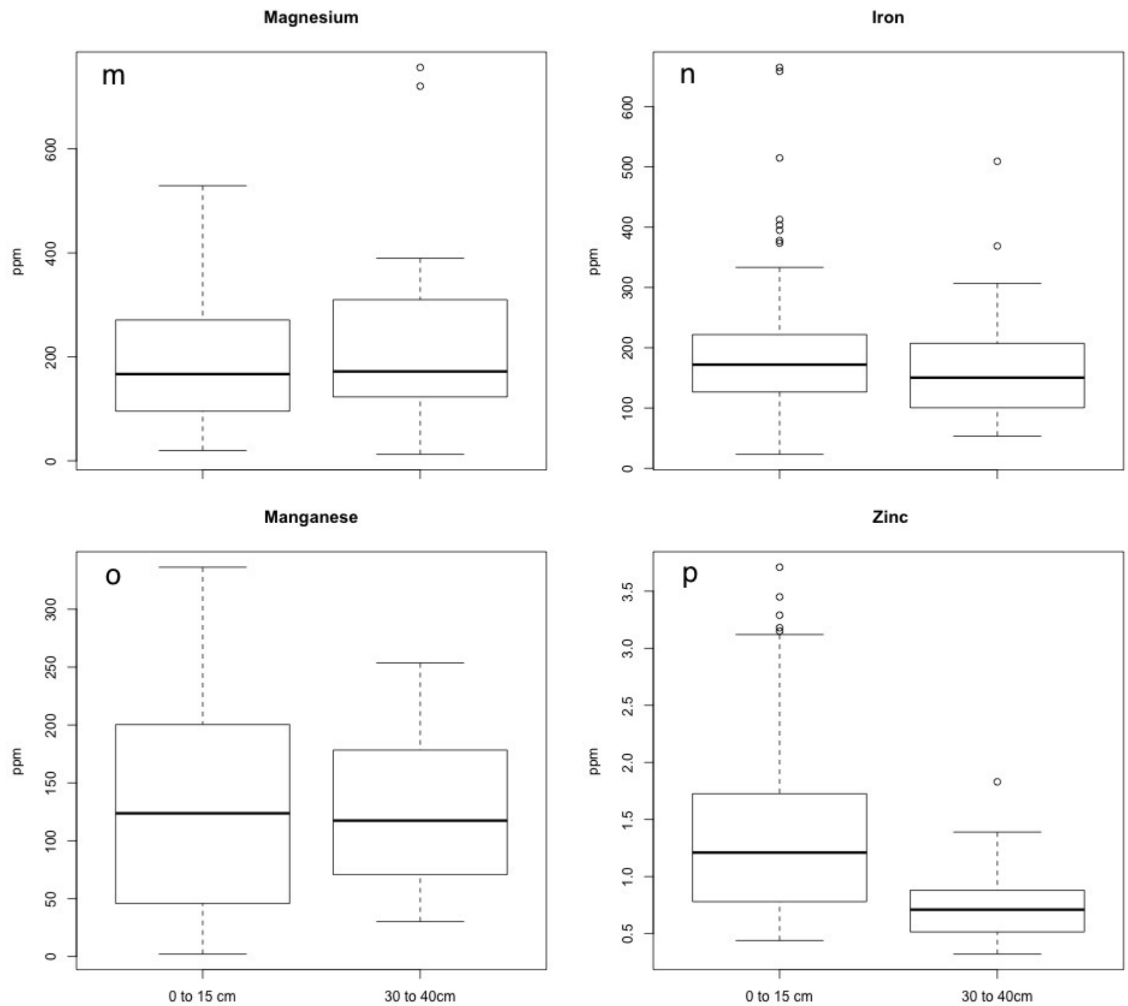


Figure 12. ‘a’ to ‘p’ (continued). Box plots of quartile variance indicator values from 0 to 15 cm and 30 to 40 cm sample horizons ('o' denoted outlier values)

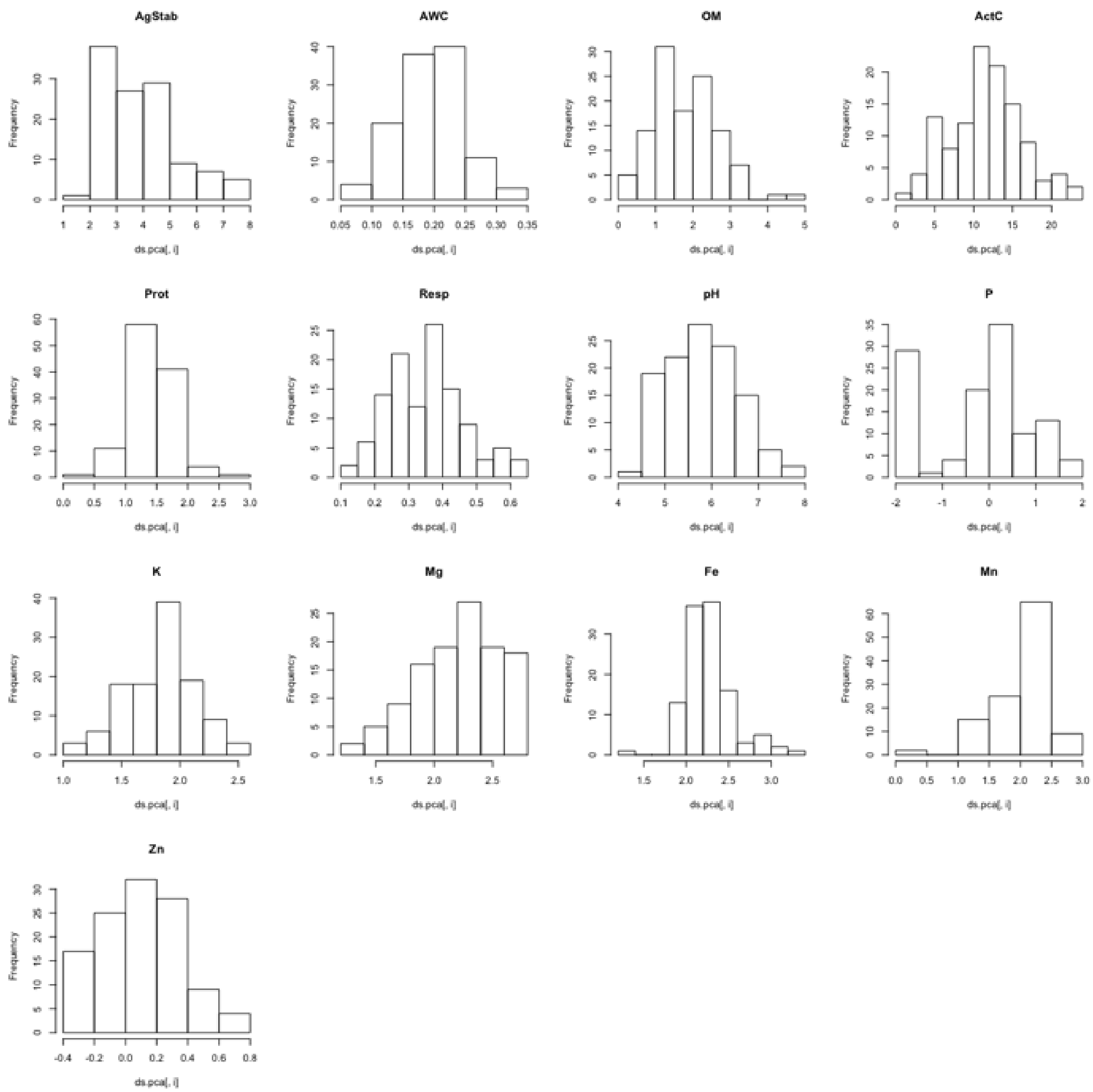


Figure 13. Transformed Histogram data for PCA

sand	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	65.904	5.059614	127	55.89231	75.91644	2
	Giridih	64.594	5.059614	127	54.58231	74.60644	2
	Gumla	52.888	4.047691	127	44.87795	60.89725	12
	Hazaribagh	50.545	3.420923	127	43.77547	57.31425	12
	Ranchi	50.710	3.758187	127	43.27357	58.14712	12
	West Singhbhum	34.158	5.842339	127	22.5974	45.71927	1

silt	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	20.31	3.524451	127	13.33387	27.28238	1
	Giridih	20.73	3.524451	127	13.752	27.7005	1
	Gumla	26.13	2.819561	127	20.5518	31.7106	12
	Hazaribagh	30.49	2.382964	127	25.77283	35.20374	12
	Ranchi	31.50	2.617897	127	26.31552	36.67621	12
	West Singhbhum	37.39	4.069686	127	29.33683	45.44317	2

clay	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	13.79	2.199435	127	9.434591	18.13916	1
	Giridih	14.68	2.199435	127	10.324591	19.02916	1
	Gumla	20.98	1.759548	127	17.498573	24.46223	12
	Hazaribagh	18.97	1.487089	127	16.024176	21.90954	1
	Ranchi	17.79	1.633699	127	14.560308	21.0259	1
	West Singhbhum	28.45	2.539688	127	23.426082	33.47725	2

agstab	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	13.84	3.034935	127	7.832537	19.84371	1
	Giridih	11.29	3.034935	127	5.287537	17.29871	1
	Gumla	21.19	2.427948	127	16.389129	25.99807	1
	Hazaribagh	15.63	2.05199	127	11.57291	19.69395	1
	Ranchi	19.31	2.254293	127	14.85123	23.77291	1
	West Singhbhum	20.62	3.504441	127	13.687844	27.55716	1

