



Risk assessment of trace elements distribution in soils of basaltic aquifers, southern Maharashtra, India

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Abstract

An assessment of soil vulnerability was evaluated in Mann Ganga River basin, within the districts of Satara, Sangli and Solapur in Deccan Volcanic Province (DVP), to ascertain the concentration and the likely source of origin of the trace element concentration of metals such as Cobalt, Chromium, Copper, Nickel, Zinc, Vanadium, Iron and Manganese. Eighty soil samples were collected during December 2016 and examined by X-ray fluorescence spectrometer. The soil fitness was estimated using several risk assessment indices viz. geoaccumulation, enrichment factor and contamination factor. In order to delineate the probable sources of different trace elements, Pearson correlation coefficient analysis and multivariate analysis (principal component analysis) was also performed. The average concentration levels of Copper, Zinc, Iron and Manganese are exceeding the natural background limit. The risk assessment indices of trace elements Copper and Vanadium reveal moderate to significant contamination. These high indices level are probably due to geogenic, industrial and agricultural activities and other anthropogenic inputs. Significant linkage between the elements Cobalt, Copper, Zinc, Vanadium, Iron and Manganese is revealed through Pearson correlation coefficient and principal component analysis. The enhanced trace elements pollution in top soil is therefore a critical problem which can have hazardous bearing on flora, fauna and human life, and needs to be monitored recurrently for such enrichments of toxic elements in order to safeguard the environment.

Keywords: Trace elements, soil, Geoaccumulation index, Enrichment factor, Contamination factor, Principal component analysis, Maharashtra.

Introduction

Soil contamination has turned out to be a grave concern in several countries due to increasing population, rapid urbanization and industrialization, sustained human impact on the environment and contamination of available resources and changing climate. As soil is an essential component of rural and urban milieu, it is of utmost priority to understand the severity of soil contamination vis-à-vis its protection. Amongst the most significant soil contaminants, trace elements in soil are of prime importance due to its enduring toxicity effect¹.

The continual use of wastewater from industries acts as catalyst to agricultural soil contamination. Also the sustainability of agricultural lands is threatened by the over-use of irrigation, chemical fertilizers and pesticides. Although some amount of trace element concentrations is necessary in plant nutrition, plants growing near industrial areas show increased concentration of trace elements. This is more predominant in semi-arid regions, where people are more dependent on farming and generally use excessive fertilizers and pesticides for better crop production. The trace elements, such as Cobalt (Co), Chromium (Cr), Copper (Cu), Nickel (Ni), Zinc (Zn), Vanadium (V), Iron (Fe) and Manganese (Mn) act as indicators to determine the amount of contamination in soil and thus

accumulation of such metals in the background has adverse effects on flora and fauna and human health². In order to understand the contributions and impact of trace elements towards human and plants health, several researchers initiated the assessment of soils and health hazards involved³⁻⁴. The speciation of distribution of metals in tropical estuarine mudflat sediments was studied in order to understand the sedimentary setting, its post-depositional progression, different trace elements in the environment that might enter the living organisms and their toxicity⁵. It has been envisaged that the metal retention ability of soil depends on several factors, viz. soil composition, humus content, amount of calcium carbonate present, water availability etc., and lack of such favourable conditions permits the metallic loads to migrate into the sediments and the underlying soil layers. Further, it is opined that the toxic trace elements entering the ecosystem may lead to geoaccumulation, bioaccumulation and biomagnifications, as human activities have distorted the geochemical cycles of trace elements⁶.

An appraisal of the environmental hazards due to soil contamination is of vital importance in semi-arid agricultural and non-agricultural regions so as to ascertain the influence of metal pollutants from anthropogenic as well as geogenic sources, which could potentially harm human health. The

purpose of the present study is to evaluate the extent of soil contamination as regards to average abundance of trace elements and to establish the relations between the different trace elements via several risk assessment indices and correlation coefficients, to categorize possible contamination sources of soil in the study area.

Materials and methods

Geology of the study area: The study locale is in the south-eastern part of Maharashtra encompassing Satara-Sangli-Solapur districts, extending from 17° 00' 00" to 17° 50' 30" north latitudes and from 74° 20' 00" to 75° 30' 00" east longitudes (Figure-1). The present study area, viz. the Mann Ganga River basin is situated on the leeward side of Western Ghats slopes, characterized by the rain shadow zone. The rainfall here is below normal and therefore is classified a drought-prone region. The average yearly rainfall in Mann Ganga River basin is about 500 mm. The total area of Mann Ganga River basin is 4753.258 sq. km. Maximum elevation of 980 m is recorded in western and

north-western part of the basin while the minimum elevation is 354 m above mean sea level (aMSL) in the north-eastern sector.

