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Geo-statistical assessment of soil quality and identification of Heavy metal contamination using Integrated GIS and Multivariate statistical analysis in Industrial region of Western India

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ABSTRACT

Soil systems are one of the most dynamic natural systems, interlinking several crucial life sustaining processes on Earth. Soil quality is degrading faster than ever, and industrial activities can be attributed as prime contributors to it. The Bagru textile Printing and Dying industrial region in Rajasthan, (India) is integral to its economy. However, the continuous discharge of effluents is slowly degrading the quality of soil and water to support life and agricultural systems. The current research aims to examine the existing quality of soil in the Bagru region of Rajasthan. A Comprehensive quantitative soil quality evaluation has been attempted based on Minimum set of interlinked biophysical and Chemical parameters in an Integrated GIS environment, applying Multivariate Statistical methods: PCA, CCM, CA, FA. PCs with eigenvalue >1.0 following Kaiser, subjected to varimax rotation were kept accounting for 77.889% of the total variance of the data, and has high loading on Mn and S. A higher average Concentration of elements like Potash (K = 325.6000 kg/ha, R^2 = 0.1844.), Phosphorous (P = 28.3243 mg kg^{-1}, R^2 = 0.0125), Sulphur (S = 20.3130 mg kg^{-1}, R^2 = 0.0544) was recorded along with pH >8, (alkaline soils). The results also indicate higher concentration of heavy metal contamination around the Industrial complex with their average values in order: Iron (Fe 5.9782 mg kg^{-1}), >Manganese (Mn 4.2093 mg kg^{-1}), >Zinc (Zn 3.4509 mg kg^{-1}) >Copper (Cu 0.1701mg kg^{-1}). The overall result reveal 46% of degraded and low-quality soil with Average SQI value of 0.482 in the region.

1. Introduction

Soil is one of earth's most indispensable resource linking fundamental natural processes across spheres, fabricating web of ecosystem services essential for sustenance. Soil systems are biologically diverse environments on which astounding number of organisms thrive (Coleman, 2015). Forming top layer of earth's crust, primarily composed of minerals (45%),

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Symbols and Abbreviation

AAS	Atomic Absorption Spectrophotometer
As	Arsenic
$CaCl_2$	Calcium dichloride
Cd	Cadmium
Cr	Chromium
Cu	Copper
CA	Cluster analysis
CV	Coefficient of variation
CCA	Correlation coefficient analysis
CCM	Correlation coefficient matrix
CM	Correlation matrix
DTPA	Diethylenetriaminepentaacetic acid
EC	Electrical Conductivity
FA	Factor analysis
FAS	Ferrous ammonium sulphate
Fe	Ferrum (Iron)
GIS	Geographic information system
GPS	Global positioning system
H_2SO_4	Sulphuric Acid
H_3PO_4	Phosphoric acid
HNO_3	Nitric acid
ICP-MS	Inductively coupled plasma mass spectrometry
K	Potash (Potassium)
kg/ha	Kilogramme per hectare
KMO	Kaiser–Meyer–Olkin
mg	Milligramme
mg kg^{-1}	Milligrammes per kilogramme
MV	Mean values
Mn	Manganese
NaF	Sodium fluoride
$NaHCO_3$	Sodium bicarbonate
NH	National Highway
Ni	Nickel
OC	Organic Carbon
OM	Organic matter
PC	Principle Component
PCA	Principal component analysis
P	Phosphorous
Pb	Lead
RIICO & RSMDC	Rajasthan State Industrial Development and Investment Corporation
S	Sulphur
SD	Standard deviation
SOC	Soil organic carbon
SOM	Soil organic matter
SQI	Soil quality index
Sn	Stannum (Tin)
SPSS	Statistical Package for the Social Sciences
S_1- S_{15}	Soil Sample
TEA	Triethanolamine
V	Vanadium
Zn	Zinc
μS/m	Micro-siemens per metre
MDS	Minimum Data Set

water (25%) air (25%) and organic matter (5%), the soil balances the pool, exchange, and mobilization of nutrients, sustains plants and animals, maintains food and nutritional security. An optimum quality of soil is intrinsic to balance the environmental processes, foster biological productivity and stimulate health of dependent life forms (both flora and fauna) in a given ecosystem (Karlen et al., 1997). The viability and quality of soil is not only closely associated with natural environment, but also human health, socio-economic wellbeing, (Yu et al., 2018), food and nutritional security around the globe (Kopittke et al., 2019).

In recent past the intensification of human activities, primarily rampant urbanization and tremendous industrialization have imperilled the natural environment, and soils being ubiquitous are most vulnerable to it (Kibblewhite et al., 2012). Soil systems are greatly influence by accelerated human activities, which in turn affect the functioning of environmental systems on which humans are dependent too (Proshad et al., 2018; Puskás and Farsang, 2009). The unbridled industrial and agricultural practices, drastic urban expansion, improper waste disposal etc. especially in developing country like India are resulting into gradual degradation of soil, leading to different types of soil pollution problems (Osman, 2014; Sehgal et al., 1994). It has either resulted in total degrading of soil or diminished its abilities to resuscitate its biological functions (Hu et al., 2013). The close interaction of soil with other environmental pools (water and atmosphere) also exemplifies its degradation. Ongoing biogeochemical circulations between them can significantly impact mobility, solubility, distribution and dispersion of contaminants in and out of the soil system affecting soil matrix (Hesterberg, 1998).

The industrially induced soil pollution is most common in developing countries like India and is often subjected to Heavy metal contamination also, such as, Zn, Pb, Cd, Cr Cu, As, V, Ni, and Sn (Hanfi et al., 2019). These compounds have been found to be notably biologically toxic (Su et al., 2014; Yang et al., 2016; Zojaji et al., 2014). The toxicity of these compounds is primarily because of their non-biodegradable nature, biomagnification, bioaccumulation properties and their perpetual ability to persist in soil environment for long (Ali et al., 2019; Luo et al., 2012). Their short term, but frequent or prolonged exposure have been linked to instigate several chronic diseases, degenerative illnesses and prolonged health complications in human beings (Järup, 2003; Real et al., 2017). Due to their bio accumulative and bioaccessibility properties, heavy metal contamination in soils can easily penetrate into the food chain and water etc. and over time can transfer into the human body through food, skin absorption etc. causing severe health implications (Gu et al., 2016; Karimi-Maleh et al., 2021; Rajendran et al., 2022). The excessive accumulation of trace elements like Cadmium, Lead and Nickel in plants have been observed to induce toxicity, retard their growth and inhibit productivity (Pandey and Sharma, 2002; Zouboulis et al., 2004).

Soil ecosystems are highly dynamic with complex interaction between physio chemical variables and biological communities, it is therefore, difficult to evaluate its quality by assessing variables individually (Hanfi et al., 2019; Yang et al., 2016). Contemplating the indicators of soil is also particularly difficult because of the magnitude and multiplicity of functions, it performs to maintain environmental productivity. Quantitative assessments of soil quality and health require cogitation of multivariate functions that soil conducts, their distinction in space and time (Doran and Parkin, 1997). Therefore, indicators for assessing the soil quality inclusively integrate physical, chemical, and biological attributes of soil.

Since, the overall quality of soil in any region is the reflection of its chemical, physical and biological parameters, taken together (Griffiths et al., 2010; Hermans et al., 2020). The present article presents a holistic assessment of soil quality near Bagru Industrial region in Rajasthan, India based on comprehensive quantitative evaluation of Minimum set of interlinked biophysical and Chemical parameters. It also intends to investigate the content of heavy metals in the soil Near Bagru industrial area and surrounding agricultural lands by applying PCA, CCM, CA and FA methods. Contents of Cu, Zn, Mn, and Fe are also assessed based on 15 soil samples acquired from the vicinity of Bagru Industrial region, which differ in their location and are marked from S_1 to $S_{15.}$ (Table 1). All the observations are produced based on combination of Intensive Laboratory based chemical analysis, Multivariate geo-statistical assessment, Soil Quality Indexing and GIS based comparative evaluation of all the soil parameters. The techniques and methods applied in the study have not been attempted so far to investigate the quality of soil, in the western part of India, Rajasthan which is dominated by printing and dying industrial units along with intensive agricultural practices. The socio- economic condition of the small town Bagru, in Rajasthan, (India) showcases typical condition persisting in many developing countries with industrial units crawling into agricultural spaces resulting into heavy degradation of water and soil systems. The method applied in this study therefore also validates the reliability of results hence amalgamation of such techniques can be replicated for soil quality assessment studies in given or similar environments in other regions also.

2. Materials and methods

2.1. Description of the study area

The study area for the current research lies in the agricultural tracts near Bagru Industrial region, located in the south western part of Jaipur district in the state of Rajasthan (India) between 26°48″07″ to 26° 50″18″N and 75°32″07″ to 75°34″06″E. Fig. 1. With 41.65 sq.kms of area, the Town is located on NH-8, 30 kms, south west of Jaipur City (Singh et al., 2015). The region lies in the semi-arid zone of Rajasthan with average annual temperature ranging from 20 °C to 48 °C. The Average annual rainfall is 600 mm, of which 90% is experienced in 3 months between July to September. The terrain is mildly sloped with average altitude of 310 to 360 m. The region is famous for cloth printing, natural dyes,