AWC	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	0.188	0.01288953	127	0.1626189	0.2136311	1
	Giridih	0.190	0.01288953	127	0.1644939	0.2155061	1
	Gumla	0.179	0.01031162	127	0.1583952	0.1992048	1
	Hazaribagh	0.193	0.00871491	127	0.1756119	0.2101024	1
	Ranchi	0.194	0.0095741	127	0.1748477	0.2127385	1
	West Singhbhum	0.226	0.01488355	127	0.1963815	0.2552852	1

OM	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	1.637	0.1956086	127	1.249801	2.023949	1
	Giridih	1.438	0.1956086	127	1.050426	1.824574	1
	Gumla	1.602	0.1564869	127	1.291941	1.911259	1
	Hazaribagh	1.828	0.1322556	127	1.566576	2.089996	1
	Ranchi	1.709	0.1452945	127	1.421109	1.996132	1
	West Singhbhum	2.627	0.2258694	127	2.179712	3.073621	2

actC	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	122.80	25.33646	127	72.65972	172.9323	12
	Giridih	190.08	25.33646	127	139.94547	240.218	2
	Gumla	77.06	20.26917	127	36.95245	117.1705	1
	Hazaribagh	145.37	17.13057	127	111.4763	179.2729	12
	Ranchi	131.20	18.81945	127	93.96436	168.445	12
	West Singhbhum	228.22	29.25603	127	170.3251	286.1099	2

Figure 14 , District Least Square means

prot	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	1.5756	0.2627177	127	1.055754	2.095496	1
	Giridih	1.9769	0.2627177	127	1.457004	2.496746	1
	Gumla	1.7696	0.2101742	127	1.353703	2.185497	1
	Hazaribagh	2.2600	0.1776296	127	1.908503	2.611497	1
	Ranchi	2.0862	0.1951418	127	1.700056	2.472357	1
	West Singhbhum	2.6383	0.3033603	127	2.038038	3.238629	1

resp	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	0.114	0.01897917	127	0.07681865	0.1519314	12
	Giridih	0.111	0.01897917	127	0.07306865	0.1481814	12
	Gumla	0.102	0.01518334	127	0.07235492	0.1324451	1
	Hazaribagh	0.168	0.01283226	127	0.14232156	0.193107	2
	Ranchi	0.134	0.01409737	127	0.1065866	0.1623789	12
	West Singhbhum	0.157	0.02191526	127	0.11330032	0.200033	12

pH	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	6.0029	0.1837058	127	5.639417	6.366458	12
	Giridih	6.3741	0.1837058	127	6.010542	6.737583	2
	Gumla	5.7877	0.1469647	127	5.496863	6.078497	12
	Hazaribagh	6.0587	0.1242078	127	5.812872	6.304442	12
	Ranchi	5.6010	0.1364533	127	5.331018	5.871051	1
	West Singhbhum	6.4763	0.2121252	127	6.056576	6.896091	2

p	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	2.31	1.943018	127	-1.5323823	6.157382	1
	Giridih	5.56	1.943018	127	1.7176177	9.407382	1
	Gumla	2.60	1.554415	127	-0.4759059	5.675906	1
	Hazaribagh	3.16	1.31372	127	0.5638136	5.763044	1
	Ranchi	6.34	1.443238	127	3.4803	9.192114	1
	West Singhbhum	2.74	2.243604	127	-1.703021	7.176354	1

K	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	54.13	31.84588	127	-8.887248	117.1472	1
	Giridih	91.20	31.84588	127	28.180252	154.2147	1
	Gumla	86.43	25.4767	127	36.020201	136.8478	1
	Hazaribagh	116.57	21.53174	127	73.961421	159.1763	1
	Ranchi	69.25	23.65453	127	22.439205	116.0553	1
	West Singhbhum	120.29	36.77245	127	47.52395	193.0561	1

Mg	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	228.57	44.75462	127	140.0056	317.1282	12
	Giridih	249.86	44.75462	127	161.3012	338.4238	12
	Gumla	202.13	35.8037	127	131.2837	272.9819	1
	Hazaribagh	231.49	30.25965	127	171.6165	291.3732	12
	Ranchi	183.78	33.2429	127	118.0017	249.5651	1
	West Singhbhum	386.68	51.67819	127	284.4157	488.9393	2

Fe	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	161.44	62.11039	127	38.53411	284.3446	1
	Giridih	183.32	62.11039	127	60.40974	306.2203	1
	Gumla	214.69	49.68832	127	116.36259	313.011	1
	Hazaribagh	343.54	41.99429	127	260.44402	426.6423	1
	Ranchi	226.67	46.13444	127	135.37344	317.9569	1
	West Singhbhum	191.80	71.71891	127	49.88373	333.7213	1

Figure 14 , District Least Square means Continued

Mn	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	162.64	24.69448	127	113.77157	211.5034	12
	Giridih	165.02	24.69448	127	116.15407	213.8859	12
	Gumla	121.27	19.75559	127	82.17446	160.3599	1
	Hazaribagh	137.59	16.69652	127	104.55432	170.6331	12
	Ranchi	122.35	18.3426	127	86.05537	158.6488	1
	West Singhbhum	224.20	28.51473	127	167.76949	280.6205	2

Zn	district	lsmean	SE	df	lower.CL	upper.CL	.group
	Bokaro	1.409	0.2444068	127	0.9257381	1.893012	1
	Giridih	1.559	0.2444068	127	1.0757381	2.043012	1
	Gumla	0.870	0.1955254	127	0.4834905	1.25731	1
	Hazaribagh	1.583	0.1652491	127	1.2561446	1.910141	1
	Ranchi	1.493	0.1815408	127	1.133867	1.85234	1
	West Singhbhum	1.720	0.2822166	127	1.1615442	2.278456	1

Figure 14 , District Least Square means Continued

Image 1, terraced and bunded Middle landscape position with uncultivated land in the background indicated by tall trees.

Image 2, Upland landscape position charaterised by orchards and water harvesting pits.

Image 3, Lowland landscape position charaterized by paddy rice production and perennially wet areas.

Image 4 , variation in soil colour by landscape position from the same catchment.

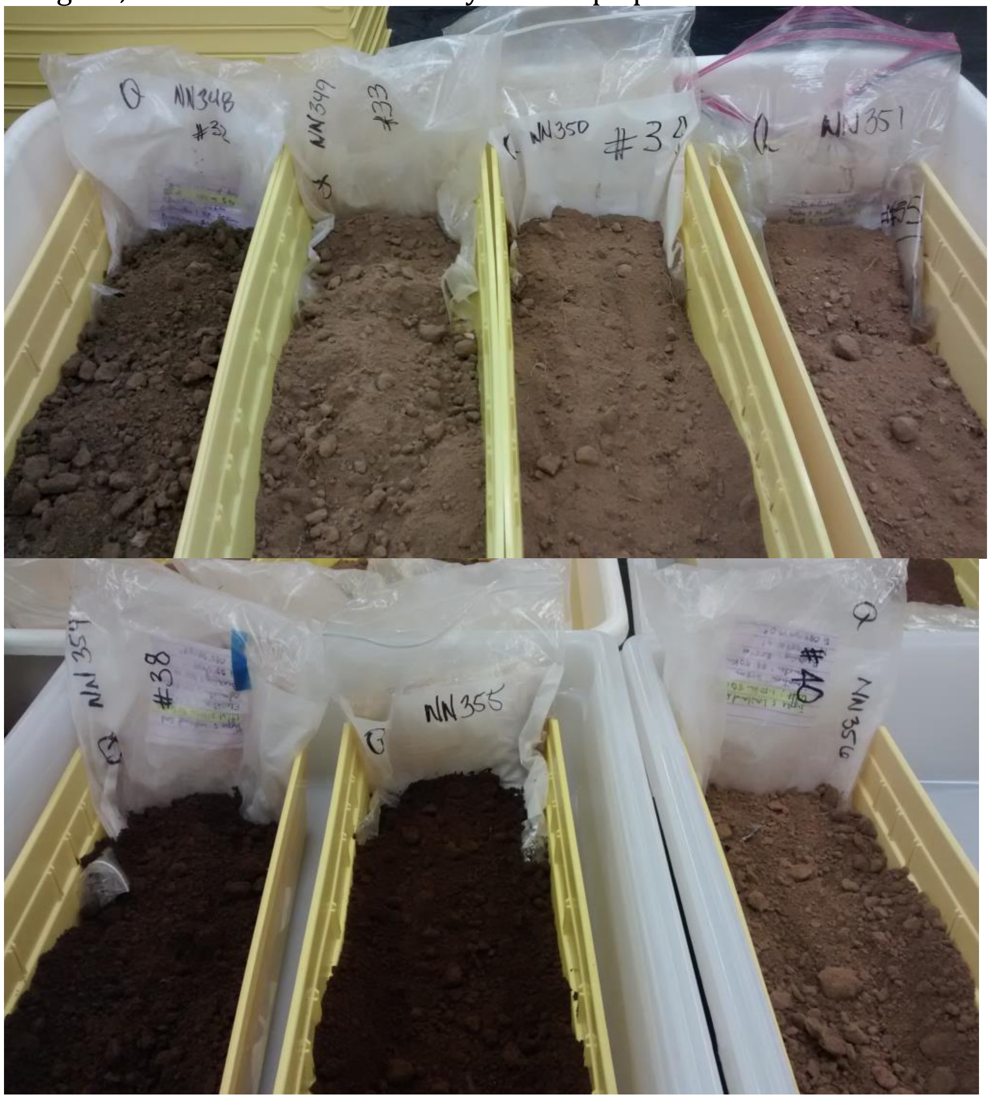


Image 5. Animal powered paddy tillage.