Geologically the study area reflects Deccan Trap basaltic lava flows of Upper Cretaceous to Lower Eocene age. The traps are either hard and compact or vesicular in nature. The study area can be generally divided into four major physiographic units namely, i. hills and Ghats, ii. foothill zones, iii. plateaus and iv. plains. The soils of the study area are primarily influenced by climate. The hill slopes are characterised by reddish brown soils, while granular black soils are predominant in the plains. Saline-alkaline soils are observed in some parts of the southern and north eastern sector, particularly from areas of low rainfall. Coarse, shallow soils mostly occur in the central and southern part and are light brown to reddish brown, loamy sand to sandy clay in texture. Mann is the major river in the area and narrow stretch along the river is typically occupied by black cotton soil⁷.

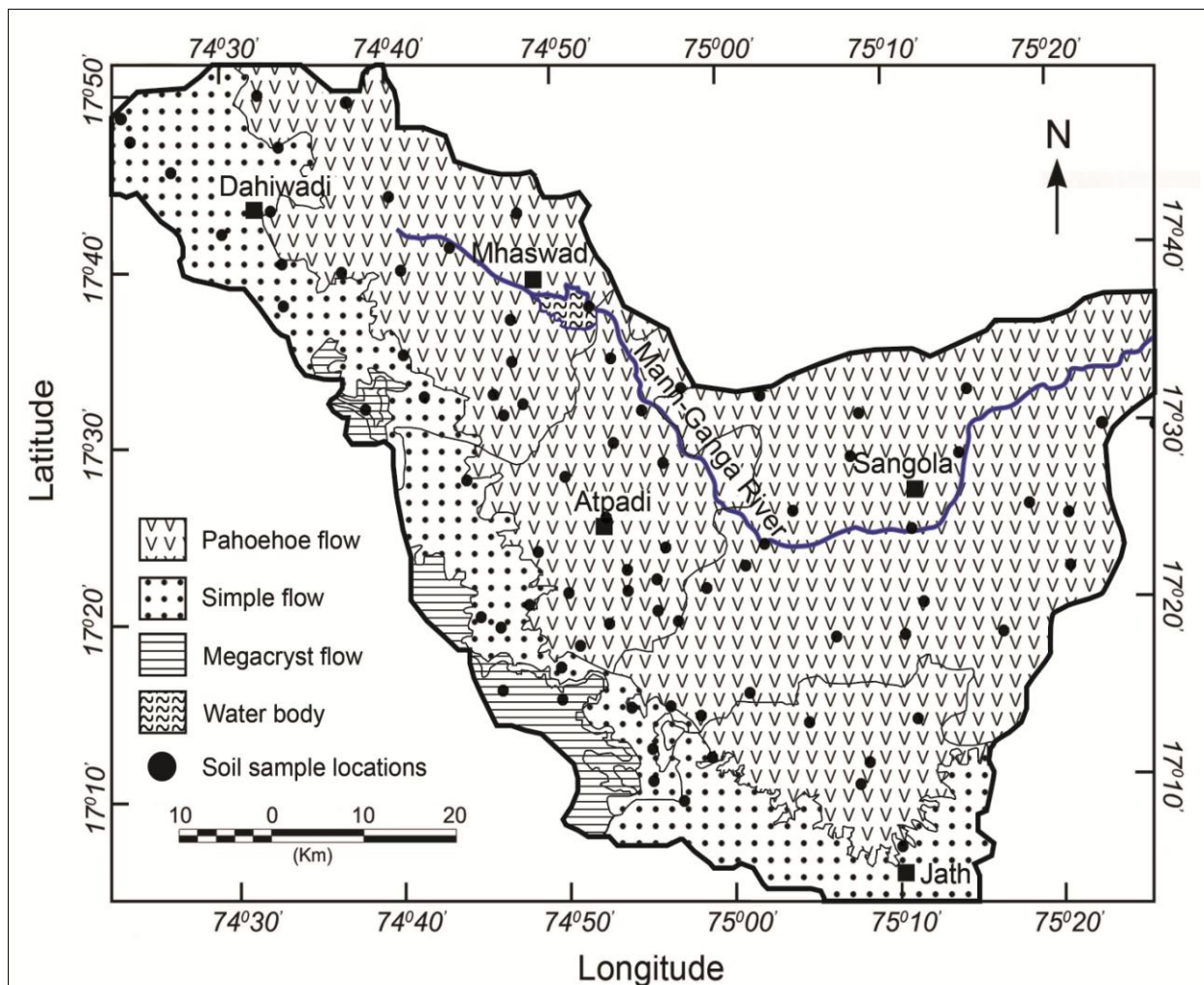


Figure-1: Map showing the general geology of Mann Ganga River basin. Also shown are the soil sample locations.

Soil sampling technique: The present study is directed towards identifying the presence of trace elements in sediments, its spatial variation and the causative natural and anthropogenic sources. Eighty soil samples from top 15-20 cm were collected from agricultural and non-agricultural areas during December, 2016 (Figure-1). In order to have a composite soil sample, 4–6 samples were arbitrarily collected and assorted properly from each sampling site. The samples were stored in polythene bags and brought to the laboratory for further investigation. About 500 g of the collected samples were first air dried to remove any moisture in them, and then sieved into coarse and fine fractions using 0.25 mm sieve.