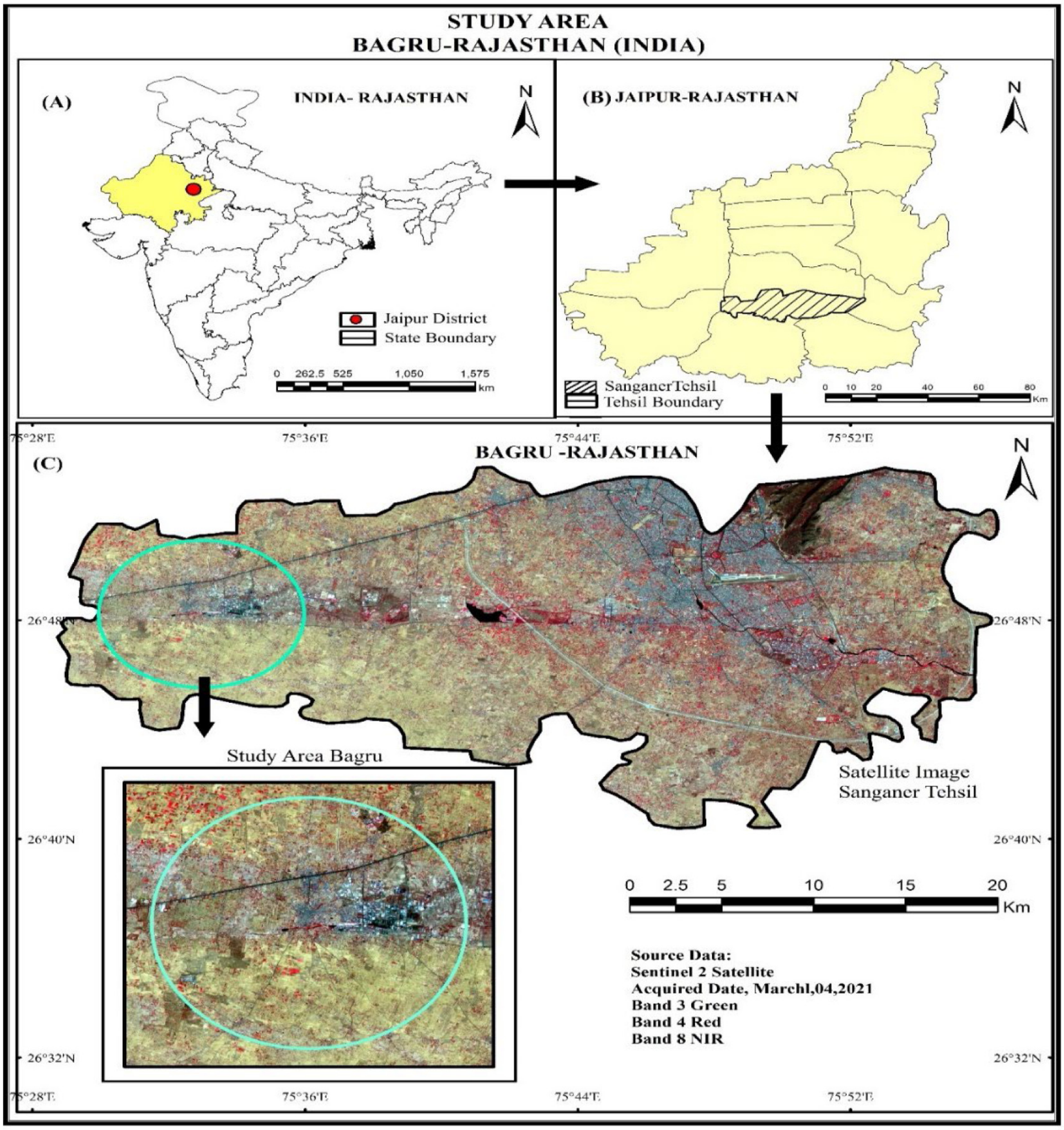

Fig. 1. Study Area — Bagru, Jaipur, Rajasthan.
Source: (Sentinel 2 data)

wooden hand block prints widely known as "Bagru Prints" with traditional history of more than 300 years. This traditional printing has been means of livelihood for thousands of indigenous craftsmen belonging to generations of local tribes of the region.

Bagru was primarily an agricultural region, but over the last decade Textile and dying industries remarkably proliferated into the adjacent agricultural space. With more than 250 individual printing units clustered together it has emerged as one of the prominent centre of printing and dying industries today. While traditionally only natural dyes were being used, growing demand, cheap production cost commenced the use of synthetic, chemical dying as well. The region with densely located dyeing and printing industrial units discharges tons of untreated industrial effluents, harmful chemical into the nearby water systems, agricultural plots, and open lands leading to soil and water pollution (Sharma et al., 2014). The dumped contaminated water into the soil is a grave threat to aquatic and terrestrial biodiversity and severely hazardous to human health as well (Trivedi and Verma, 2016). It can severely hamper the quality of agricultural output in the region thereby potentially affecting food nutrition and overall health. It also inhibits soil's original ability to carry on its physio-biological functions altering its physio-chemical properties over the course of time, degrading the overall ecosystem services of the region.

Table 1
Description of soil sample site location — BAGRU.
Source: Primary data.

Sample points	Latitudinal and Longitudinal position	Elevation (m)	Description
S_1	26.5008 N, 75.3053 E	363	Agriculture field North east of Industrial region
S_2	26.5026 N, 75.3234 E	369	Agriculture field North of Industrial region
S_3	26.4957 N, 75.3409 E	368	Agriculture field, North East of Industrial region
S_4	26.4744 N, 75.3511 E	354	Agriculture field, west of Industrial region
S_5	26.4617 N, 75.3413 E	350	Agriculture field, south of Industrial region
S_6	26.4543 N, 75.3256 E	348	Agriculture fields, south of Industrial region
S_7	26.4555 N, 75.3127 E	346	Agriculture field, South west of Industrial region
S_8	26.4645 N, 75.3015 E	353	Agriculture field South West of Industrial region
S_9	26.4802 N, 75.2955 E	344	Agriculture field, West of Industrial region
S_{10}	26.4912 N, 75.3014 E	350	Agriculture field, North West of Industrial region
S_{11}	26.4938 N, 75.3153 E	361	Agriculture field, North of Industrial region
S_{12}	26.4720 N, 75.3110 E	350	Agriculture field, West of Industrial region
S_{13}	26.4654 N, 75.3240 E	359	Agriculture field, south of Industrial region
S_{14}	26.4724 N, 75.3358 E	359	Agriculture field, south of Industrial region
S_{15}	26.4829 N, 75.3103 E	347	Agriculture field, West of Industrial region

2.2. Soil collection sites and soil sampling

To ascertain the overall Soil Quality of the agricultural land and level of soil pollution induced from industrial waste, quantitative soil assessment is conducted in the vicinity of Bagru Industrial region encompassing New Industrial area (RICCO), and (RSMDC) industrial zone. To access soil contamination induced from industrial effluents, soil samples from random 15 location sites from within the 5 kms radius of Bagru Industrial region were gathered. Basic essential cleanliness standards were followed during sampling and plastic tools were preferred over metal ones. 250 g of soil samples were extracted and gathered randomly in triplicates from 15 different sample location sites, within the depth range of 45 cm to 60 cm. (Table 1, Fig. 2). All the samples were gathered in a clean plastic zip lock container and double sealed. The samples, and each collection site have been marked from S_1 to S_{15} and accurately geo-tagged using Garmin GPS (Global positioning system) device (model 68s) which helped retrieving wide variety of location-specific information (Luo et al., 2011). The location site description is given in (Table 1, Figs. 2, 3) All the collected samples were evaluated using numerous geo-statistical, and laboratory analysis techniques to contemplate the soil quality of the region.

2.3. Chemical analysis

Identifying indicators of soil quality is cumbersome, since soil systems are highly dynamic with multivariate functions, sustaining several Bio-physical and environmental systems in tandem. Integrating several aspects of physio-chemical, and biological soil attributes, in order to understand the functional diversity of soil systems, is complex. However qualitative assessment of soil systems required evaluation of these in an environment considering variation in spatio-temporal scenario (Doran and Parkin, 1994). The soil quality assessment has been attempted on several occasion using varying physio-chemical and Biological indicators (M. A. (Charlie) Arshad et al., 1997; Arshad and Coen, 1992; Cambardella and Karlen, 1999; Filip, 2002; Lowery et al., 1997; Schloter et al., 2003; Smith et al., 1993). For the particular study, the collected 250 g of soil samples form varying depths covering 15 different location sites have been assessed on the basis of elaborated laboratory based physio-chemical analysis of 10 functional indicators of soil quality (Doran and Parkin, 1997; YanBing et al., 2009). These 10 physio-chemical indicators include pH, EC, OC, P, S, K, Zn, Fe, Cu, and Mn. Six of the 10 elements P, S, Zn, Fe, Cu, and Mn were measured and recorded in mg/kg, K in kg/ha. EC in (μS/m), SOC in percentage (%), and pH based on pH acid and base scale. The calculations were completed to obtain each analyte in their unit values for all soil samples in triplicates. Then, the average of all set of triplicates was calculated and that value was recorded into the data table (Juhos et al., 2019).

pH:- is one of the indigenous functional component for evaluating the quality of soil (Filip, 2002). Significant variation in field may exists in Soil pH and depth at with soil pH constraint reaches, Adamchuk et al. (2007) and is also related to its fertility and regeneration capacity. Ideal pH facilitates nutrient mobilization, microbial activity and nutrient availability in soil for plant uptake (Karthika et al., 2018). The "ideal" soil pH is close to neutral, and are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5″ (Jensen, 2010). For the study, the Soil pH was measured on each triplicated soil sample using a pH probe and meter. The probe was calibrated using pH standards of 7 and the scale was calibrated with its automatic internal calibration. 20 ml of double distilled water was mixed with 10 g of dry soil in a 50 ml glass beaker. Each sample was placed on a shaker on low speed for 10 min, and removed for 1 hr until complete separation of solid and liquid was confirmed. It was carefully filtered thereafter using filter paper. The pH of soil was measured using an appropriate electrode connected to a glass electrode pH meter which was immersed in the obtained filtered liquid soil sample. The pH probe was placed in the liquid portion of the tube for reading, and the soil