Image 6, medium landscape positions paddy tillage areas after harvest.

R code Principal Component Analysis

```
ds <- read.csv("~/India analysis David Rossiter/IndiaSoilHealthR.csv")##
ds$CSHT_ID <- as.character(ds$CSHT_ID)
ds$lat <- as.character(ds$GPS_northing)
ds$long <- as.character(ds$GPS_Easting)
## a big mess with the coordinates, convert to decimal degrees
## I had to clean up a few in the spreadsheet before export
deg <- as.numeric(substr(ds$lat,1,2))
min <- as.numeric(substr(ds$lat,4,5))/60
sec <- as.numeric(substr(ds$lat,7,10))/(60*60)
ds$lat.dd <- deg+min+sec
deg <- as.numeric(substr(ds$long,1,2))
min <- as.numeric(substr(ds$long,4,5))/60
sec <- as.numeric(substr(ds$long,7,10))/(60*60)
ds$long.dd <- deg+min+sec
ds.pca <- ds[,c(4,13:25)]
#remove highest (max) value for K Zn and Mg
ds.pca$K[which.max(ds.pca$K)] <- NA
ds.pca$Zn[which.max(ds.pca$Zn)] <- NA
ds.pca$Mg[which.max(ds.pca$Mg)] <- NA
ds.pca$P <- log10(ds.pca$P+0.01)
ds.pca$Fe <- log10(ds.pca$Fe)
ds.pca$Mg <- log10(ds.pca$Mg)
ds.pca$Mn <- log10(ds.pca$Mn)
ds.pca$Zn <- log10(ds.pca$Zn)
ds.pca$K <- log10(ds.pca$K)
ds.pca$AgStab <- sqrt(ds.pca$AgStab)
ds.pca$ActC <- sqrt(ds.pca$ActC)
ds.pca$Resp <- sqrt(ds.pca$Resp)
ds.pca$Prot <- sqrt(ds.pca$Prot)
par(mfrow=c(4,4))
for (i in 2:dim(ds.pca)[2]) {
 hist(ds.pca[,i], main=names(ds.pca)[i])
}
par(mfrow=c(1,1))

 dim(ds.pca)

## [1] 116  14

ds.pca.a <- na.omit(ds.pca)
# remove the ID column
ds.pca.a <- ds.pca.a[, -1]
dim(ds.pca.a)

## [1] 113  13
```

```
# 'scale=TRUE' standardizes the data
pc <- prcomp(ds.pca.a, scale = TRUE, center = TRUE)
summary(pc)

## Importance of components:
##                          PC1    PC2    PC3     PC4     PC5     PC6    PC7
## Standard deviation     2.2808 1.4697 1.2362 0.96838 0.88534 0.73321 0.6500
## Proportion of Variance 0.4001 0.1662 0.1176 0.07213 0.06029 0.04135 0.0325
## Cumulative Proportion  0.4001 0.5663 0.6839 0.75600 0.81630 0.85765 0.8901
##                            PC8     PC9    PC10    PC11    PC12    PC13
## Standard deviation     0.59210 0.54518 0.51973 0.45767 0.42845 0.34223
## Proportion of Variance 0.02697 0.02286 0.02078 0.01611 0.01412 0.00901
## Cumulative Proportion  0.91712 0.93998 0.96076 0.97687 0.99099 1.00000

screeplot(pc, main = "Scree plot of variances after pca", xlab = "component")
abline(1, 0)
text(7, 1.5, "Kaisers rule > 1")

par(mfrow=c(1,1))
biplot(pc, main="Biplot pc1 and pc2",cex=c(1,1),xlabs=rep(".", nrow(ds.pca.a)))

biplot(pc, choices=3:4, main= "Biplot pc3 and pc4",cex=c(1,1),xlabs=rep(".", nrow(ds.pca.a)))

biplot(pc, main="Figure 11: Biplot pc1 and pc2",xlabs=rep(".", nrow(ds.pca.a)))
```

R Code ANOVA for Landscape positions with catchment as the random variable, and district. n=133

```
library(lme4)
library(lmerTest)
ds.anova.13a <-lmer(sand ~ landscape.pos +(1|site.pin), data= ds.anova)
library(lme4)
ds.anova.14a <-lmer(sand ~ district +(1|site.pin), data= ds.anova)
ds.anova.16a <-lmer(sand ~ district*landscape.pos + (1|site.pin), data= ds.anova)
```

R Code TukeyHSD district pairwise comparisons

```
library(gplots)
ds.anova <-read.csv("~/India analysis David Rossiter/June 2017/IndiaSoilsFinal.csv")
ds.anova$site.pin <- as.factor(ds.anova$site.pin)
ds.anova$district <- as.factor(ds.anova$district)
means.sand2 <- round(tapply(ds.anova$sand,ds.anova$district,mean),digits=2)
plotmeans(ds.anova$sand ~ ds.anova$district, digits=2,ccol="red", mean.labels=T, main="Plot
of sand means by district")
boxplot(ds.anova$sand~ds.anova$district, main= "mean of sand by district (Black diamond is
mean)", xlab="district", ylab= "Sand %", col= rainbow(4))
points(means.sand2,col= "black",pch= 18)
```

```
ds.aov.sand2 <-aov(ds.anova$sand ~ ds.anova$district)
summary(ds.aov.sand2)
tuk.sand2 <-TukeyHSD(ds.aov.sand2)
tuk.sand2
```

R Code TukeyHSD landscape position pairwise comparisons

```
library(gplots)
ds.anova <-read.csv("~/India analysis David Rossiter/June 2017/IndiaSoilsFinal.csv")
ds.anova$site.pin <- as.factor(ds.anova$site.pin)
ds.anova$district <- as.factor(ds.anova$district)
## indicator and landscape position
#sand
means.sand1 <- round(tapply(ds.anova$sand,ds.anova$landscape.pos,mean),digits=2)
plotmeans(ds.anova$sand ~ ds.anova$landscape.pos, digits=2,ccol="red", mean.labels=T,
main="Plot of sand means by landscape position")
boxplot(ds.anova$sand~ds.anova$landscape.pos, main= "mean of sand by landscape position
(Black diamond is mean)", xlab="landscape position", ylab= "Sand %", col= rainbow(4))
points(means.sand1,col= "black",pch= 18)
ds.aov.sand1 <-aov(ds.anova$sand ~ ds.anova$landscape.pos)
summary(ds.aov.sand1)
# there is no relationship between the means of sand and landscape pos
tuk.sand1 <-TukeyHSD(ds.aov.sand1)
tuk.sand1
```

R Code, Welch two sample t-test, 0 to 15 and 30 to 40 cm depth

```
library(gplots)
ds.sp.A
ds.sp.B
sapply(ds.sp.A@data[,9:24], summary)
sapply(ds.sp.B@data[,9:24], summary)
#Sand
boxplot(ds.sp.A$sand,ds.sp.B$sand, main="Mean values of A and B sand ('o' denote outlier
value) ", xlab="0 to 15cm and 30 to 40 cm profiles", ylab= "% Sand ", col= rainbow(4))
t.test(ds.sp.A$sand,ds.sp.B$sand)
```

R Code, Results of Best Subset Regression identifying the best-fitting regression models using Soil Health indicators as predictors (N = 133). Vars is the number of variables included in each model, R-sq (adj) is adjusted coefficient of determination.

```
score <- read.csv("~/India analysis David Rossiter/Final/SH score sheet.csv")
colnames(score)
score = score[,-(1:12),drop=FALSE]
```

```
colnames(score)
library(leaps)
regsubsets.out <-
  regsubsets(SHscore ~ agstab + AWC +     OM + actC +  prot +  resp +  pH +   P +     K
        + Mg +          Fe +    Mn +   Zn,
          data = score,
          nbest = 2,      # 1 best model for each number of predictors
          nvmax = NULL,    # NULL for no limit on number of variables
          force.in = NULL, force.out = NULL,
          method = "exhaustive")
regsubsets.out
summary.score <- summary(regsubsets.out)
print(as.data.frame(summary.score$outmat))
View(as.data.frame(summary.score$outmat))
View(as.data.frame(summary.score$which))
plot(regsubsets.out, scale="adjr2",main= "Adjusted R^2")
print(regsubsets.out, scale="adjr2",main= "Adjusted R^2")
#step function
stepSH <-lm(SHscore ~ agstab+AWC+      OM+   actC+  prot+   resp+  pH+    P+     K
        +Mg+  Fe+     Mn+   Zn-1, data = score)
stepSH1 <-step(stepSH)
# step(stepSH,direction = c("both"), trace=1, )summary(s)
summary(stepSH1)
stepSH1$anova
```