The homogeneous powdered samples were analyzed by an energy dispersive polarised X-ray fluorescence (XRF) spectrometer (SPECTRO XEPOS). For homogenization, samples are powdered using a Fritsch Pulverisette (Fritsch, France) planetary mono-mill for 30 minutes and later the powdered material are kept in the oven overnight to remove any moisture. About 3 g of sample is packed in plastic cups for the XRF analysis using a prolene 4 µm thick membrane. This technique was used to evaluate the trace element concentrations (Co, Cr, Cu, Ni, Zn, V, Fe and Mn) in the study area. Each sample was measured three times and the average of the three readings was taken into consideration.

Statistical schemes such as correlation coefficients and principal component analysis (PCA) were used for identifying trace element contamination. Several geochemical indices, viz. geo-accumulation index (I_{geo}), enrichment factor (EF) and contamination factor (CF) are also used to calculate the relative toxicity of samples at each site.

Risk Assessment Analysis: The geoaccumulation index (I_{geo}) is commonly used to estimate the enrichment of metal concentrations above background values⁸. The method measures the level of metal pollution based on seven enrichment classes (Table-2). This I_{geo} is calculated as follows,

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \quad (1)$$

Where: C_n is the concentration of trace element in the enhanced samples, and B_n is the background value for the metal n ⁹. The factor 1.5 is used to reduce the effect of probable variations in the background values which could be due to lithogenic variations in the sediments.

The anthropogenic impact on the environmental media was evaluated by calculating a regularized enrichment factor (EF) for metal concentrations beyond unpolluted background values¹⁰. The EF index normalises the measured trace element concentration with respect to a sample reference metal which has insignificant anthropogenic sources¹¹. Here strontium (Sr) is used as reference metal as it is one of the chief components in the crust of the Earth. All the metals are normalized with

strontium for calculation of EF, as it is formed by geogenic progression. Enrichment factor values were calculated as stated by (Equation-2),

$$EF = \frac{C(\text{sample})/C(\text{ref})}{Sr(\text{sample})/Sr(\text{ref})} \quad (2)$$

Where: C(sample) is the concentration of the measured element in the study area, C(ref) is the concentration of the measured element in the reference environment (e.g., trace element concentration in continental crust), Sr(sample) is the concentration of reference element in the study area, while Sr(ref) is the concentration of the reference element in the reference environment¹⁰.

The classification of soil samples based on EF are fivefold and is given as EF<2 indicating none to minimal contamination, EF ranges from 2-5 suggests moderate enrichment, EF ranges from 5-20 means significant enrichment, EF ranges from 20-40 reveals excessive enrichment and EF>40 indicates enormously elevated enrichment¹².

Contamination factor (CF) was evaluated to assess the soil fitness and to determine the amount of trace element contamination of soils. The CF is defined as the ratio of the concentration of individual metal and the background value (i.e. concentration in uncontaminated soils) and is given by the following equation¹³,

$$CF = \frac{C(\text{Trace element})}{C(\text{Background})} \quad (3)$$

Where: $C_{(\text{Trace element})}$ is the measured concentration of trace element in the soil sample and $C_{(\text{Background})}$ is the background value for the same trace element.

The CF was classified to evaluate the metal contamination levels into four classes and varies from CF<1 suggestive of low CF; 1<CF≤3 indicates moderate CF; 3<CF≤6 indicative of considerable CF and CF>6 reveals very high CF⁸.

Principal component analysis: Principal component analysis (PCA) is primarily used for source assignment study in numerous pollution investigations¹⁴. This analysis is carried out to minimize the multivariate data dimensionality and to explain the pattern that accounts for the maximum data variation¹⁴. In this technique, a data set represented by several inter-related dependent variable observations are estimated. Thus it is possible to take out the vital facts as a set of orthogonal variables which essentially explain their total variance. These variables are called principal components (PCs). A set of scores is allocated to each unit which correspond to its projection on the components¹⁵. Each component thus evaluated is expressed by the variation (eigen value) of its projection or by the proportion of the variance explained. In order to maximize the variances in the loading factor for the variables, Varimax

normalization rotation has been applied to interpret the associations and the imaginary cause of metals, whether geogenic or anthropogenic¹⁵.

Descriptive analysis of the data, such as mean, standard deviation, minimum and maximum concentration was performed on the trace elements concentration in the soil of the study area. Correlation coefficients were also computed to examine the interrelation amongst divergent elements so as to classify analogous sources of elements.