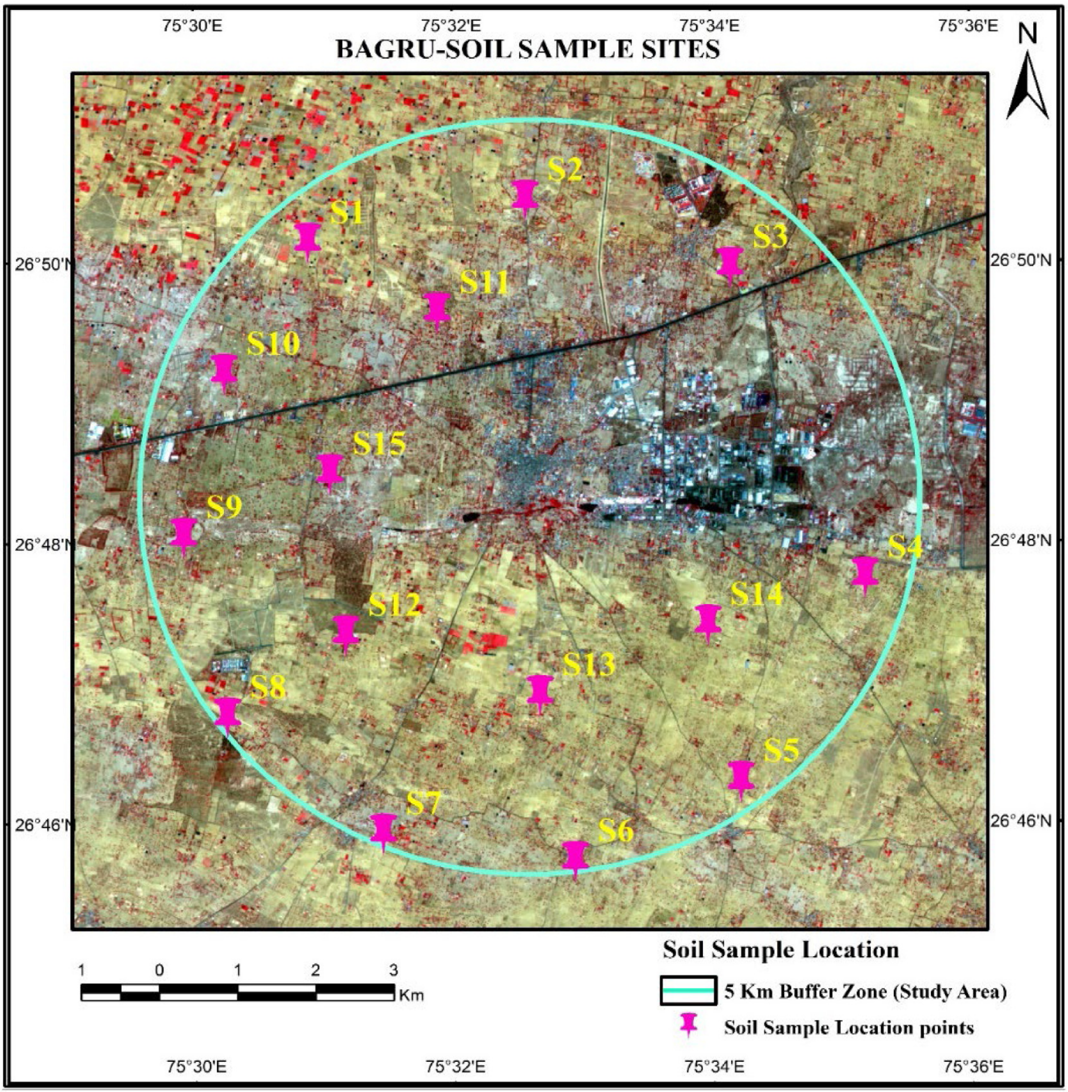

Fig. 2. Soil sample location sites — Bagru, Jaipur.
Source: (Sentinel 2 data)

pH measurement was recorded (Schofield and Taylor, 1955; Sumner, 1994; Thomas, 1996). The process was repeated for each soil sample.

EC: represents the level of salinity in soil and is important indicator of its quality (Hardie and Doyle, 2012). The electrical conductivity (EC) was measured the same way as the pH, an electrical conductivity meter (a calibrated EC probe and instrument) (McNeill, 1992; Rhoades and Corwin, 1981). The calibrated EC probe was placed into the liquid portion of 1:1 soil solution (deionized water) for reading. The EC was recorded for each soil sample and average was calculated from all three reps. for each soil (Amacher, 1996).

Soil organic carbon (SOC) — is the organic fraction of soil which includes organic residue (plants and animals) at different levels of decomposition. It is directly and indirectly related to the physico-chemical properties of the soil (Campbell, 1978). Organic Carbon estimation makes up more than half of soil organic matter (SOM) by weight hence allows to determine SOM efficiently (Sikora and Stott, 1997). Its concentration is one of the significant indicator of soil quality (Unger, 1997). For the study, the soil sample sets were dried and thoroughly sieved with 2-mm strainer (0.5) for organic carbon estimation. The Walkley–Black titration method (Walkley and Black, 1934) is used to estimate the content of soil organic carbon in the soil. This method involved the oxidation of organic matter in the presence of sulphuric acid with known amount of chromate which quantify the content of oxidizable organic matter in soil (Gelman et al., 2012; Sato et al., 2014). Under the process, in a 500 ml conical flask 1gm of soil sample is taken and 10 ml of 1N $K_2Cr_2O_7$ solution

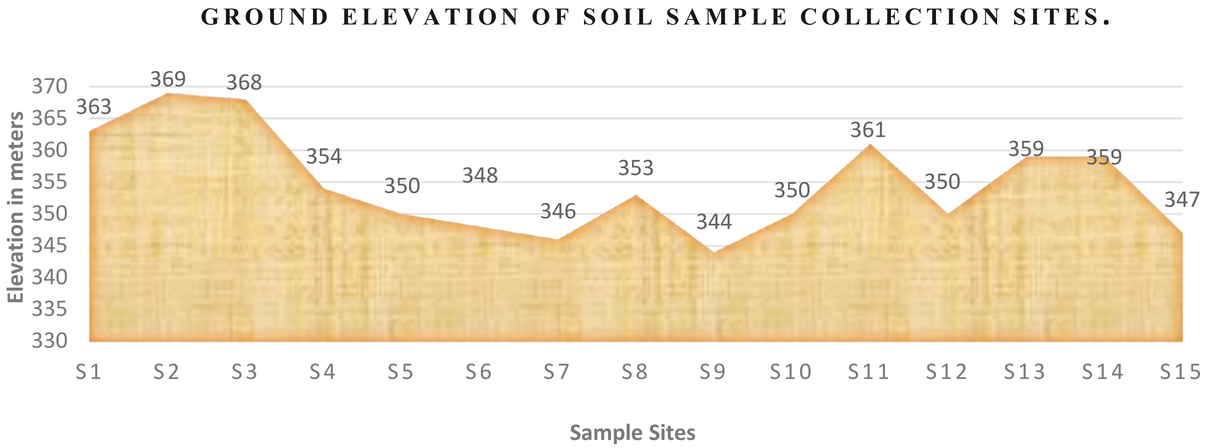

Fig. 3. Ground elevation of Soil sample location sites.
Source: (Primary data)

along with 20 ml of concentrated conc. H_2SO_4 is mixed to it and the reaction is allowed for about 30 min. Thereafter, 200 ml of distilled water is added to dilute the solution of 10 H_3PO_4 solution and 10 ml NaF, finally 2 ml diphenylamine is added to it and remixed thoroughly. After cooling, the solution is then titrated to acquire brilliant green colour using standard FAS solutions. In addition, a blank sample is run parallel to it in a 500 ml conical flask without soil (FAO, 2020; Morona et al., 2017).

Phosphorus, Sulphur & Potash

P (Phosphorus):- is one of the primary macro nutrient after Nitrogen in soil, essential for determining the overall soil fertility, plant growth and agricultural productivity (Malhotra et al., 2018). Similarly, presence of sulphur in soil is also attributed to its fertility, pH levels, plant growth and efficient nitrogen fixation process (Jordan and Ensminger, 1959). A test of an ascorbic acid method by Olsen 1954 is applied to detect the phosphorus content in the soil. According to the theory: phosphorus is extracted from the soil with 0.5M $NaHCO_3$ at a constant pH of about 8.5. and phosphate ion in the solution at a nearly constant pH of 8.5 when treated with ascorbic acid in an acidic medium to provide a blue colour solution complex which determines the amount of phosphorus in the soil (Olsen et al., 1954). In the phosphorus test method, 2 ppm standard phosphorus solution of 0,1,2,3,4,5 mL etc. is taken. All these standard varying concentrations of phosphorus have been taken into a 25 ml volumetric flask. A 5 ml 0.5M $NaHCO_3$ extracting solution is poured into each flask and then 5N H_2SO_4 is added by dropper for acidification. After this, 10 ml of distilled water and 4 ml of reagent is poured into the "B" volumetric flask followed by the solution of the volumetric flask. Thereafter, 25 ml of distilled water is added. Finally, after 10 min the blue intensity at 660 nm and wavelength is noted through UV spectrophotometer. The extractable P present in the topsoil is separated by adding 0.01 M CaCl2, in the soil sample. The extract solution obtained from the topsoil is further treated to extract subsoil, and the third-layer soil is further extracted using the extract solution from the subsoil at a soil/solution ratio of 1:5. The S and P contents are determined by using a UV-V spectrometer after the final solution was filtered and analysed. Phosphorous from the soil is further determined post extraction by 0.5 m $NaHCO_3$. The phosphate ion in the solution provides a blue colour complex at a nearly constant pH of 8.5. when treated with ascorbic acid in an acidic medium (Murphy and Riley, 1962; Olsen et al., 1954).

Sulphur: — Soil solution contains Sulphur along with other minerals. Sulphur presence in the soil is mainly found in adsorbed SO_4 ions. Priority is the substitution of SO_4 ions, with a preference for substituting phosphate ions for adsorption. Phosphate ions are in the form of monocalcium phosphate. The extraction is conducted by $CaCl_2$ solution (Calcium salt is better useful for easier filtration) which involves the substitution of previously improved SO_4 ions in a more efficient manner. The turbulence approximation of SO_4 extracts is detected by a colorimeter/spectrophotometer. If the sulphur content remains very low in soil, it becomes difficult to measure it efficiently. To avoid this problem, a seed solution of known Sulphur concentration is added thereby increasing the concentration to a desirable level. Thereafter the Sulphur in extracted soil solution is estimated through barium chrome using a colorimetric method (Palaskar et al., 1981; Németh, 1963). Also Turbid metric method is used for detection of sulphur in soil (Chesnin and Yien, 1951). In this test, a 20-g soil sample is taken in a 250 ml conical flask and mixed with 100 ml monocalcium phosphate extract solution, stirred for 1 h and then filtered using Whatman no. 42 filter paper after 1 h. Post filtration 10 ml extract is poured into a volumetric flask of 25 ml. This is followed by addition of 2.5 ml of 25% HNO_3 and 2 ml acetic-phosphoric acid in it. The solution is then diluted to 22 ml and flask is closed and shake well. The $BaSO_4$ seed suspension is shaken well and 0.5 mL is poured into the volumetric flask and then 0.2 g of $BaCl_2$ crystals are thoroughly mixed by pulsing the $BaCl_2$ crystals and the solution is turned upside down for 10 min. 1 ml gum acacia-acetic acid solution is added to increase the volume and kept for 90 min. The wavelengths are then noted at 440 nm (blue filter) using the UV spectrophotometer.