R Code, Correlation data for Soil Health indicators

```
cds <-read.csv("~/India analysis David Rossiter/Final/IndiaSoilsFinal.csv")
colnames(cds)
cds = cds[,-(1:9),drop=FALSE]
colnames(cds)

all <-cds[,1:16]
physical <- cds[,1:5]
biological <- cds[,6:9]
chemical <- cds[, 10:16]
carbon = cds[,6:7]

ggpairs(physical, title = "Phyical correlations", axisLabels= "internal",
lower=list(continuous="smooth"))
ggpairs(biological, title= "Biological correlations", axisLabels=
"internal",lower=list(continuous="smooth"))
ggpairs(chemical, title = "Chemical correlations", axisLabels=
"internal",lower=list(continuous="smooth"))
ggpairs(carbon, title= "carbon correlations", axisLabels= "internal"
,lower=list(continuous="smooth"))
```

```
# output of correlations
matcor(all,all)
```

R Code District Least Mean Squares data

```
library(lsmeans)
library(multcompView)
library(MASS)
library(xtable)
## site pin/catchment cannot be analysed as they are random variables and will change with
every test.
summary(mod4.sand <-aov(ds.anova$sand~site.pin, data= ds.anova))
TukeyHSD(mod4.sand, "site.pin",ordered=TRUE)
plot(TukeyHSD(mod4.sand,"site.pin"))
mod4.sand.lsm <- lsmeans(mod4.sand,~site.pin)
cld(mod4.sand.lsm, alpha=0.05)
#Two LS means that share one or more of the same grouping symbols are not significantly
different and cld compact letter display alpha from 0.1 to 0.001
contrast(mod4.sand.lsm, method= "eff", ordered=TRUE)
# eff = differences between each mean and the overall mean
```

Raw Data for n= 133 soil samples

	village.name	new.google.pin	CSHT.LAB.II	sample.ID	elevation	AB	landscape.pos	texture	sand
1	silam , gumla	1.3	L_906	4	660	TRUE	lowland	sandy loam	62.7
2	Chichikala	3.1	L_908	7	596	TRUE	Upland	silt loam	22.68
3	Chichikala	3.2	L_909	8	595	TRUE	Middle	silt loam	28.07
4	Chichikala	3.3	L_910	9	593	TRUE	lowland	silt loam	30.82
5	Chichikala	3.4	L_911	10	598	TRUE	lowland	loam	37.08
6	Chichikala	3.5	L_912	11	601	TRUE	Uncultivated	sandy loam	54.51
7	Chichikala	3.6	L_913	12	601	TRUE	Uncultivated	sandy loam	62.35
8	Chichikhurd	4.1	L_914	13	586	TRUE	Upland	loam	40.74
9	Chichikhurd	4.2	L_915	14	582	TRUE	Middle	silt loam	27.52
10	Chichikhurd	4.3	L_916	15	584	TRUE	lowland	loam	36.14
11	Chichikhurd	4.4	L_917	16	585	TRUE	lowland	silt loam	21.03
12	Chichikhurd	4.5	L_918	17	586	TRUE	Upland	sandy loam	69.14
13	Chichikhurd	4.6	L_919	18	571	TRUE	Middle	loam	39.64
14	Chichikhurd	4.7	L_920	19	570	TRUE	lowland	loam	32.57
15	Sulumjur Stadium	5.1	Nn_336	20	266	TRUE	Uncultivated	sandy loam	67.04
16	Sulumjur Stadium	5.2	Nn_337	21	257	TRUE	Upland	loamy sand	82.63
17	Sulumjur Stadium	5.3	Nn_338	22	250	TRUE	Middle	sandy loam	52.41
18	Sulumjur Stadium	5.4	Nn_339	23	253	TRUE	lowland	loam	45.72
19	Surbura CKP	6.1	Nn_340	24	209	TRUE	Uncultivated	sandy loam	70.13
20	Surbura CKP	6.2	Nn_341	25	211	TRUE	Upland	clay loam	38.95
21	Surbura CKP	6.3	Nn_342	26	204	TRUE	Middle	sandy clay loam	46.58
22	Surbura CKP	6.4	Nn_343	27	197	TRUE	lowland	sandy clay loam	50.38
23	Bundu-Bhagadih	7.1	Nn_344	28	271	TRUE	Uncultivated	sandy loam	54.9
24	Bundu-Bhagadih	7.2	Nn_345	29	282	TRUE	Upland	sandy clay loam	60.68
25	Bundu-Bhagadih	7.3	Nn_346	30	271	TRUE	Upland	loam	49.1
26	Bundu-Bhagadih	7.4	Nn_347	31	275	TRUE	Middle	sandy loam	53.68
27	Bundu-Bhagadih	7.5	Nn_348	32	266	TRUE	lowland	silty clay loam	12.83
28	Banda Pancho Narsanda	8.1	Nn_349	33	608	TRUE	Uncultivated	sandy loam	61.28
29	Banda Pancho Narsanda	8.2	Nn_350	34	597	TRUE	Upland	sandy loam	71.85
30	Banda Pancho Narsanda	8.3	Nn_351	35	588	TRUE	Middle	sandy loam	69.28
31	Banda Pancho Narsanda	8.4	Nn_352	36	577	TRUE	lowland	sandy loam	75.6
32	Tamar -Paprida	9.1	Nn_353	37	314	TRUE	Uncultivated	loam	35.56
33	Tamar -Paprida	9.2	Nn_354	38	309	TRUE	Upland	silt loam	19.05
34	Tamar -Paprida	9.3	Nn_355	39	300	TRUE	Middle	silt loam	20.23
35	Tamar -Paprida	9.4	Nn_356	40	278	TRUE	lowland	silt loam	8.68
36	Chandaha Bokaro	10.1	Nn_434	41	318	TRUE	Uncultivated	sandy loam	57.9
37	Chandaha Bokaro	10.2	Nn_435	42	304	TRUE	Upland	sandy loam	57.34

	village.name	new.google.pin	SHT.LAB.II	sample.ID	elevation	AB	landscape.pos	texture	sand
38	Chandaha Bokaro	10.3	Nn_436	43	296	TRUE	Middle	loamy sand	87.27
39	Chandaha Bokaro	10.4	Nn_437	44	284	TRUE	lowland	loam	36.07
40	Rupaidih	11.1	Nn_438	45	704	TRUE	Uncultivated	loam	45.81
41	Rupaidih	11.2	Nn_439	46	707	TRUE	Upland	loam	51.67
42	Rupaidih	11.3	Nn_440	47	699	TRUE	Middle	clay loam	22.05
43	Rupaidih	11.4	Nn_441	48	693	TRUE	lowland	silt loam	5.69
44	khairajara	12.1	Nn_442	49	245	TRUE	Uncultivated	loam	36.44
45	khairajara	12.2	Nn_443	50	251	TRUE	Upland	clay loam	29.42
46	khairajara	12.3	Nn_444	51	243	TRUE	Middle	silty clay loam	17.35
47	khairajara	12.4	Nn_445	52	242	TRUE	lowland	silty clay loam	8.01
48	Gumia	13.1	Nn_446	53	417	TRUE	Uncultivated	silty clay loam	19.02
49	Gumia	13.2	Nn_447	54	420	TRUE	Upland	silty clay	12.92
50	Gumia	13.3	Nn_448	55	412	TRUE	Middle	clay loam	39.92
51	Gumia	13.4	Nn_449	56	404	TRUE	lowland	silty clay	8.24
52	Sohagarh	14.1	Nn_450	57	193	TRUE	Uncultivated	loam	47.39
53	Sohagarh	14.2	Nn_451	58	199	TRUE	Upland	loamy sand	82.21
54	Sohagarh	14.3	Nn_452	59	181	TRUE	Middle	sandy loam	63.36
55	Sohagarh	14.4	Nn_453	60	171	TRUE	lowland	sandy loam	59.25
56	Tisri Baraipat	15.1	Nn_454	61	241	TRUE	Uncultivated	sandy loam	71.98
57	Tisri Baraipat	15.2	Nn_455	62	259	TRUE	Upland	loamy sand	85.31
58	Tisri Baraipat	15.3	Nn_456	63	246	TRUE	Middle	loamy sand	84.24
59	Tisri Baraipat	15.4	Nn_457	64	246	TRUE	lowland	loamy sand	87.25
60	Debidih- GUMLA	18.1	Nn_458	73	336	TRUE	Uncultivated	loam	46.31
61	Debidih- GUMLA	18.2	Nn_459	74	343	TRUE	Upland	sandy loam	70.37
62	Debidih- GUMLA	18.3	Nn_460	75	324	TRUE	Middle	sandy loam	49.86
63	Debidih- GUMLA	18.4	Nn_461	76	322	TRUE	lowland	loamy sand	81.48
64	Bisunpur Netarhat	19.1	Nn_462	77	262	TRUE	Uncultivated	sandy clay loam	53.31
65	Bisunpur Netarhat	19.2	Nn_463	78	270	TRUE	Upland	loam	49
66	Bisunpur Netarhat	19.3	Nn_464	79	257	TRUE	Middle	sandy loam	78.78
67	Bisunpur Netarhat	19.4	Nn_465	80	241	TRUE	lowland	sand	89.49
68	Tirra/Tisra GUMLA	20.1	Nn_466	81	290	TRUE	Uncultivated	sandy loam	62.27
69	Tirra/Tisra GUMLA	20.2	Nn_467	82	280	TRUE	Upland	sandy loam	69.73
70	Tirra/Tisra GUMLA	20.3	Nn_468	83	281	TRUE	Middle	loamy sand	83.11
71	Tirra/Tisra GUMLA	20.4	Nn_469	84	261	TRUE	lowland	sand	93.05
72	KANASKELI	21.1	Nn_470	85	292	TRUE	Uncultivated	sandy loam	64.44
73	KANASKELI	21.2	Nn_471	86	284	TRUE	Upland	loam	44.59
74	KANASKELI	21.3	Nn_472	87	275	TRUE	Middle	clay loam	41.24