Results and discussion

Risk assessment of trace elements: The statistical summary of metal concentration in soil acquired from the study area is given in Table-1. In order to understand the risks in soils associated with trace elements, index of geoaccumulation (I_{geo}), enrichment

factor (EF) and contamination factor (CF) were evaluated in Mann Ganga River basin. Table-3 gives the details of I_{geo} , EF and CF for different trace elements under consideration. As mentioned in Equation (1) earlier, it is vital to select the background concentration (Bn) of trace elements in soil samples. Despite the fact that the factor (1.5) in calculating I_{geo} values take care in counter-balancing the background concentration, any wrong Bn value might lead to erroneous results. Therefore in the present work, the background concentrations of trace elements in soil of basaltic terrain are selected for calculating I_{geo} values⁹. It is observed from Table-3 that the average I_{geo} values of Co, Cr, Ni, Zn, Fe and Mn are less than 0 indicating uncontaminated soil. The trace elements Cu and V reveal average values of 0.91 and 0.67 respectively, signifying moderate contamination.

Table-1: Statistical summary of metal concentration in soil in mg/kg.

Element	Co	Cr	Cu	Ni	Zn	V	Fe	Mn
Minimum	21.8	58.6	139.5	78.1	90.9	351	76800	1189
Maximum	76.8	258.4	417.4	144.4	166.5	914	164700	3076
Mean	45.4	115.8	249	101.7	127	610	123613	1899
Skewness	0.11	1.24	0.45	0.90	0.07	0.11	-0.24	0.63
Std. Dev.	7.92	32.47	43.85	13.20	15.64	134.01	16327.37	270.02
Kurtosis	3.49	3.59	2.63	1.23	-0.08	-0.59	0.52	3.74
Natural background values*	48	170	87	130	105	250	86500	1500

*Maximum permissible concentration of metals in basaltic soils⁹.

Table-2: Seven classes of Index of geoaccumulation (I_{geo}) for contamination levels in soil⁸.

I_{geo} value	Class	Level of contamination
≤ 0	1	Practically uncontaminated
0-1	2	Uncontaminated to moderately contaminated
1-2	3	Moderately contaminated
2-3	4	Moderately to strongly contaminated
3-4	5	Strongly contaminated
4-5	6	Strongly to extremely contaminated
≥ 5	7	Extremely contaminated

Table-3: Statistical summary of contamination indices of trace elements in soil.

Metals	Minimum	I_{geo} Maximum	Average	Minimum	EF Maximum	Average	Minimum	CF Maximum	Average
Co	-1.72	0.09	-0.69	0.75	1.5	0.27	0.45	1.6	0.95
Cr	-2.12	0.02	-1.19	0.65	15.2	1.98	0.34	1.52	0.68
Cu	0.1	1.7	0.91	2.67	52.3	8.44	1.6	4.8	2.86
Ni	-1.32	-0.4	-0.92	0.81	14.5	2.3	0.6	1.11	0.78
Zn	-0.23	0.024	-0.09	1.3	18.2	3.5	0.87	1.59	1.22
V	-0.1	1.29	0.67	2.1	37.9	6.97	1.4	3.66	2.44
Fe	-1.4	-0.3	-0.73	1.42	22.6	4.03	0.89	1.9	1.43
Mn	-0.92	0.45	-0.26	1.27	17.79	3.56	0.45	1.6	0.95

The enrichment factor of all the trace elements evaluated using Eqn. (2) is given in Table-3. The EFs obtained indicate that the soils of the area are moderately to significantly enriched with contaminants. The average enrichment value is highest for copper (8.44), followed by Vanadium (6.97), suggesting that the soil is significantly contaminated by these metals. Also other trace elements like Fe, Mn, Zn and Ni suggest moderate to significant enrichment.

The contamination factor, also known as anthropogenic factor, was evaluated for each trace element using Equation (3) and the values obtained are given in Table-3. The CF values suggest low to moderate contamination of soil in the entire study region. However, the average CF values in trace elements Cu, Zn, V, Fe and Mn suggests moderately contaminated soil.

From the foregoing it is observed that the risk assessment indices (viz. I_{geo} , EF and CF) vary in concentration ranging from uncontaminated to significantly contaminated soils for the trace metals under consideration. It is envisaged from Table-3 that the maximum I_{geo} value of Cu is 1.7, symptomatic of moderately polluted level of concentration in soil. Similarly, trace element V exhibits a maximum I_{geo} value of 1.29 suggesting moderately polluted soil. Likewise, the average EF values (Table-3) of Cu and V is 8.44 and 6.97 respectively. The average CF values for both these metals are also high (Table-3). The relatively high values of Cu are due to the fact that Deccan Trap basalts are chiefly composed of quartz tholeiitic and therefore the concentration of Cu is abundance in the soil. It has been reported that large phenocryst basalt of plagioclase has abundant Cu concentration in basaltic flows, especially in Western Ghats of DVP¹⁶.