Potash (K): — is another essential macronutrient in soil which is essential for maintaining soil pH balance and its fertility. Its presence in soil boost protein development, enzyme synthesis, nitrogen fixation and mobilization in plants. Since plants take up large quantities of K during their life cycle, and is often added through fertilization process to soil if found deficit (Morgan and Connolly, 2013). However its deficiency and excess in soil both have been related to soil quality and degradation (Sillanpää, 1982). Following the method describe by Lu (1999), and using flame-photometer the content of Potash in soil was determined. Extraction was carried out by ammonium acetate. Only after emission spectrometry, interchangeable potassium was determined in extraction. The test of potash in soil was determined by the flume-photometer (Jackson, 1969; Lu, 1999).

Heavy Metals in Soil: - Micronutrients and heavy metals are naturally present micronutrients in soil although their increased accumulation is dangerous due to advancing human activities. Industrial waste generated soil pollution contains alarming quantities of such hazardous metals which are detrimental for human and ecological health (Ahmadi Doabi et al., 2019; Gu et al., 2016; Tepanosyan et al., 2018). Certain essential heavy metals like Zn, Cu, Fe, etc. are essential in traces to support plant and animal metabolisms including human beings. However, when such elements accumulate in excess can inhibit plant growth as well have long term detrimental impact on human health (Hanfi et al., 2019). Typically, residuals generated from industrial areas contain many hazardous chemicals, like Cr, Pb, Mn, Fe, Cd, As, Ni, Cu, Zn, and V, and Sn which are often dumped directly into surrounding natural environment. Most of them remain hazardous, mainly because of their specific properties of persistent biomagnification in food chain, non-degradation and bioaccumulation in the environment (Weissmannová and Pavlovský, 2017; Wuana and Okieimen, 2011). The soil toxicity near industrial regions is further aggravated due to presence of acidifying compounds and other soil constituents like pH, SOM, EC etc. which continuously interact with these heavy metals and intensify conditions of their accumulation, mobilization, absorption and bioavailability in soil (Morton-Bermea et al., 2010).

Several studies have been conducted in the past 100 years to study the Heavy metal pollution with emphasis on their origin, distribution within soil profile and bio environmental implications (Kuzmanoski et al., 2014; Solgi, 2016). Various commonly acceptable analytical techniques such as, AAS, ICP-MS, ICP-OES, ICPOES, XRF and much recent ICPOES have been used over the years for determination of heavy metal concentration such as Cr, Cu, Pb, Zn, Cd, and Ni in environment (Fergusson and Ryan, 1984; Harrison, 1979; Madany et al., 1994; Zhang and Wang, 2009). In the particular study the Testing of heavy metals Zn, Cu, Mn, Fe have been done following DTPA-Extractable protocol wherein 0.005 M DTPA is used along with atomic absorption spectrometry equipment to determine the heavy metal concentration in soil (Lindsay and Norvell, 1978; Soriano et al., 2007). Sequential extraction for soil was done according to the method described by *Tessier 1979* wherein the soil samples were filtered in sequence and dried in air (Tessier et al., 1979; McGrath, 1996). The DTPA-extractable method uses 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M TEA (Fonseca et al., 2010; Lindsay and Norvell, 1978; Zhu et al., 2012) to determine heavy metal concentration.

2.4. Geo-statistical analyses

A comprehensive assessment of various soil quality indicators has been conducted to accurately access the overall quality of soil in the region. The quantitative evaluation is based on combination of physio chemical, geotechnical, physicochemical analysis of soil samples along with application of descriptive statistics and statistical modelling. The result data is obtained after chemical testing of selected soil samples in the chemical laboratory which are thereafter evaluated with data analysis on SPSS software (version 22 for Windows). Many statistical methods are involved in data analysis and data analysis models including SD, MV and CV have been used (Li et al., 2016; Zhu et al., 2019). Along with this, the SQI has been compiled to ascertain the overall soil quality of the area using site-specific indicator evaluation outputs. The SQI method is one of the most useful and frequently used method to ascertain soil quality (Arshad and Martin, 2002; Wang and Gong, 1998; YanBing et al., 2009). The indicators taken for the study include specific soil properties that are sensitive to changes in soil functions (Doran and Jones, 1996). In combination with Laboratory generated output, the analytes were also assessed geo-statistically using multivariate statistical analysis tools. Soil samples collected from soil layer between 40 cms to 65 cms depth have also been assessed for the presence of heavy metals. They were determined using combination of various statistical techniques with comparative assessment of results to minimize discrepancies. Multivariate statistical technique like Principal Component Analysis (PCA), has been applied to reduce the dataset into new variables, create a minimum data set (MDS) and analyse relationships between various heavy metal content in soil and other soil characterization components/indicators like pH, EC, TOC etc, along with factor analysis (FA) that identify specific factor weight of each metal (Weissmannová et al., 2015; Wold et al., 1987). The interrelationship among the two are explained through variables called principle components (PC) (Esbensen and Geladi, 2010). The soil variable data obtained from the characterizations was, transformed, auto scaled, and evaluated using the PCA to geochemically distinguish soils. Relationships among samples was demonstrated by data points. All the Component in Principal Analysis (PCA) have been rotated by a Varimax rotation and analysis was conducted on Statistica 12.5® software and SAS Systems for Windows 10 platform (Gąsiorek et al., 2017). The CCA, CA have been used to demarcate the common source of the heavy metals in the area (Dziuban and Shirkey, 1974). GIS based assessment for generating Soil Quality Index maps, spatial distribution maps, Area maps, Thematic maps etc. for the region has been done using Sentinel 2 Satellite data (March 2021) in bands: 3,4,8 prepared on ArcGIS software 10.8 (2020).

Table 2
Parameters — Soil quality assessment.

Parameters		Quantity of sample	SQI (Mean)	Std. Deviation	Std. Error	Maximum	Minimum
1.	pH	15	7.854	0.005	0.003	8.410	7.550
2.	EC (μS/m)	15	0.1363	0.0005	0.0003	0.1510	0.1200
3.	Organic carbon (%)	15	0.1143	0.0005	0.0003	0.1810	0.0700
4.	Phosphorous (mg kg^{-1})	15	28.3243	0.0005	0.0003	36.4510	16.0700
5.	Sulphur (mg kg^{-1})	15	20.3130	0.0005	0.0003	24.2310	15.6100
6.	Potash (kg/ha)	15	325.600	0.4714	0.2722	449.0000	235.0000
7.	Zn (mg kg^{-1})	15	3.4509	0.0002	0.0001	4.7860	1.9970
8.	Fe (mg kg^{-1})	15	5.9782	0.0002	0.0001	7.8750	3.4250
9.	Cu (mg kg^{-1})	15	0.1701	0.0005	0.0003	0.2350	0.1230
10.	Mn (mg kg^{-1})	15	4.2093	0.0003	0.0002	7.8950	1.7380

3. Results and discussion

Increasing cognisance towards earth's biological systems and critical role of soil in balancing it, has intrigued global interest for soil quality assessment studies. Several attempts have been made on several occasions to access the soil quality using several indicators (Armenise et al., 2013; Raiesi and Kabiri, 2016; Schindelbeck et al., 2008; Seybold et al., 2018). Industrial effluents, waste waters, and improper agricultural practices can be associated with degrading soil quality in the region. The untreated textile dye waste water released from textile industries is discharged in large quantities to adjoining land area or water systems. Each of the soil samples located near Bagru industrial area has been analysed with the following characteristics: pH, electrical conductivity (μS/m), organic carbon (%), phosphorus (mg kg^{-1}), potash (mg kg^{-1}), and Sulphur (mg kg^{-1}). Along with this, zinc (mg kg^{-1}), iron (mg kg^{-1}), copper (mg kg^{-1}), and manganese (mg kg^{-1}) heavy metals were also analysed in the soil samples. Among these factors, maximum values were found as pH = 8.40, Electrical Conductivity = 0.150 μS/m, Organic Carbon = 0.14%, Phosphorous = 36.450 mg kg^{-1}, Potash = 380 mg kg^{-1}, Sulphur = 24.230 and Metals: Zn = 4.786 mg kg^{-1}, Fe = 7.325 mg kg^{-1}, Cu = 0.226 mg kg^{-1}, Mn = 7.894 mg kg^{-1}. The average value of the total heavy metal content was analysed using principal component analysis. The concentration of all the parameters of soil quality is presented in (Table 2)

3.1. pH, electrical conductivity & Total soil organic carbon content

pH: — The result obtained from chemical testing of soil samples has determined the average pH value of the soil in the study area to be 7.85, which falls in the category of slightly alkaline soils. The pH values of most soil samples were found to be nearly identical in the study area and ranged between 7.550 (minimum) to 8.410 (maximum), with 75% of the sample points having a value of ≤7.85, indicating that most of the area has slightly alkaline soil with $R^2 = 0.4972$. It can be noted that highest pH vale of 8.40 (alkaline soil) was recorded in S_{12} and S_{14} which are closely located to the RIICO industrial region (Fig. 4A).

EC: — The Average Electrical Conductivity (Estimation of soil salinity) values for the region is .1363 μS/m which ranges from 0.1510 μS/m to 0.1200 0. The concentration of Salt in soil was observed to be uniform in the region with $R^2 = 0.0012$. Slightly higher concentration of 0.150 μS/m was observed in S11 and S12 location site, due to their close proximity to industrial region (Fig. 4B).