	village.name	new.google.pin	CSHT.LAB.II	sample.ID	elevation	AB	landscape.pos	texture	sand
75	KANASKELI	21.4	Nn_473	88	266	TRUE	lowland	sandy loam	56.48
76	Padma	22.1	Nn_474	89	616	TRUE	Uncultivated	loam	41.35
77	Padma	22.2	Nn_475	90	611	TRUE	Upland	sandy loam	72.2
78	Padma	22.3	Nn_476	91	601	TRUE	Middle	loam	43.19
79	Padma	22.4	Nn_477	92	602	TRUE	lowland	sandy loam	60.79
80	Barahkatha G.T. Road	23.1	Nn_478	93	578	TRUE	Uncultivated	clay loam	38.98
81	Barahkatha G.T. Road	23.2	Nn_479	94	565	TRUE	Upland	loam	47.35
82	Barahkatha G.T. Road	23.3	Nn_480	95	570	TRUE	Middle	sandy loam	58.43
83	Barahkatha G.T. Road	23.4	Nn_481	96	560	TRUE	lowland	sandy loam	77.22
84	Pathratu	24.1	Nn_482	97	612	TRUE	Uncultivated	clay loam	31.59
85	Pathratu	24.2	Nn_483	98	608	TRUE	Upland	sandy clay loam	55.06
86	Pathratu	24.3	Nn_484	99	604	TRUE	Middle	loamy sand	87.6
87	Pathratu	24.4	Nn_485	100	600	TRUE	lowland	loam	41.39
88	Ambala Gadha	25.1	Nn_486	101	490	TRUE	Uncultivated	loamy sand	85.65
89	Ambala Gadha	25.2	Nn_487	102	484	TRUE	Upland	sandy loam	64.28
90	Ambala Gadha	25.3	Nn_488	103	481	TRUE	Middle	sandy loam	62.93
91	Ambala Gadha	25.4	Nn_489	104	474	TRUE	lowland	loamy sand	82.04
92	Ukrid, Hazaribag	28.1	Nn_490	113	399	TRUE	Uncultivated	sandy loam	54.96
93	Ukrid, Hazaribag	28.2	Nn_491	114	390	TRUE	Upland	sandy loam	68.87
94	Ukrid, Hazaribag	28.3	Nn_492	115	384	TRUE	Middle	sandy clay loam	50.23
95	Ukrid, Hazaribag	28.4	Nn_493	116	376	TRUE	lowland	clay loam	23.83
96	Barkidundi	29.1	Nn_494	117	351	TRUE	Uncultivated	loamy sand	84.65
97	Barkidundi	29.2	Nn_495	118	348	TRUE	Upland	sandy loam	77.99
98	Barkidundi	29.3	Nn_496	119	350	TRUE	Middle	sandy loam	72.73
99	Barkidundi	29.4	Nn_497	120	338	TRUE	lowland	loamy sand	85.5
100	Badgunda Kala Kolharia	16.1	Nn_505	65	331	TRUE	Uncultivated	sandy clay loam	60.54
101	Badgunda Kala Kolharia	16.2	Nn_506	66	326	TRUE	Upland	loamy sand	78.69
102	Badgunda Kala Kolharia	16.3	Nn_507	67	319	TRUE	Middle	sandy loam	68.12
103	Badgunda Kala Kolharia	16.4	Nn_508	68	314	TRUE	lowland	sandy loam	78.67
104	Gargaon Bero	17.1	Nn_509	69	255	TRUE	Uncultivated	sandy loam	57.36
105	Gargaon Bero	17.2	Nn_510	70	268	TRUE	Upland	sandy loam	52.24
106	Gargaon Bero	17.3	Nn_511	71	250	TRUE	Middle	clay loam	20.74
107	Gargaon Bero	17.4	Nn_512	72	229	TRUE	lowland	sandy loam	57.12
108	Kadwa Hazaribag	26.1	Nn_513	105	426	TRUE	Uncultivated	sandy loam	70.46
109	Kadwa Hazaribag	26.2	Nn_514	108	408	TRUE	lowland	loam	26.49
110	Godhea, Hazaribag	27.1	Nn_515	109	377	TRUE	Uncultivated	sandy loam	66.63
111	Godhea, Hazaribag	27.2	Nn_516	110	378	TRUE	Upland	clay loam	34.64

	village.name	new.google.pin	CSHT.LAB.II	sample.ID	elevation	AB	landscape.pos	texture	sand
112	Godhea, Hazaribag	27.3	Nn_517	111	366	TRUE	Middle	clay loam	34.58
113	Godhea, Hazaribag	27.4	Nn_518	112	364	TRUE	lowland	sandy clay loam	53.27
114	Padma	22.5	NN_806	121	619	FALSE	Uncultivated	loam	43.3
115	Padma	22.6	NN_807	122	600	FALSE	lowland	sandy loam	58.51
116	Padma	22.7	NN_808	123	608	FALSE	Middle	sandy clay loam	51.15
117	Padma	22.8	NN_809	124	626	FALSE	Upland	silty clay	8.53
118	Pathratu	24.5	NN_810	125	613	FALSE	Uncultivated	clay	30.6
119	Pathratu	24.6	NN_811	126	604	FALSE	lowland	sandy loam	60.42
120	Pathratu	24.7	NN_812	127	605	FALSE	Middle	loam	41.73
121	Pathratu	24.8	NN_813	128	610	FALSE	Upland	silty clay	15.2
122	Bundu-Bhagadih	7.6	NN_814	129	284	FALSE	Uncultivated	sandy loam	63.91
123	Bundu-Bhagadih	7.7	NN_815	130	266	FALSE	lowland	sand	92.24
124	Bundu-Bhagadih	7.8	NN_816	131	287	FALSE	Middle	sandy clay loam	52.18
125	Bundu-Bhagadih	7.9	NN_817	132	288	FALSE	Upland	sand	90.49
126	Kadwa Hazaribag	26.3	NN_818	133	425	FALSE	Uncultivated	sandy clay loam	55.73
127	Kadwa Hazaribag	26.4	NN_819	134	416	FALSE	lowland	sandy loam	62
128	Kadwa Hazaribag	26.5	NN_820	135	413	FALSE	Middle	sandy loam	67.58
129	Kadwa Hazaribag	26.6	NN_821	136	425	FALSE	Upland	sandy loam	67.13
130	Ukrid, Hazaribag	28.5	NN_822	137	402	FALSE	Uncultivated	sandy clay loam	51.3
131	Ukrid, Hazaribag	28.6	NN_823	138	368	FALSE	lowland	clay loam	42.95
132	Ukrid, Hazaribag	28.7	NN_824	139	376	FALSE	Middle	sandy loam	63.14
133	Ukrid, Hazaribag	28.8	NN_825	140	380	FALSE	Upland	sandy clay loam	52.12