The content of vanadium in soil depends to a certain degree on the parent rock substance and shows maximum I_{geo} value of 1.29, average EF and CF values of 6.97 and 2.44 respectively

(Table-3). This is attributable to their connection with iron minerals or their sequestration with iron oxy-hydroxides in the Deccan Trap basalts. Enhanced vanadium may also be caused due to its usage in petroleum products, textile industries, and industries dealing with metallurgical and electronics products¹⁷. It is pertinent to mention here that there are several such small and medium-scale industries in the study region which contributes to contamination in soils.

It is envisaged that the enhancement in Cu and V is likely to be from geogenic activity as well as anthropogenic sources, as majority of the farming community in this region make excessive use of pesticides and fertilizers, cow dung and wastewater from industrial activities, which are responsible for the enrichment of trace elements^{17,18}.

In order to observe the degree of concentration and the most affected sectors in the study region, the kriging interpolated spatial variation maps of copper and vanadium are presented in Figures-2a,b. Both these trace elements are above the background levels compared with the soils of the world.

Studies reveal the quantity of copper profusion in the Deccan Trap is much more compared to other basaltic terrains of the world¹⁹. This is due to the fact that quartz tholeiites, which is prevalent in Deccan Trap of Maharashtra, are rich in copper, attributing to geogenic activity in the study area. Figure-2a reveals that the assemblage of copper is very high almost in the entire study area and is beyond the average concentration of 87 mg/kg. The locations of intense copper concentration are observed in the north-western, western, central and north-eastern parts of the study area along the course of Mann Ganga River. It is also well known that prolonged and extensive use of pesticides, manure or inorganic fertilizers in agricultural land may cause heavy metals such as copper to accumulate in the topsoil²⁰. Heavy metals are emitted from multiple anthropogenic

sources into the environment and get deposited over prolonged time, which results in abnormal enrichment inducing surface contamination. Some of the major sources of copper enrichment in the study area are due to numerous small and medium scale

industries dealing with extraction and processing of copper, manufacturing copper products such as wire, pipes and sheet metal, and fossil fuel combustion.

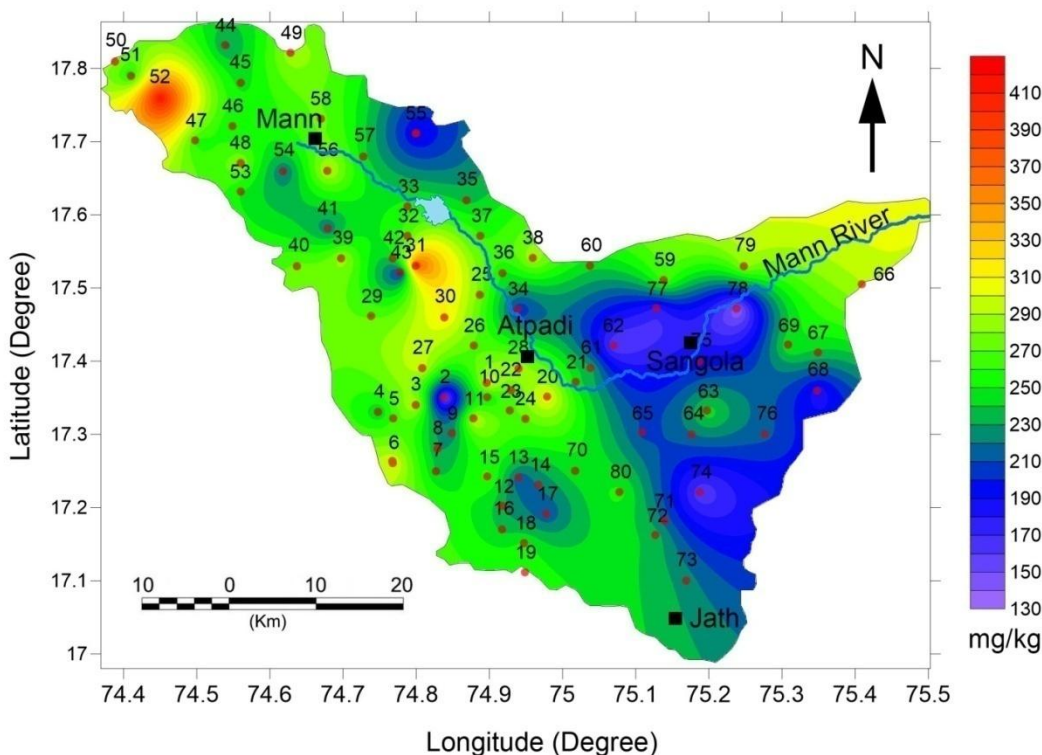


Figure-2a: Spatial distribution map of Copper in the study area.