SOM: — The C content of SOM varies considerably and in arid regions the amounts of organic matter than other climatic regions is less, therefore desert soil have less SOM. The Total Soil Organic Carbon Content ranged from 0.1510% to 0.070% with average SOM to be 0.11% and the predictive determinant coefficient value R^2 is 0.0305 with non-uniform concentration of SOM as per its average value in the region. While most of the region had varying SOM concentration with S4 and S14 sites having high values of organic content (Fig. 4C). The high SOM in S4 and S14 sites can be attributed to their close proximity to Textile Industrial region, waste textile (organic matter) based effluents and waste water leading to increase in SOM (Ajmal and Khan, 1985; Eriksson, 2017).

3.2. Phosphorous (mg kg^{-1}), sulphur (mg kg^{-1}) & potash (kg/ha) in soil

Phosphorous (P): The average Phosphorous (mg kg^{-1}) concentration in the soil was observed to be 28.3243 mg kg^{-1} with range of 16.0700 to 36.4510 mg kg^{-1}. Nearly 70% of the region had concentration below the average value, with S2 having minimum of 16.0700 mg kg^{-1} and S2 and S14 possessing highest concentration of 36.4510 mg kg^{-1} in the region. While the high concentration of Phosphorous in S14 can be attributed to its closer location to the Textile Industries (Yaseen and Scholz, 2019), the high concentration in S_2 site can potentially be related to application of Phosphorous rich fertilizers in agricultural fields and their accumulation in soil over time. The coefficient of fixation R^2 for phosphorus was $R^2 = 0.0125$, indicating a constant trend in phosphorus concentrations in the region (Fig. 4D).

Sulphur (S):- Similarly, pertaining to Indian Agriculture, S is another important micronutrient after N, and P (Singh and Singh, 2016). During inoculation, the weight, diameter, filled seed capitulum-1 and 100 of the greater thalamus were recorded in VAM, PSB and Azotobacter. The average content of sulphur in the region was 20.3130 mg kg^{-1} derived through chemical analysis with minimum and maximum range of 15.6100 mg kg^{-1} and 24.2310 mg kg^{-1} respectively. At $R^2 = 0.0544$ the value the average Sulphur concentration is observed to be stable within the region with slight increase in S7, S11 and S14 sites (Fig. 4E). Higher content of Sulphur in S11, S14 can be associated with their close vicinity to Industrial region (Panigrahi and Santhoskumar, 2020). Higher concentration in S7 site can be linked to Traditional agricultural practices and application Sulphur rich fertilizers (ammonium sulphate, potassium sulphate, zinc sulphate etc, in soil leading to accumulation over time (Patra et al., 2013; Secondary Plant Nutrients, 2021).

Potash (K):— The concentration of Exchangeable K is significant for plant growth and important indicator of soil fertility (Zörb et al., 2014). However prolonged application of NPK fertilizers and their over dose to agricultural soil may lead to accumulation affecting the soil properties (Kumar and Yadav, 2001). The concentration of Potash (kg/ha) was observed to be very high in the region with average value of 325.6000 kg/ha. The concentration remains high though out the region with value of $R^2 = 0.1844$. An abnormally high concentration of 449.0000 kg/ha can be evidenced in S6 site which is not close to the industrial complex, mainly attributed to intensive agriculture activities, with heavy or prolonged application of K rich fertilizers which has allowed potash to accumulate in soil over time (Fig. 4F).

3.3. Presence of heavy metals in the soil

The quantity of heavy metal concentration has been detected using array of soil testing chemical methods and geo-statistical techniques. The results reveal higher content of heavy metal in the soils of the region with average concentration values in the soil samples in the following order Fe = 5.9782 mg kg^{-1}> Mn = 4.2093 mg kg^{-1}, > Zn = 3.4509 mg kg^{-1} > Cu = 0.1701 mg kg^{-1}.

Zinc (Zn) :- The presence of Zn appears to be scattered throughout the mineral fraction of soils (Lindsay, 1972). The presence of Zn in traces is important for plant growth and development. The average concentration of Zinc was calculated to be 3.4509 with range of 1.9970 to 4.7860 and coefficient of determination (R^2) value of 0.2077. Highest value of Zinc concentration i.e. 4.786 was found to be near S13 location, which is in close range to the industrial site (Fig. 4G). The waste water generation form textile industries especially processing and dying of Viscose rayon fibre can be one of the potential reasons for higher zinc concentration near Industrial complex sites (Pajot et al., 2011).

Iron (Fe): Plants require Iron in small quality but is crucial for their growth and functioning. Although Fe is one of the most abundant metals in the earth's crust, its availability to plant roots is very low since its mobility is dependent on other soil properties like soil redox and pH (Morrissey and Guerinot, 2009). The average Fe accumulation in the soil was found to be 5.9782 mg kg^{-1} ranging between 3.4250 to 7.8750 mg kg^{-1} and R^2 value of 0.0598 showing non uniform concentration in the region (Fig. 4H).

Copper (Cu): Cu is another significant plant micronutrient found in soil as trace element. Its role in photosynthesis, respiratory processes, cell formation is crucial (Pietrini et al., 2019). The concentration of Cu has a strong affinity to other properties to soil like organic matter and pH levels (Mengel and Kirkby, 2001). The copper content in soil of the region is low with average value of 0.1701 ranging between 0.1230 to 0.2350 and R^2 is 0.0419. Higher average concentration is observed in S5, S6, S7, S8, S15 sites located along agricultural fields of the region (Fig. 4I). Higher copper concentration in this belt could be attributed to use of Copper based fungicides under traditional farming practices and their accumulation in soil over time (Ghorbani, 2007). Although copper is used in dyes synthesis in Textile industries (Sungur and Gülmez, 2015) but the concentration near industrial region was comparatively lower as compared to adjoining agricultural regions.

Manganese (Mn): is another trace element, essential plant micronutrient, important for their physiological processes particularly photosynthesis. Manganese deficiencies are often associated with sandy soils, and fluctuates with concentration of pH levels in soil (Hakala et al., 2006). Manganese can cause toxicity and deficiency problems in plants and humans both and with less pH, deficiency in soil is common. The average concentration of Manganese in soil was observed to be 4.2093 mg kg^{-1} ranging between 1.7380 to 7.8950 mg kg^{-1}. The value of R^2 is 0.3712 depicting non-uniform distribution of Manganese in the region. While 50% of the region depict below average concentration, agricultural plots near industrial area (S13, S14, S15) records higher accumulation of the trace metal. A higher concentration in these locations may be the outcome of both agricultural as well as industrial activities (see Table 3), (Fig. 4J). While magnesium sulphate and magnesium oxide is commonly used in fertilizers, (Secondary Plant Nutrients, 2021) it is also used in Textile dying industry (Pajot et al., 2011).

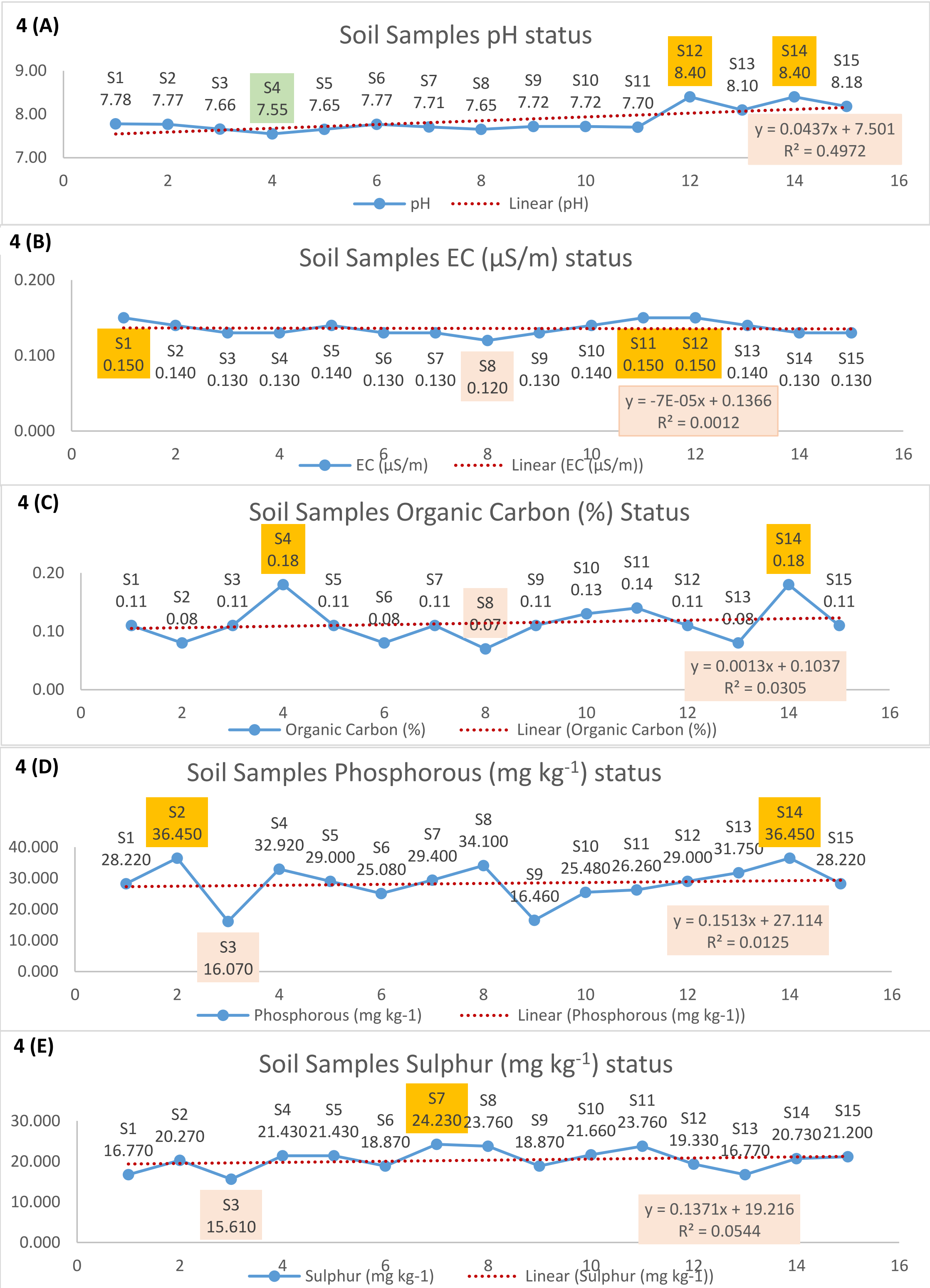

Fig. 4. Concentration of all elements in soil, Bagru Industrial region, Rajasthan.
Source: (Primary data)