	silt	clay	agstab	AWC	OM	actC	prot	resp	pH	P	K
1	22.78	14.52	19.45	0.14	1.24	115.19	1.89	0.09	4.9	4.94	47.7
2	58.84	18.47	14.84	0.28	2.49	134.87	3.64	0.21	4.72	0.81	75.33
3	54.71	17.21	7.41	0.23	2.05	125.92	3.65	0.14	4.51	1.92	59.63
4	51.53	17.65	18.64	0.23	1.96	116.98	2.63	0.27	4.93	0.56	48.76
5	43.2	19.72	6.72	0.23	2.65	413.95	4.06	0.37	6.85	14.21	210.1
6	29.88	15.61	36.71	0.17	1.47	4.27	3.35	0.21	4.89	1	102.74
7	25.77	11.89	52.53	0.14	1.33	163.49	3.24	0.32	6.807	0.56	108.7
8	36.05	23.21	44.02	0.15	1.77	2.48	2.33	0.19	6.753	1	124.25
9	51.71	20.77	22.97	0.26	2.09	122.34	3.46	0.31	6.817	2	116.95
10	45.62	18.25	7.86	0.19	1.77	161.7	1.75	0.19	6.829	1	57.94
11	59.52	19.46	10.85	0.27	2.26	356.7	3.28	0.36	6.786	1	81.84
12	20.64	10.21	17.26	0.13	1.39	97.3	1.92	0.19	5.311	35.11	169.41
13	37.51	22.85	8.64	0.18	2.1	240.42	2.32	0.15	5.589	1	91.22
14	43.98	23.45	20.65	0.25	2.42	315.55	3.26	0.37	5.342	0.11	105.99
15	18.91	14.05	34.48	0.11	1.18	127.8	2.27	0.16	5.868	1.72	111.51
16	13.22	4.14	21.32	0.07	0.24	12.84	0.88	0.06	4.94	5.84	14.52
17	34.54	13.05	14.57	0.18	1.15	16.61	1.73	0.06	5.08	2.13	22.13
18	38.05	16.23	9.64	0.23	1.52	16.7	1.8	0.07	5.23	1.41	30.21
19	10.99	18.88	32.84	0.12	1.38	120.26	1.42	0.11	5.99	0.24	74.3
20	33.38	27.67	12.06	0.23	1.79	197.53	2.05	0.08	5.46	1.03	86.09
21	26.3	27.12	39.12	0.21	2.03	397.3	2	0.18	5.78	0.3	71.5
22	26.81	22.81	24.43	0.23	1.65	267.26	1.91	0.17	5.79	0.99	65.34
23	26.91	18.19	50.72	0.17	1.15	27.92	1.68	0.06	4.75	0.66	39.42
24	16.73	22.59	39.65	0.14	1.67	20.38	1.73	0.09	5.28	0.65	50.68
25	36.09	14.81	10.81	0.22	1.24	35.46	2.19	0.1	5.8	0.7	32.49
26	30.72	15.61	7.25	0.2	1.38	54.3	1.67	0.08	5.496	1.64	28.47
27	47.95	39.22	7.98	0.26	2.43	257.84	1.75	0.13	6.67	0.32	104.28
28	21.43	17.3	20.86	0.23	2.1	27.92	2.49	0.27	5.214	2.53	33.89
29	16.55	11.59	31.28	0.18	1.81	16.61	3.19	0.24	5.227	13.08	70.8
30	16.82	13.9	24.16	0.21	1.93	154.19	1.91	0.21	4.822	2.86	37.97
31	17.53	6.86	25.92	0.2	2.22	318.15	4.41	0.38	6.881	38.14	170.34
32	49.35	15.1	8.76	0.26	2.37	267.26	3.09	0.2	6.007	14.13	256.5
33	63.24	17.7	4.37	0.33	3.07	402.95	3.78	0.25	6.066	25.13	127.29
34	61.65	18.12	8.31	0.32	3.15	255.96	2.63	0.13	6.843	2.46	75.65
35	64.9	26.42	7.83	0.26	2.04	208.84	2.25	0.14	6.453	1.8	66.67
36	26.87	15.24	4.55	0.21	2.66	451.52	5.55	0.13	6.051	13.85	104.79
37	23.69	18.97	5	0.19	1.29	140.18	1.47	0.07	5.388	0.51	64.13

	silt	clay	agstab	AWC	OM	actC	prot	resp	pH	P	K
38	5.57	7.16	15.63	0.1	0.44	31.73	1.12	0.04	5.685	0.79	51.04
39	43.54	20.39	5.18	0.29	2.45	215.39	2.49	0.15	6.525	0	91.99
40	39.31	14.88	5.32	0.19	1.39	92.95	2.44	0.09	5.16	31.89	38.43
41	35.97	12.36	5.36	0.17	1.24	82.46	1.76	0.05	4.577	24.55	52.79
42	38.14	39.8	15.29	0.22	2.8	82.46	1.72	0.07	4.947	0	139.34
43	70.1	24.21	7.22	0.31	2.85	206.65	2.89	0.16	5.29	2.72	99.35
44	38.45	25.11	18.67	0.21	2.71	119.19	3.79	0.21	5.891	0.6	93.11
45	38.75	31.82	29.5	0.24	2.99	288.85	2.41	0.24	7.053	0	94.53
46	46.11	36.54	25.39	0.24	2.2	178.66	0.88	0.2	7.645	0	103.58
47	52.01	39.98	39.14	0.24	2.45	295.85	2.33	0.16	6.731	0	163.49
48	52.79	28.2	9.61	0.29	4.01	498.75	5.02	0.22	6.314	17.09	253.41
49	46.82	40.25	24.87	0.26	3.3	246.87	2.95	0.15	5.918	0	162.06
50	32.51	27.57	16.63	0.23	4.51	225.89	2.75	0.16	6.772	0	84.23
51	41.57	50.19	53.3	0.21	2.51	45.73	0.9	0.15	7.743	0	177.12
52	39.29	13.31	5.18	0.23	2.17	166.42	2.42	0.09	5.544	1.82	45.42
53	11.18	6.61	12.22	0.14	0.72	124.44	1.01	0.07	6.28	2.08	30.62
54	23.15	13.48	6.99	0.18	1.18	175.16	1.58	0.11	7.026	0	28.77
55	27.13	13.63	6.17	0.2	1.35	80.60822824	1.65	0.13	6.35	0.01	31.63
56	13.67	14.35	14.66	0.22	1.99	204.5611059	1.73	0.13	6.292	0	66.57
57	6.56	8.13	7.69	0.16	0.54	114.4135585	1.4	0.05	6.986	2.07	78.24
58	6.54	9.23	7.61	0.17	1	44.92482407	1.17	0.05	6.304	1.13	62.06
59	6.13	6.62	39.92	0.16	0.71	54.31519359	0.24	0.13	6.79	0	57.58
60	30.03	23.66	19.43	0.17	1.93	182.024219	2.14	0.14	7.462	47.62	277.06
61	23.6	6.02	22.44	0.17	0.61	5.485272096	1.52	0.03	4.748	17.07	92.7
62	45.37	4.77	6.76	0.21	2.08	165.1215539	2.34	0.18	6.819	0.56	119.39
63	7.7	10.82	9.11	0.17	0.84	7.363346	0.84	0.08	6.04	2.68	151.48
64	26.26	20.43	6.44	0.28	2.62	475.003748	8.1	0.34	7.316	11.24	250.76
65	31.22	19.77	5.74	0.24	1.42	117.65	1.49	0.02	6.082	0	124.78
66	12.2	9.02	6.18	0.22	0.72	136.58	0.8	0.05	5.818	1.68	20.93
67	6.27	4.24	10.42	0.13	0.33	299.32	0.68	0.1	6.77	5.05	14.58
68	18.03	19.7	9.93	0.18	2.52	255.8	2.29	0.17	5.733	0	41.3
69	11.85	18.42	12.35	0.17	1.09	195.24	1.24	0.06	6.014	0	70.37
70	8.33	8.56	8.89	0.14	0.53	159.29	0.58	0.06	6.381	0.03	19.12
71	3.87	3.08	6.24	0.13	0.15	301.21	0.33	0.05	5.928	2.38	10.59
72	22.13	13.42	9.4	0.19	1.67	236.87	2.73	0.13	6.824	0.69	39.26
73	30.24	25.17	7.76	0.23	2.1	106.3	2.2	0.11	6.693	0	83.04
74	30.69	28.07	23.97	0.22	2.94	178.21	2.5	0.1	6.234	0	78.14