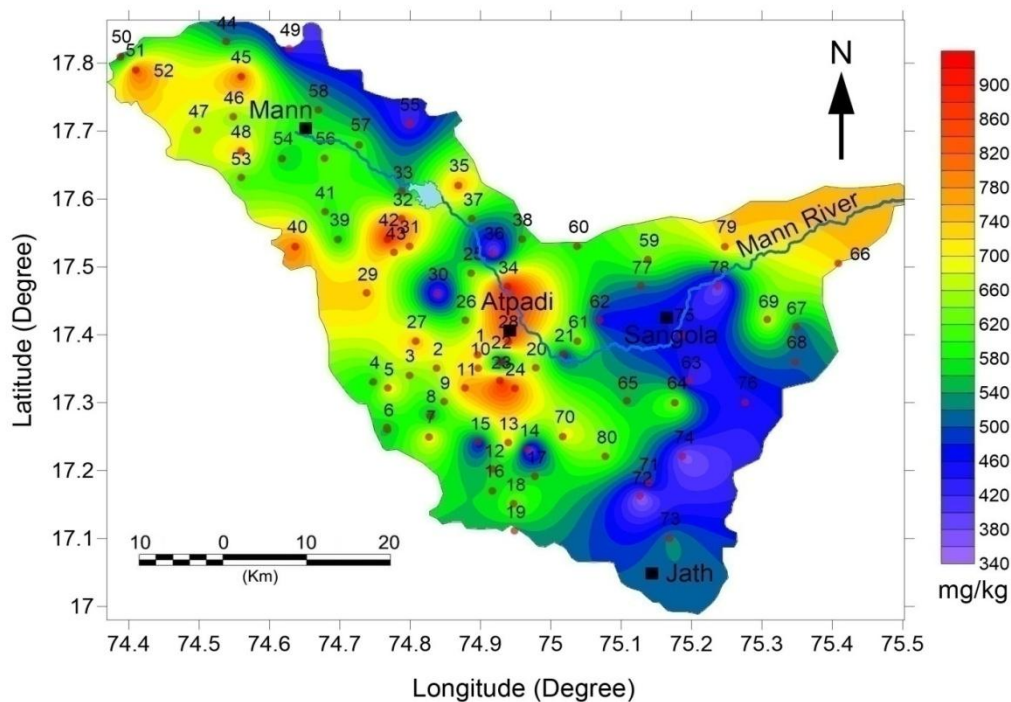


Figure-2b: Spatial distribution map of Vanadium in the study area.

Vanadium is broadly disseminated in the earth’s crust²¹. Some of the principal causes of vanadium discharge into soil can be attributed to weathering of rock-bearing vanadium minerals, residual deposits of vanadium from the atmosphere, deposition of suspended matters from water, and plant and animal excretion. However, the primary source of vanadium released into soil is due to the natural weathering of geological morphology. It is advocated that the major transporter of vanadium is ferric hydroxides and solid bitumens during the sedimentation process²¹. Iron acts as a carrier for trivalent vanadium due to the high affinity between trivalent vanadium and trivalent iron, and is thus responsible for its dispersion through molten rocks where it is trapped during crystallization, thereby enhancing the vanadium concentration in soils. However, anthropogenic sources of vanadium to soil are less and are caused mainly due to the usage of certain fertilizers containing high vanadium content such as rock phosphate, superphosphate etc²². Industrial contributions include dumped wastes material, refuse and leach residues from mining activities, which are also probable causes of higher vanadium concentration in soil. It can be observed from Figure-2b that the entire study area reflects vanadium concentration which is higher than the average background concentration (250 mg/kg). The higher concentrations are more predominant along the Mann Ganga River course, with the hot spots located in the north-western, central and eastern sectors of the study area.

Correlation between trace elements: Correlation analysis was adopted to substantiate the inter-relationship involving the trace elements under consideration, wherein connection between all possible pairs of trace elements have been considered to facilitate identification of similar sources of elements. In the first step, the data is transformed by considering the logarithms of the elements, which removes the skewness of the original concentration of each trace element and also minimizes the fluctuations in the correlations between them. The Pearson

correlation matrix of the trace elements for all the 80 soil samples is given in Table-4. A high correlation coefficient (close to +1 or -1) suggests a superior linkage between two variables, while a near zero concentration reveals no correlation between them at a significant level of 0.05%. Strong correlation is exhibited if r is less than 0.7, whereas if r values revolve between 0.5 to 0.7, it is suggestive of moderate relationship between two dissimilar parameters.

It is observed from Table-4 that moderate positive correlation exists between Co with Cu, Zn, Fe and Mn. Also Co is weakly correlated with Ni and V. Chromium (Cr) shows moderate positive correlation with Ni and a rather weak association with Zn and Fe. Copper (Cu) reveals a good association with Zn, Fe and Mn, while Ni also has a moderate link with Fe. Zinc (Zn) shows a rather strong correlation with V, Fe and Mn, so also V with Fe, and Fe with Mn. Considerable positive connections within these trace elements divulge their common source, viz., disproportionate use of manure, insecticides and natural geogenic mechanisms which descend in to soils of the study locale. From Table-4, it can be surmised that Fe has a higher affinity with most elements. As a matter of fact, iron is a major constituent of basaltic soil and sediments, and therefore it is expected to show moderate to strong positive correlation with most of the elements.