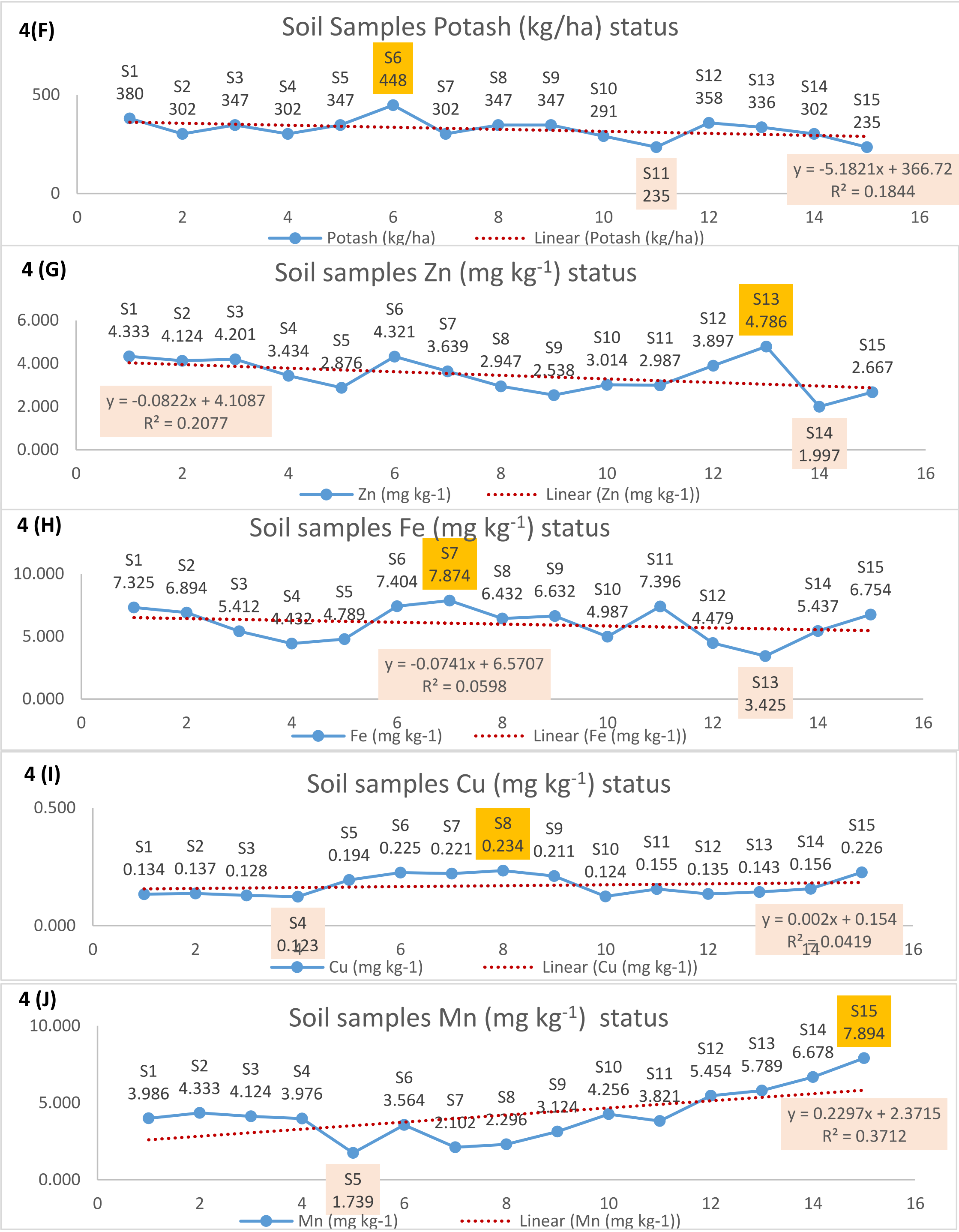

Fig. 4. (*continued*).

3.4. Heavy metals assessment in soil by PCA technique

The impact of Anthropogenic activities on soil, water and atmospheric systems has been profound over the years, leading to several bio-physical and health problems. Extensive Industrial waste generation into environment systems especially soil systems has led to their degradation (Wuana and Okieimen, 2011). Chemical Contamination of soil and over accumulation of trace elements in soil may lead to both short and long terms health problems (Real et al., 2017). The

Table 3
Soil Quality Index (SQI).

Parameters	Quantity of sample	SQI (Mean)	Std. Deviation	Std. Error	Maximum	Minimum
pH	15	7.854	0.005	0.003	8.410	7.550
EC (μS/m)	15	0.1363	0.0005	0.0003	0.1510	0.1200
Organic carbon (%)	15	0.1143	0.0005	0.0003	0.1810	0.0700
Phosphorous (mg kg^{-1})	15	28.3243	0.0005	0.0003	36.4510	16.0700
Sulphur (mg kg^{-1})	15	20.3130	0.0005	0.0003	24.2310	15.6100
Potash (kg/ha)	15	325.6000	0.4714	0.2722	448.0000	235.0000
Zn (mg kg^{-1})	15	3.4509	0.0002	0.0001	4.7860	1.9970
Fe (mg kg^{-1})	15	5.9782	0.0002	0.0001	7.8750	3.4250
Cu (mg kg^{-1})	15	0.1701	0.0005	0.0003	0.2350	0.1230
Mn (mg kg^{-1})	15	4.2093	0.0003	0.0002	7.8950	1.7380

Table 4
Correlation matrix.

		pH	EC	OC	P	S	Potash	Zn	Fe	Cu	Mn
Correlation	pH	1.000	.196	.123	.298	−.191	−.101	−.117	−.286	−.085	.789
	EC	.196	1.000	.057	.008	−.201	−.076	.314	−.101	−.575	.115
	OC	.123	.057	1.000	.104	.207	−.435	−.516	−.217	−.405	.245
	P	.298	.008	.104	1.000	.399	−.207	−.053	−.137	−.072	.193
	S	−.191	−.201	.207	.399	1.000	−.523	−.570	.307	.406	−.290
	Potash	−.101	−.076	−.435	−.207	−.523	1.000	.490	−.022	.126	−.361
	Zn	−.117	.314	−.516	−.053	−.570	.490	1.000	−.082	−.326	−.074
	Fe	−.286	−.101	−.217	−.137	.307	−.022	−.082	1.000	.510	−.260
	Cu	−.085	−.575	−.405	−.072	.406	.126	−.326	.510	1.000	−.257
	Mn	.789	.115	.245	.193	−.290	−.361	−.074	−.260	−.257	1.000

Table 5
KMO and Bartlett's test.

Kaiser–Meyer–Olkin measure of sampling adequacy.		.415
Bartlett's test of sphericity	Approx. Chi-square	63.361
	df	45
	Sig.	.037

Soil samples collected from soil layer between 40 cms to 65 cms depth, in the agricultural soils, around Bagru Industrial Area have been assessed for the presence of Trace metals. The metal concentration of 4 heavy metals **Zn, Cu, Mn Fe** have been determined in the region using Multivariate Geo- statistical techniques and modern data analysis and models (Lu et al., 2010).

PCA, has been used to signify relation between heavy metal presence in soil and other soil characterization components like pH, EC, TOC etc. along with FA which determines particular factor weight of each specific metal (Weissmannová et al., 2015; Wold et al., 1987). Based on PCA, FA and CA analyses Heavy Metals Zn, Cu, Mn, Fe were selected as the reference element. Principle component analysis has been used in several studies to assess heavy metals soil contamination in Urban and industrial regions of the world (Guo et al., 2013; Manta et al., 2002; Skrbic and Djurisic-Mladenovic, 2007; Slavkovic Beskoski et al., 2004). In principal component analysis the interrelationship among the two elements are explained through variables called principle components (PC) (Esbensen and Geladi, 2010). The soil variable data is transformed, auto scaled and relationships among samples is demonstrated through data points in the score plot. Important variables loaded on the samples are demonstrated by complementary PC (Principal component) subspace distributions in the loading plot. Highly clustered samples in the score plot allows for the down-selection of statistically distinguished samples to avoid redundancies in the future experiments. The scores and loadings plot for all of the samples combined reveal the chemical and physical soil properties on the loadings plots that influence each order on the score plots.

The Factor analysis method is use to compose the retained variables into groups according to their statistical factors as per their correlation matrix (Table 4). In order to remove the influence of different units on variable, FA is constructed using a standardized value for all the soil quality Indicators along with correlation matrix (Lin et al., 2002). Kaiser–Meyer–Olkin (KMO) test is conducted to test the adequacy of the sample to apply factor analysis (Kaiser, 1974). The outcome of FA is considered inappropriate if the Kaiser–Meyer–Olkin (KMO) test result value is less than <0.5., higher values of more than >0.5 closer to 1.0 indicate higher degree of adequacy in the Factor analysis results. In the test outcome, KMO had fewer FA results than chemical analysis of soil samples. Therefore, the result of the FA obtained here is not suitable for KMO. There is no cut-off point associated with this test and the results for the sample reveal lesser indication of suitability of the FA, since the value of KMO was 0.415 (less than <0.5) hence, FA does not have significant impact in KMO testing (Table 5).

Table 6.A
Total variance.
Source: Primary data.

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	2.716	27.156	27.156	2.716	27.156	27.156	2.240	22.399	22.399
2	2.588	25.880	53.037	2.588	25.880	53.037	2.129	21.292	43.691
3	1.392	13.923	66.960	1.392	13.923	66.960	2.062	20.615	64.306
4	1.093	10.929	77.889	1.093	10.929	77.889	1.358	13.583	77.889
5	.939	9.390	87.278						
6	.524	5.237	92.515						
7	.463	4.630	97.145						
8	.149	1.494	98.639						
9	.084	.842	99.480						
10	.052	.520	100.000						

Extraction method: Principal component analysis.