	silt	clay	agstab	AWC	OM	actC	prot	resp	pH	P	K
75	23.83	19.68	15.63	0.19	1.45	219.84	1.85	0.15	7.123	0	65.66
76	32.14	26.51	52.9	0.2	1.59	123.33	1.96	0.08	4.9	0	162.66
77	18.64	9.16	15.94	0.14	0.61	17.36	1.42	0.04	4.873	4.02	64.63
78	30	26.81	8.54	0.2	1.7	119.55	1.94	0.09	6.198	0	126.51
79	20.24	18.97	7.13	0.17	1.23	45.74	1.71	0.06	5.563	16.91	84.5
80	28.38	32.64	18.5	0.21	2.94	180.1	3.35	0.32	6.054	2.59	241.56
81	38.11	14.53	10.18	0.21	1.46	81.7	2.56	0.1	5.353	0.86	62.88
82	25.36	16.22	9.26	0.18	1.47	70.35	2.74	0.09	5.438	1.2	56.98
83	12.61	10.17	15.32	0.16	0.91	28.71	0.88	0.05	5.643	0.42	27.93
84	33.05	35.36	58.61	0.17	2.79	142.26	2.68	0.14	5.663	0	100.98
85	23.92	21.02	9.98	0.21	1.79	117.65	1.97	0.08	6.2	1.89	81.5
86	6.35	6.05	14.33	0.1	0.43	0.327	1.08	0.04	5.529	2.14	33.92
87	36.9	21.71	6.19	0.22	1.75	91.16	2.42	0.15	6.078	9.48	98.67
88	8.28	6.07	23.61	0.1	0.79	19.25	1.89	0.1	5.97	3.05	27.54
89	20.37	15.35	20.85	0.17	1.27	17.36	1.34	0.02	5.561	0	36.85
90	18.09	18.98	35.86	0.19	1.72	15.47	1.76	0.09	6.03	0	42.12
91	9.49	8.46	23.94	0.15	0.89	4.11	1.43	0.06	5.225	0.95	38.97
92	26.31	18.74	13.94	0.22	2.3	144.15	2.52	0.15	6.155	0	63.21
93	19.53	11.6	6.32	0.2	1.35	64.67	1.77	0.08	5.558	0.38	63.98
94	24.13	25.64	11.77	0.24	2.25	187.67	2.31	0.09	6.016	0	62.14
95	45.96	30.21	21.51	0.26	2.47	176.32	2.17	0.17	5.511	0	124.92
96	10.03	5.32	16.92	0.16	1.4	219.84	2.42	0.16	5.247	4.24	79.51
97	10.81	11.19	8.61	0.15	1.06	70.35	0.77	0.08	6.057	2.68	22.52
98	15.8	11.46	5.72	0.17	1.19	100.62	1.22	0.11	5.195	7.99	26.65
99	6.38	8.12	19.2	0.11	0.52	55.21	0.72	0.03	5.888	1.53	20.97
100	13.24	26.22	29.51	0.23	2.21	149.82	1.22	0.13	6.003	0	65.89
101	13.47	7.84	6.23	0.12	0.74	178.21	1.62	0.05	5.966	14.14	40.43
102	20.04	11.84	9.43	0.16	1.33	113.87	1.58	0.07	5.301	0.87	29.62
103	11.93	9.41	8.71	0.13	1.04	140.36	1.48	0.11	5.217	1.41	20.79
104	28.32	14.32	21.77	0.24	2.91	113.87	2.12	0.29	5.344	12.73	119.1
105	31.63	16.12	17.04	0.25	3.18	57.1	2.11	0.13	5.678	0.58	43.49
106	47	32.26	18.54	0.24	2.88	34.39	2.2	0.17	5.049	0	96.43
107	25.65	17.22	9.74	0.18	2.24	212.2732026	1.68	0.12	5.917	0.16	49.44
108	17.2	12.34	6.86	0.13	1.39	234.9817135	2.89	0.12	4.842	0.89	66.94
109	48.88	24.63	5.98	0.22	2.02	333.39	2.04	0.15	8.209	0	95.2
110	21.39	11.97	3.14	0.11	1.29	219.84	2.9	0.25	5.586	13.75	1406.35
111	30.81	34.55	16.2	0.21	3.23	151.72	2.89	0.04	6.016	4.14	65.27

	silt	clay	agstab	AWC	OM	actC	prot	resp	pH	P	K
112	34.65	30.77	30.15	0.21	3.12	214.17	3.29	0.17	6.707	1.99	65.25
113	26.71	20.02	18.15	0.19	1.38	161.18	1.39	0.19	5.982	3.19	75.73
114	33.64	23.06	27.01	0.16	1.49	105.1	1.84	0.1	5.179	1.86	93.02
115	27.01	14.47	2.8	0.18	1.05	80.17	1.43	0.08	5.648	5.25	42.22
116	23.16	25.7	20.88	0.15	1.77	34.74	1.52	0.1	5.312	1.5	78.14
117	50.32	41.15	49.99	0.23	2.48	104.62	0.81	0.12	6.36	1.27	199.8
118	29.36	40.04	37.31	0.18	2.86	113.36	0.94	0.16	6.9	1.08	129.51
119	26.55	13.03	11.89	0.17	0.97	64.44	1.63	0.09	6.286	2.32	53.78
120	34.28	23.99	2.64	0.26	2.15	189.67	2.67	0.16	5.456	1.93	59.32
121	44.25	40.54	26.73	0.22	2.69	44.82	0.38	0.15	8.373	1.34	169.16
122	20.66	15.43	21.98	0.11	1.34	28.72	1.09	0.09	5.845	0.93	40.37
123	4.19	3.57	10.05	0.04	0.3	26.93	1.01	0.1	6.421	1.94	16.52
124	27.6	20.22	21.2	0.17	1.73	78.79	2.26	0.14	5.14	1.66	37
125	5.34	4.17	37.27	0.05	0.4	1.895	0.5	0.03	5.403	2.3	14.32
126	22.18	22.09	21.76	0.17	1.87	53.76	1.44	0.14	6.403	1.02	68.46
127	21.83	16.17	10.7	0.15	0.73	96.68	0.83	0.11	7.494	1.41	50.26
128	18.35	14.08	4.6	0.18	1.24	118.14	1.74	0.12	7.017	1.12	54.85
129	16.34	16.53	6.46	0.16	1.15	30.51	1.55	0.09	6.089	1	53.18
130	25.25	23.46	10.22	0.19	2.68	100.26	1.64	0.12	6.322	1.59	59.05
131	29.61	27.43	13.86	0.19	2.09	35.87	2.19	0.06	5.688	1.32	48.27
132	18.83	18.04	8.62	0.19	1.3	19.78	0.78	0.08	6.751	1.47	73.65
133	17.15	30.73	17.38	0.23	2.21	43.03	0.74	0.08	7.186	0.73	80.69

	Mg	Fe	Mn	Zn	district	site.pin	ubsite.pi	lat.dd	long.dd
1	86.5	1031.04	29.54	1.17	gumla	1	3	22.9673889	84.5226111
2	76.41	222.93	103.86	1.42	Hazaribagh	3	1	23.8999722	85.4471944
3	64.65	869.05	28.79	2.25	Hazaribagh	3	2	23.9011389	85.4480278
4	119.79	770.64	45.71	2.11	Hazaribagh	3	3	23.9019722	85.4494444
5	292.66	1537.32	76.86	6.01	Hazaribagh	3	4	23.9034722	85.4513889
6	99.14	169.23	200.33	0.89	Hazaribagh	3	5	23.9026111	85.4602778
7	91.97	182.47	194.31	1.15	Hazaribagh	3	6	23.9026667	85.4603611
8	192.56	111.49	192.16	0.76	Hazaribagh	4	1	23.9034722	85.4675833
9	132.13	271.45	83.17	2.01	Hazaribagh	4	2	23.9040278	85.4673333
10	149.97	403.72	40.83	1.04	Hazaribagh	4	3	23.9051667	85.4661111
11	211.27	1927.82	143.89	2.95	Hazaribagh	4	4	23.9059444	85.4658333
12	85.97	147.12	120.7	3.15	Hazaribagh	4	5	23.9158333	85.4670556
13	206.87	658.76	47.26	1.47	Hazaribagh	4	6	23.9153889	85.4681667
14	324.86	821	68.73	3.45	Hazaribagh	4	7	23.916	85.4689167
15	94.65	126.83	148.74	1.92	Ranchi	5	1	23.3628333	85.8483333
16	40.79	67.78	3.03	0.53	Ranchi	5	2	23.3651667	85.8450833
17	58.4	146.95	31.14	0.58	Ranchi	5	3	23.3627778	85.8459722
18	129.51	256.03	28.18	0.86	Ranchi	5	4	23.3610556	85.8458611
19	223.51	82.98	102.89	0.48	Ranchi	6	1	23.1616944	85.8504444
20	266.49	155.39	287.12	1.04	Ranchi	6	2	23.16275	85.8504722
21	420.65	373.68	138.01	1.46	Ranchi	6	3	23.1609167	85.8484722
22	337.4	394.91	136.56	0.95	Ranchi	6	4	23.1577778	85.8481389
23	165.23	104.11	162.1	0.61	Ranchi	7	1	23.1653889	85.6498889
24	117.18	84.36	135.87	0.52	Ranchi	7	2	23.1639167	85.6503611
25	142.47	218.76	188.19	0.76	Ranchi	7	3	23.1641667	85.6490833
26	55.12	188.17	27.16	0.45	Ranchi	7	4	23.1658611	85.6496111
27	529.38	97.43	182.32	1.08	Ranchi	7	5	23.1698333	85.6516667
28	140.69	514.89	24.1	3.71	Ranchi	8	1	23.36075	85.4446667
29	25.62	84.48	16.37	1.6	Ranchi	8	2	23.3598056	85.4455
30	36.53	412.82	16.5	1.86	Ranchi	8	3	23.3606389	85.4451111
31	272.55	165.95	235.84	3.96	Ranchi	8	4	23.3573611	85.4441667
32	194.03	312.19	274.84	4.72	Ranchi	9	1	22.9544167	85.649
33	391.46	665.04	46.66	4.41	Ranchi	9	2	22.9553056	85.6496389
34	603.6	331.67	239.46	3.12	Ranchi	9	3	22.9573333	85.6498056
35	376.22	207.03	158.09	1.33	Ranchi	9	4	22.9667778	85.6552778
36	237.76	175.56	59.98	1.72	west singhbhu	10	1	22.7703889	85.5758333
37	224.72	267.18	17.77	1.39	west singhbhu	10	2	22.76875	85.5761667