Principal component analysis (PCA): As mentioned earlier, principal component analysis (PCA) evaluates the correlation composition of the variables by finding hypothetical source of both natural and anthropogenic trace elements variables known as principal components (PCs). This helps in accounting for as much as possible of the variance in a multi-dimensional data set. To comprehend the relationship of soil samples from the study area, depending on trace elements content, Principal Component Analysis was applied via SPSS software (version 20.0 for Windows).

Table-4: Pearson correlation between trace elements in soil from the study area.

	Co	Cr	Cu	Ni	Zn	Y	V	Fe	Mn
Co	1.00								
Cr	0.07	1.00							
Cu	0.53*	-0.05	1.00						
Ni	0.37*	0.59*	0.07	1.00					
Zn	0.57*	0.23 ⁺	0.63*	0.37*	1.00				
V	0.47*	0.09	0.34*	0.36*	0.63*	-0.02	1.00		
Fe	0.68*	0.18	0.59*	0.53*	0.79*	0.42*	0.74*	1.00	
Mn	0.57*	0.08	0.69*	0.27 ⁺	0.69*	0.54*	0.52*	0.73*	1.00

*Correlation is significant at the 0.01 level (2-tailed), +Correlation is significant at the 0.05 level (2-tailed)

The outcome of PCA for trace element contents is given in Table-5. Using Varimax rotation with Kaiser Normalization, the components of the PCA were obtained on the trace element dataset by magnifying the summation of the variance of the factor coefficients. This procedure groups variables into different sectors. According to eigen value criterion, only PCs with eigen value greater than one are considered for interpretation. The Scree plot of the PCA is shown in Figure-3. Two principal components having eigen values greater than 1 accounted for 60.566% of all the data variation which are considered essential and important in Mann Ganga River basin. The factor loadings are grouped into strong, moderate, and weak with loading values ranging from >0.75, 0.75 to 0.5, and 0.5 to 0.3, respectively.

The rotated component matrix reveals that the first principal component (PC1) accounts for 36.243% of total variation and depicts strong positive loadings in Cu and Mn, while it has a moderate loading in Co, Zn and Fe. It is envisaged that atmospheric deposition due to enhancement in industrial operations is responsible for the supplement of these metals. The trace elements concentration in top soil is a result of weathering of basaltic rocks in soil-forming processes, apart

from agricultural and human activities²³. The strong loadings in Cu and Mn suggest that these two metals might develop from same sources. Though Fe and Mn are derived primarily from natural sources, their loadings in soil suggest moderate association in PC1. Both Fe and Mn have close distribution pattern in sediment and are associated with different factors such as erosion, differences in hydrodynamics, periodic dredging activities etc⁹.

The second PC (PC2, variance of 24.323%) suggest a strong loading with V and moderate loading with Fe. The correlation matrix also suggests that vanadium and iron are strongly correlated (Table-4). This is due to the fact that in trap covered areas, ferric hydroxides are the main carriers of vanadium during sedimentation process.

From Table-5 it is observed that all trace metals under consideration could not be distributed in one factor, for instance, V is partially loaded in PC1, whereas Co, Ni and Zn has partial loading in PC2. This suggests that Cu, Zn, Ni and V etc. might be controlled by several other factors and may depict mixed sources of origin.