In addition to this, Chi-square distribution of Bartlett's test of sphericity was conducted wherein the conjecture of correlation matric being an identity matrix is evaluated, indicating that the variables are not associated and not suitable for structure detection (Tobias and Carlson, 1969). Small values (less than 0.05) of significance level indicate the utility of the significance level with the data given in the factor analysis (Table 5). The chi-square distribution of Bartlett's test of the given sampled dataset with a spherical score of 63.361indicate a high relevance of factor analysis.

A graphical representation of the factor loading through a dipole using the first three components (Fig. 5) has been provided based on Joliffe criterion considering that Kaiser's criterion is too large (Jolliffe, 1972). According to the Kaiser criterion (Kaiser, 1960) it is evident that only eigenvalue $> \mathbf{1}$ (more than 1) are retained in factor, so accounting for the percentage (%) of variance, the 3 components out of the 4 PC ranges (component based on Jolliffe's criterion) were placed first where percentage of variance (22.399 + 21.292 + 20.615 + 13.583) is 77.889% of the total variance of data obtained in PCA technique. The extraction sum of squared loading percentage of variance (27.156 + 25.880 + 13.923 + 10.929) is 77.889% of the total variance of the data obtained through PCA technique Table 6.A.

Applying correlation matrix, in order to evaluate the fraction of variance of each attribute explained by each selected factor loading, the PCs with >1 eigenvalues were subjected to varimax rotation with Kaiser. *The Varimax rotation method* has been applied at one level of factor analysis attempts to clarify the relationship among factors, using PCA. The result analysis and varimax rotation method of factor analysis, using principal components, are given in Table 6.B (6.C) (Kaiser, 1958; Maiz et al., 2000).

According to the results of PCA and FA analysis, Mn, pH, EC formed the First component (PC_1) explaining 27.156 of the total variance. S, OC, P formed the second component (PC_2) with total variance of 25.880%, pH, Cu, Mn fell in PC_3 with total variance of 13.923% and PC_4 included Phosphorous with total variance of 10.929%. The first, second, third and fourth extraction factor explains 27.156 + 25.880 + 13.923 and 10.929. i.e., 77.88% of the total variance and had a high loading on Mn, and S (Table 6.A). It is clear by PCA technique that copper (Cu) has the most loading on PC1. However, (**PC1:** Mn, pH, EC); (**PC2:** S, OC), (**PC3:** pH, Cu, Mn) and (**PC4**: Phosphorous) these factors are also important. (explains 27.156% and 25.880% total variance, respectively). Both Tables 6.B and 6.C show that the ratio of Manganese (Mn) on both PC1 and PC3 is similar. The loading of Mn on these factors is also even, compared to the first and third factor, hence, it can be concluded that both the first and third factors are associated with MN and the first, second, third and fourth rotated factor explains 22.399%, 21.292%, 20.615% and 13.583% of the total variance (Table 6.A) and had a high loading on Zinc (Zn), Potash (K), Copper (Cu), Manganese (Mn), Phosphorus (P) as shown in Fig. 6(B) (C).

It is also important to emphasize that Zn and Potash are high loading on **PC1** and Cu, pH, Mn, Phosphorous and S are high loading on **PC2, PC3 and PC4** and are important as well. Both (**PC1:** Zn, Potash); (PC2: Cu), (PC3: Mn, pH) and (PC4: P, S) all factors are not similar, (Table 6.C) explains 22.399% and 21.292% of the total variance respectively.

The two main sources corresponding to the cluster elements have been identified by PCA along with CA and CCA (Dziuban and Shirkey, 1974). The content of Mn in PC1 is derived from the original rock material (lithogenic component) and a significant correlation was found between the lithogenic metal concentrations and other soil chemical parameters like pH, SOM, EC etc. Additionally, other metal concentration like Zn and Cu can be related to anthropogenic origin such as Industrial and agricultural activities in the region, along with their lithological origin as trace elements. Based on the results obtained in the study area from the data analysis of the soil by PCA and other techniques, it can be concluded that the use of chemicals in industrial and anthropogenic wastes can be associated with soil pollution in the surrounding agricultural soil near the industrial areas. Soil quality standards are highly integral to maintain the quality of agricultural soil. Mainly on Zn, Cu and partly Mn is also relevant. Increased amounts of metals such as Fe, Zn, Cu, and Mn in soil have also been associated with other soil chemistry parameters obtained. The effectiveness of the dynamics and bioavailability of other elements in the soil can be ascertained (Gąsiorek et al., 2017; Luo et al., 2012). Based on the obtained data analysis, the accumulation of metals such as: Cu and Zn, Mn can be correlated with other chemical parameters of soil i.e. pH, EC, P, S and K, clay content, and TOC of soil. etc. Neutral to alkaline soil Ph ($\geq$7 values) with higher TOC possess higher metal

Table 6.B
Component matrix[a].

	Component			
	1	2	3	4
Cu	−.754	.230	.548	
Mn	.751	.223	.483	−.128
pH	.669	.183	.632	
Fe	−.629	.112		.166
EC	.514	−.257	−.394	.386
Zn	.127	−.840		.360
S	−.416	.777	−.159	.352
Potash	−.239	−.758	.224	
OC	.416	.574	−.433	−.339
P	.238	.400	.188	.724

Extraction method: Principal component analysis.
[a]4 components extracted.

Table 6.C
Rotated component matrix[a].

	Component			
	1	2	3	4
OC	−.831	−.296	.118	−.114
Zn	.808	−.440		
Potash	.741			−.349
Cu	.118	.939	−.123	.113
EC	.117	−.763		.196
Fe		.478	−.405	.201
pH			.920	.183
Mn	−.164	−.126	.905	
P			.235	.844
S	−.531	.357	−.362	.620

Extraction method: Principal component analysis.
Rotation method: Varimax with Kaiser normalization.
[a]Rotation converged in 5 iterations.

binding abilities hence impact their mobility, bioaccessibility and surface metal retention in soil layers (Kabata-Pendias and Szteke, 2015; Ma and Cd, 2016). With this aspect, Higher pH, TOC, and EC content in soil of the region could be one of the potential reasons for accumulation of heavy metals in certain locations (S_{13}, $S_{14,}$ S_{15} which possess higher pH, TOC, and EC) as compared to the other location within the region with lower value of such soil indicators.

Besides, trace elements the agricultural drylands had greater accumulations of metals such as Potash and Phosphorus as evident from PC_1 and PC_2 which can be associated with higher rate of Potash and phosphorus fertilizer application and a longer farming history in the region. The concentration of Sulphur ($PC_{4)}$ can also be related to both industrial and agricultural activities in the region (Micó et al., 2006).

3.5. SQI and overall soil quality assessment

Soil health and quality indicates the status of its biological, chemical, and physical attributes essential for its long-term functional capacity and sustainable environment productivity. Soil quality Index provides a holistic picture of overall Soil quality of the region (Bhattacharyya, 2017). Soil Quality Index uses minimum set of parameters or Minimum Data Set (MDS) pertaining to the numerical data indicating functional capacity of soil (Klimkowicz-Pawlas et al., 2019; Mukherjee and Lal, 2014). Based on the given 10 parameters i.e. pH, EC, OC, P, S, K, Zn, Fe, Cu, and Mn a comprehensive Environmental Soil Quality Index (SQI) has been prepared for the region for the assessment of soil quality. Based on MDS the Average soil quality index (SQI) value for the whole region is estimated to be 0.482 which ranges between minimum of 0.342 and maximum of 0.567. Under the proposed framework the SQI values of the whole region has been divided into 3 categories: − Category 1(C1) = SQI value ≤ 0.4 (Less degraded); Category2(C2) = SQI value 0.41–0.5 (Moderately degraded), Category 3(C3) SQI value ≥ 0.51 = Degraded. Only 13.3% of the soil in the area with SQI value ≤ 0.4 has least soil contamination and appropriate soil health, while 40% of the soil was moderately contaminated with SQI values between 0.41–0.5 and 46.6% with SQI value ≥ 0.51 had degraded soil, with low soil quality. Nearly 53.3% of the area falls below the Average SQI Value with S_3, S_4, S_5, S_8, S_9 and S_{10} sites having index values below 0.482. (Fig. 6(A)). Among all the sites S14 with 0.564 SQI score value was found to be highest in SQI Index followed by S12, S11, S15 (having SQI score above average). All these regions are located in close proximity (1–2.5 kms) to the Bagru Industrial region. High SQI scores of 0.536 and 0.531 have been recorded in S_6 and S_7 sites also, located away from industrial zone. The higher degradation of soil in these sites could be related to highly intensive agricultural practices, traditional farm methods, excessive use of fertilizers

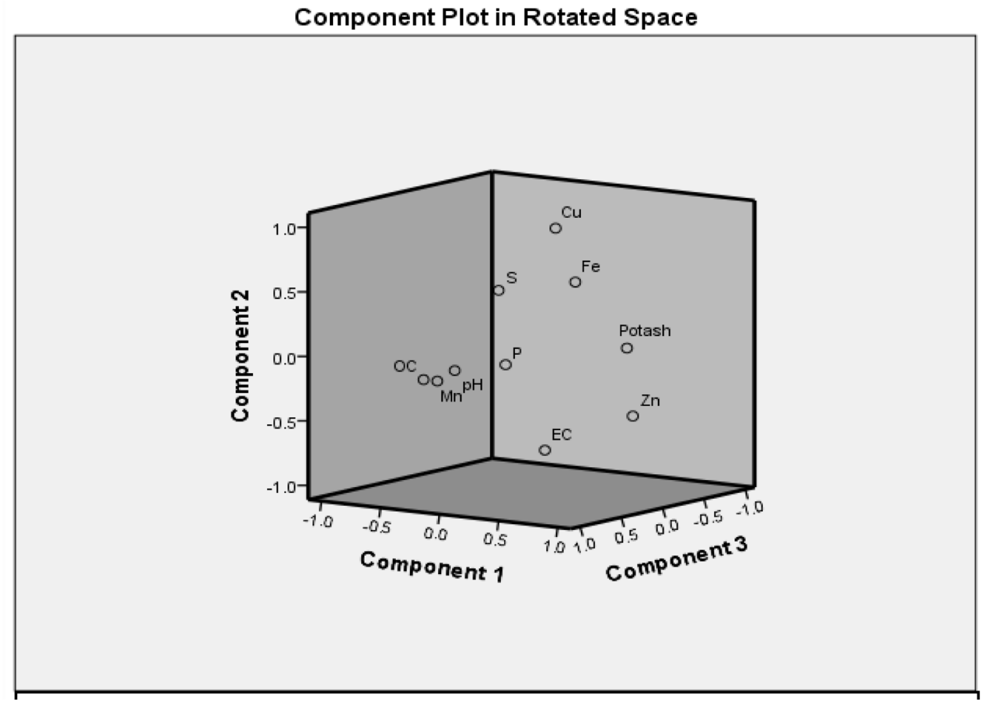

Fig. 5. Principal Component Analysis (PCA) results, loading plot of components influencing geochemical variation in soil near Bagru Industrial region.