	Mg	Fe	Mn	Zn	district	site.pin	ubsite.pi	lat.dd	long.dd
38	114.16	124.16	139.23	0.47	ѵest singhbhuı	10	3	22.7654167	85.5735833
39	475.19	333.4	336.29	1.83	ѵest singhbhuı	10	4	22.7633056	85.5709167
40	50.9	190.2	37.8	0.78	Ranchi	11	1	23.3086944	85.0545
41	20.08	184.82	46.1	1.13	Ranchi	11	2	23.30825	85.0531111
42	166.84	79.47	90.82	1.22	Ranchi	11	3	23.3101944	85.0536111
43	91.54	269.13	136.24	1.83	Ranchi	11	4	23.3122778	85.0536667
44	203.88	164.07	414.4	1.71	ѵest singhbhuı	12	1	22.5602778	85.7586111
45	165.69	243.22	211.37	1.73	ѵest singhbhuı	12	2	22.5581111	85.7584167
46	292.88	126.51	222.49	0.89	ѵest singhbhuı	12	3	22.5612222	85.7585278
47	614.55	171.97	249.39	1.93	ѵest singhbhuı	12	4	22.56317	85.75822
48	175.11	177.89	405.25	3.88	ѵest singhbhuı	13	1	22.16453	85.38308
49	436.09	206.91	248.32	1.49	ѵest singhbhuı	13	2	22.16222	85.38286
50	629.26	185.98	283.47	2.16	ѵest singhbhuı	13	3	22.16436	85.38214
51	1070.84	124.78	102.38	1.44	ѵest singhbhuı	13	4	22.16811	85.38208
52	261.15	195.38	170.73	1.66	Bokaro	14	1	23.67336	86.32847
53	110.63	147.38	229.98	1.07	Bokaro	14	2	23.67189	86.33100
54	194.74	127.58	30.66	1.15	Bokaro	14	3	23.67442	86.32561
55	173.72	215.71	123.7	1.4	Bokaro	14	4	23.67628	86.32186
56	436.54	152.17	188.15	1.19	Bokaro	15	1	23.64881	86.07067
57	140.88	101.05	324.97	0.83	Bokaro	15	2	23.66494	86.06042
58	207.35	94.58	356.63	0.74	Bokaro	15	3	23.66172	86.06217
59	602.74	23.02	36.02	0.46	Bokaro	15	4	23.65931	86.06353
60	245.49	264.67	238.52	4.66	Giridih	18	1	24.32125	86.22203
61	24.76	219.67	117.38	1.67	Giridih	18	2	24.31867	86.22317
62	299.24	182.96	200.48	2.45	Giridih	18	3	24.32356	86.22381
63	169.7	96.97	34.08	0.92	Giridih	18	4	24.32478	86.22461
64	352.04	291.79	176.62	1.98	Giridih	19	1	24.65419	86.05292
65	175.06	125.96	206.93	0.83	Giridih	19	2	24.65278	86.05561
66	96.71	137.81	16.27	0.75	Giridih	19	3	24.65400	86.05133
67	93.09	136.44	11.86	0.69	Giridih	19	4	24.65519	86.05064
68	342.01	138.7	110.87	0.94	Giridih	20	1	24.15450	86.22114
69	228.51	144.83	203.83	1.37	Giridih	20	2	24.15264	86.22289
70	152.33	181.95	13.94	0.71	Giridih	20	3	24.15264	86.22531
71	59.38	146.81	2	0.55	Giridih	20	4	24.15133	86.22772
72	322.71	232.16	290.84	1.53	Giridih	21	1	23.98978	86.05742
73	454.92	243.44	317.26	1.98	Giridih	21	2	23.98867	86.05672
74	495.87	190.74	351.71	1.89	Giridih	21	3	23.98658	86.05625

	Mg	Fe	Mn	Zn	district	site.pin	ubsite.pi	lat.dd	long.dd
75	485.98	198.14	347.73	2.03	Giridih	21	4	23.98325	86.05472
76	98.4	105.82	59.22	0.56	gumla	22	1	23.16169	84.54072
77	36.2	99.89	88.76	0.48	gumla	22	2	23.16094	84.53900
78	269.39	147.74	294.43	1.45	gumla	22	3	23.16303	84.53814
79	111.18	136.38	95.4	0.63	gumla	22	4	23.16389	84.54050
80	226.58	115.26	152.13	0.88	gumla	23	1	23.48908	84.35758
81	96.88	145.4	252.25	1.14	gumla	23	2	23.48753	84.35950
82	96.65	118.41	177.33	0.86	gumla	23	3	23.48928	84.35783
83	148.98	267.17	22.51	0.97	gumla	23	4	23.49053	84.35747
84	213.89	97.32	117.3	0.84	gumla	24	1	22.98906	84.53744
85	252.4	229.53	214.29	1.22	gumla	24	2	22.98783	84.53678
86	79.71	107.77	41.87	0.61	gumla	24	3	22.98686	84.53786
87	279.97	190.63	221.87	1.9	gumla	24	4	22.98511	84.53878
88	47.34	76.56	90.78	0.67	gumla	25	1	22.81297	84.88650
89	93.03	139.97	37.89	0.48	gumla	25	2	22.81317	84.88800
90	176.06	200.59	253.68	0.53	gumla	25	3	22.81561	84.88575
91	106.31	157.7	109.75	0.44	gumla	25	4	22.81761	84.88392
92	394.98	257.91	249.04	3.18	Hazaribagh	28	1	23.65117	85.23478
93	136.02	132.25	102.22	1.79	Hazaribagh	28	2	23.65250	85.23331
94	423.92	175.44	291.97	1.64	Hazaribagh	28	3	23.65372	85.23219
95	623	157.5	160.34	1.63	Hazaribagh	28	4	23.65506	85.23022
96	54.14	68.05	46.01	0.9	Hazaribagh	29	1	23.66261	85.59831
97	57.67	151.3	34.86	0.7	Hazaribagh	29	2	23.66353	85.59294
98	64	257.64	27.93	0.96	Hazaribagh	29	3	23.66028	85.59450
99	55.52	195.6	38.81	0.65	Hazaribagh	29	4	23.65756	85.59419
100	244.04	93.68	110.16	1.04	Bokaro	16	1	23.65881	85.81539
101	36.73	105.4	54.79	0.57	Bokaro	16	2	23.65750	85.81506
102	100.89	219.91	336.9	1.6	Bokaro	16	3	23.65592	85.81133
103	34.46	377.85	41.05	3.29	Bokaro	16	4	23.65503	85.80769
104	201.68	146.34	113	2.64	Bokaro	17	1	23.78656	85.81669
105	152.66	220.77	165.27	1.58	Bokaro	17	2	23.78744	85.81653
106	433.72	187.32	162.61	1.8	Bokaro	17	3	23.78878	85.81450
107	325.14	174.89	157.58	1.53	Bokaro	17	4	23.78267	85.81717
108	103.9	112.17	204.24	1.24	Hazaribagh	26	1	24.22536	85.40253
109	462.09	157.98	182.45	1.21	Hazaribagh	26	2	24.22786	85.39822
110	137.05	143.52	114.66	0.78	Hazaribagh	27	1	24.17911	85.59414
111	209.18	232.69	163.51	1.65	Hazaribagh	27	2	24.18069	85.59219

	Mg	Fe	Mn	Zn	district	site.pin	ubsite.pi	lat.dd	long.dd
112	515.34	215.27	263.85	1.86	Hazaribagh	27	3	24.18083	85.59586
113	327.62	233.5	184.26	1.23	Hazaribagh	27	4	24.18033	85.59803
114	82.73	136.91	142.38	0.59	gumla	22	5	23.16178	84.54053
115	116.64	368.76	52.08	0.76	gumla	22	6	23.16389	84.54017
116	95.05	77.3	92.41	0.44	gumla	22	7	23.16186	84.53869
117	788.33	102.46	44.88	0.87	gumla	22	8	23.16017	84.54042
118	389.85	68.13	49.93	0.57	gumla	24	5	22.98900	84.53736
119	166.22	213.01	178.65	0.71	gumla	24	6	22.98514	84.53906
120	238.36	943.94	131.53	1.83	gumla	24	7	22.98692	84.53633
121	756.67	89.48	80.82	1.16	gumla	24	8	22.99714	84.53806
122	147.11	106.25	192.34	0.42	Ranchi	7	6	23.16531	85.64992
123	90.04	509.35	178.04	1.01	Ranchi	7	7	23.16894	85.65319
124	129.4	189.07	253.52	0.64	Ranchi	7	8	23.16531	85.64967
125	12.33	53.55	30.18	0.32	Ranchi	7	9	23.16403	85.64983
126	301.31	207.92	242.31	0.86	Hazaribagh	26	3	24.22736	85.40336
127	227.55	103.18	60.65	0.89	Hazaribagh	26	4	24.22675	85.39825
128	235.49	150.37	194.91	0.76	Hazaribagh	26	5	24.22644	85.40125
129	171.95	164.1	137.02	0.47	Hazaribagh	26	6	24.22739	85.40158
130	318.72	306.68	117.4	2.02	Hazaribagh	28	5	23.65950	85.23478
131	140.95	202.81	464.73	0.38	Hazaribagh	28	6	23.65417	85.22886
132	373.01	206.57	104.73	1.39	Hazaribagh	28	7	23.65406	85.23000
133	720.66	98.56	83.28	0.56	Hazaribagh	28	8	23.65325	85.23308