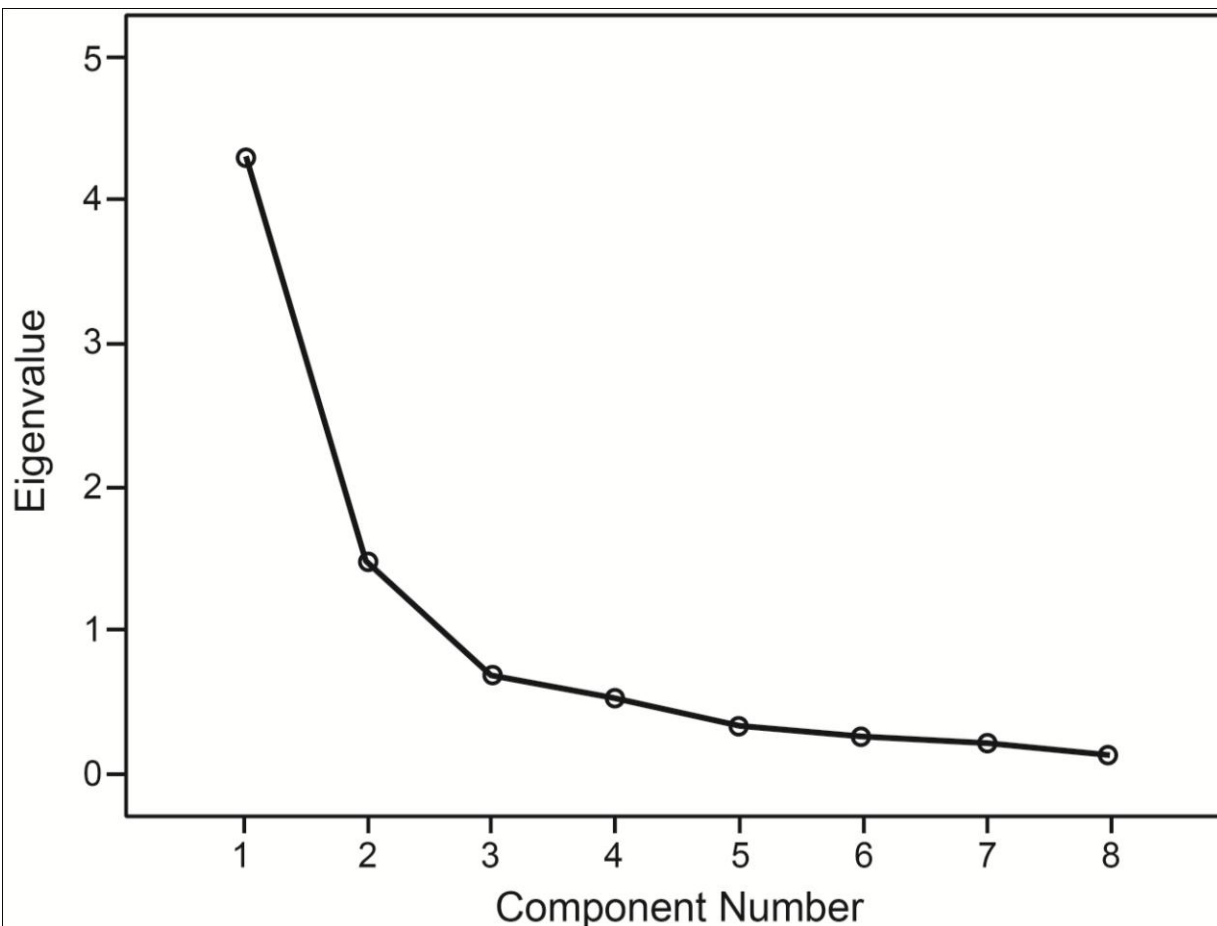


Figure-3: Scree plot showing eigen values of principal components.

Table-5: Varimax normalized factor loading matrix of trace element contents

Metals	PC1	PC2
Co	0.628	0.429
Cr	0.037	-.075
Cu	.932	.047
Ni	.096	.408
Zn	.705	.471
V	.265	.901
Fe	.624	.674
Mn	.818	.317
Initial Eigen value	4.33	1.490
% of variance	36.243	24.323
Cumulative	36.243	60.566

Moderate to strong factor loadings are given as boldface

Conclusion

The Mann Ganga River basin and the surrounding areas have been experiencing severe drought due to paucity of rainfall over several decades. The populace here relies chiefly on agriculture and consequently excessive and erratic use of fertilizers and pesticides are being used to enhance the crop production. This has resulted in soil contamination which persists in the subsurface stratum for several years. Therefore it is of utmost importance to evaluate the suitability of soil for agricultural practices, protection of aquifers and human health. Soil samples from 80 different locations in the surveyed region were collected and evaluated for eight trace element concentrations utilizing several risk assessment indices, correlation coefficients and principal component analysis (PCA). The results reveal significant contamination of the soil quality over Mann Ganga River basin. Several toxic trace elements like Cu, Zn, V, Fe and Mn has moderate to high concentration in the soils of the study expanse as revealed from index of geoaccumulation, enrichment factor and contamination factor.

Relatively elevated values of Cu are observed almost throughout the study area which is due to the composition of quartz tholeiitic in basalts thereby increasing its abundance in the soil. The high concentration of vanadium is due to both geogenic and anthropogenic sources.

PCA results suggest that the trace elements in PC1 accounts for 36.243% of total variation with a strong positive loading in Cu

and Mn, and is moderately correlated with Zn and Fe, displaying high loadings. PC2 showed a variance of 24.323%, with strong loading in V, while a moderate loading is revealed in Fe. The results of PCA recognized two factors controlling the inconsistency in trace elements of the soil of drought-prone Mann Ganga River basin. The variation in Fe, Mn, Co and Zn is related in the same factor and is controlled by lithogenic origin. The inconsistency of Cu, V, Ni and Cr is however dominated by both geogenic and anthropogenic sources.

The current research evidently signifies that the soils from Mann Ganga River basin are contaminated with certain toxic trace metals. The potentially toxic metal pollutants can aggravate the groundwater aquifers due to leaching, which can have deleterious effect on the environment in general, and crops and human beings in particular. Subsequently, a dire need is felt to rectify and reduce at least the environmental pollution and pollutants arising out of human activity in the study region.

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