etc. in the region. Based on the SQI scores S_{14} site has recorded maximum soil contamination in the region however it is important to note that high score is because of higher accumulation of chemicals and other elements like sulphur and not because of trace metal, which were found to be low. (see Fig. 6(B)). High SQI value pertaining to accumulation of Trace metal was found in S6, (0.275) and S7 (0.242) region which are primarily dominated by agricultural activities. Nearly 50% of the total contaminants in the study have been recorded from these two-sample site (S_6 and S_7) with Cu > Fe > Zn > Mn concentrations. For the whole region the SQI values of Heavy Metal were in Sequence Fe (0.056) > Zn (0.052) > Cu 0.044 > Mn 0.04. The lowest SQI value for the region has been recorded for $S_3$0.342, located in the North Eastern part of the region, flowed by S_9 located in the western extremity of the study area, both being predominantly agricultural lands. (See Fig. 6(A), (B), (C)).

4. Conclusion

Based on the comprehensive quantitative evaluation of 10 interlinked biophysical and Chemical parameters viz- pH, EC, OC, P, S, K, Zn, Fe, Cu, and Mn the soil quality of the Bagru industrial region has been assessed using Multivariate Statistical methods: PCA, CCM, CA, FA on Integrated GIS platform. The study concludes toxic discharge from existing industrial and agricultural activities are altering physicochemical properties, fertility and the soil matrix of the region. High levels of ph, EC, OC, Sulphur, phosphorous were recorded in the industrial vicinity with less degree of variability within the region. Among all the parameters, values found of pH = 8.40 i.e. > 8.0 indicate alkaline soil with Electrical Conductivity = 0.150, Organic Carbon = 0.14, Phosphorous = 36.450, Potash = 380, Sulphur = 24.230 and Metals: Zn = 4.786, Fe = 7.325, Cu = 0.226, Mn = 7.894. A higher average Concentration of elements like Potash (K = 325.6000 kg/ha, R^2 = 0.1844.), Phosphorous (P = 28.3243 mg kg^{-1}, R^2 = 0.0125), Sulphur (S = 20.3130 mg kg^{-1}, R^2 = 0.0544) was recorded in the agricultural zones located along the industrial vicinity. The discharge of industrial effluents with presence of compounds like chlorides, cations, anions etc. were observed beyond the existing standard discharge limits. Using principal component analysis and multivariate statistical analysis tools the concentration of Heavy metals was observed in sequence: - Iron (Fe 5.9782 mg kg^{-1}), > Manganese (Mn 4.2093 mg kg^{-1}), > Zinc (Zn 3.4509 mg kg^{-1}) > Copper (Cu 0.1701 mg kg^{-1}) . PCs with eigenvalue >1.0 following Kaiser, subjected to varimax rotation were kept accounting for 77.889% of the total variance of the data, and has high loading on Mn, and S. Evidences of heavy metal pollution in the soil highlight combination of both Industrial and agricultural activities dominated by constantly altering land use and resource utilization dynamics in the region. The average SQI value of the region was 0.482 ranging between 0.342 and 0.567 indicating "Moderately degraded to "degraded soil" quality. Only 13.3% of the soil in the area with SQI value $\leq$ 0.4 has least soil contamination and appropriate soil health, while 40% of the soil was "moderately degraded" with SQI values

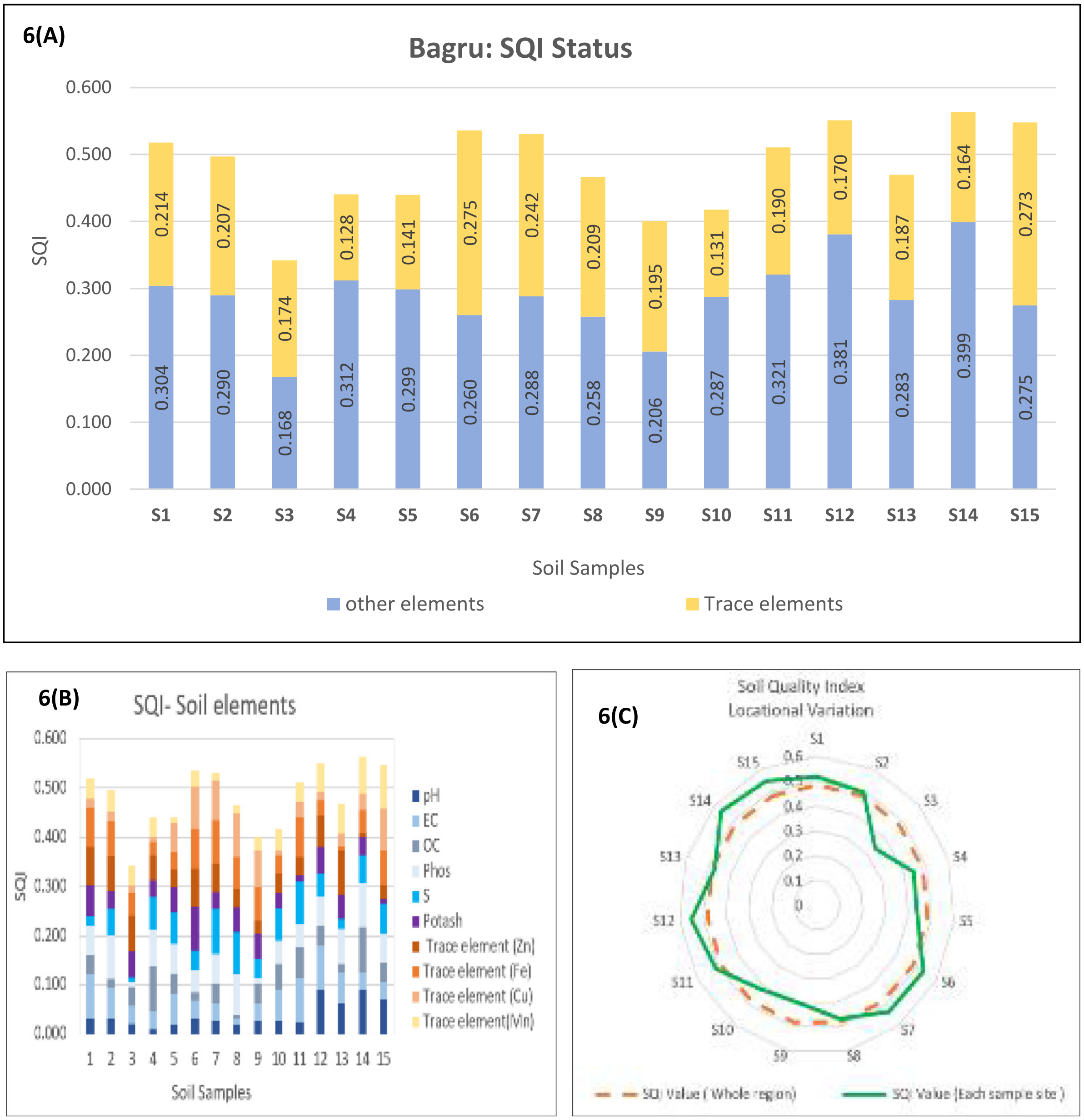

Fig. 6. Soil Quality Index: 6 (A) Over all SQI of the region; 6 (B) SQI values: each element of Soil quality; 6(C) SQI and Sample site wise variation in Index values.
Source: (Primary data)

between 0.41–0.5 and 46.6% of the total soil of the region with SQI value ≥ 0.51 highlighting "degraded soil" with very low soil quality standard in the region.

The study therefore, concludes soil contamination and degradation problems exist in the region with predominance of human activities leading to accumulation of harmful chemicals and heavy metals with potential impact on environment and health. The study conducted applying such integrated methodology have not been attempted in the western region of India (in Rajasthan) so far, for the assessment of soil quality. Therefore, the study validates the application of multivariate statistical analysis methods like PCA, FA, CA for soil quality assessment studies and encourages its application in given or similar environment especially in developing countries. Since most of the regions in India and many developing countries have experienced industrial expansions sprawling into traditional agricultural spaces, such studies are importance in highlighting the impact of unchecked industrial discharges and its potential impact on soil systems, agriculture, health and environment altogether.

Assessing Quality of soil regionally, is difficult to contemplate because of spatial variability in pollutants and underlying relationship between them. The study therefore, suggests further validation of results with further research in the region which would improve the basis for proposing minimum soil quality standard for the particular region and effective natural resource management planning in future. Based on the current result of the study and considering the fast expansion of Bagru Industrial region, the study suggests immediate need for Industrial waste treatment, guided by proactive governmental policy interventions, as quintessential for environmental sustainability of the region.

CRediT authorship contribution statement

Jabbar Khan: Sample collection, Sample preparation, Performed all chemical laboratory analysis, Conducted Geo-statistical evaluation for geochemical assessments of all soil samples of the region, Prepared initial draft of tables. **Rani Singh:** Conducted data assimilation, Data compilation, Data assessment. **Pallavi Upreti:** Prepared initial draft of tables, Conducted data assimilation, Data compilation, Data assessment, Prepared result report, tables, diagrams and maps for the study, Conducted data analysis, Conceptualization, Drafting, Writing, Editing, Validation, Preparation and finalization of graphs and diagrams. **Rajesh Kumar Yadav:** Prepared GIS maps of the area.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The data set used, maps prepared, original tabulation, and data analysed during the present study can be obtained from the corresponding author on reasonable request.

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