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Microarthropod as soil quality indicator for ravenous soils of North-West Bundelkhand region

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ABSTRACT

In this study microarthropod population was compared with established soil quality index (SQI), so that indicator potential of soil microarthropods could be established. Forty-three georeferenced sites based on advanced techniques were selected from the major representative land uses *viz.,* arable land, forest, grazing land and degraded land that fall under four administrative districts *viz.,* Datia, Jalaun, Hamirpur and Tikamgarh. The samples were analysed for soil physical, chemical, and biological parameters. The soil quality index (SQI) was computed using minimum data set derived through principal component analysis and based on expert opinion. Soil organic carbon, microbial biomass carbon, nitrogen, potassium, and clay content were selected as contributors of soil quality index. Regression between SQI and micro arthropod abundance established a definite relationship, establishing that the soil micro arthropods might be used as soil quality index for monitoring soil quality for this geography.

Figures : 05 References : 42 Tables : 07

KEY WORDS : Microarthropods, Microbial biomass carbon, NPK, Soil organic carbon, Soil Quality Index (SQI)

Introduction

Soils are living systems containing vast assemblages of organisms which perform many of the functions that are critical to sustainable function of ecosystems. The soil microarthropod plays an important role in various soil processes and is an important mediator of soil food web[6,25]. They are sensitive towards the changing climate, soil environment and above ground changes in biodiversity [18,40]. The activities of this group are essential to the functioning of natural ecosystems, and so also serve as an important indicator for the management of agricultural systems [5,8].

Microarthropods as soil quality indicator are not well established for Indian soils. From management purposes this kind of tools become more apt for degraded poor soils. The north-western tract of Bundelkhand region (India)constituted of Betwa-Dhasan river drainage basin. Droughts are frequent in this region. However, it receives erratic rainfall which makes it prone to soil erosion. The poor capacity of vegetation regeneration further adds to the problem. This delicate soil ecosystem underlines the need for monitoring of soil quality and its maintenance for sustainable productive systems. The importance of microarthropods as indicator of soil fertility is immense specifically for the degraded lands.

Since microarthropod (especially collembola and mites) abundance and diversity is based on soil physical

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TABLE-1 : Sampling locations and land uses in selected districts.

Site (circle no.) refer Fig.1B	Location	Land use	Longitude (N)	Latitude (E)	Altitude (ft)	Soil Class	Dominated Vegetation
Datia(2)	1	Arable land	25° 66' 2.8" N	78° 30' 17.2" E	568	Clay	Sorghum (fodder)
		Forest	25° 47' 48.8" N	78° 30' 21.1" E	627	Silty clay	*Prosopis juliflora*
		Forest	25° 42' 12.8" N	78° 29' 8.1" E	692	Clay loam	*Prosopis juliflora*
		Grazing Land*	25° 50' 41.8" N	78° 32' 3.8" E	605	Silty clay loam	
	2	Arable land	26° 0' 29.7" N	78° 48' 27.8" E	522	Clay loam	*Sorghum bicolor* (fodder)
		Grazing Land*	26° 1' 48" N	78° 47' 5.8" E	524	Silty clay	
	3	Arable land	25° 45' 0.3" N	78° 44' 46.9" E	559	Clay loam	Sorghum bicolor (fodder)
		Grazing Land*	25° 52' 25.3" N	78° 47' 22.9" E	541	Clay loam	
		Degraded land	25° 46' 32.5" N	78° 45' 27.4" E	565	Silty clay loam	
Tikamgarh (4)	1	Grazing Land*	25° 18' 10.7" N	78° 46' 35.3" E	830	Loam	
		Arable land	25° 03' 52.2" N	78° 48' 18.1" E	1022	Silty clay loam	*Sorghum bicolor* (fodder)
		Forest	25° 10' 4.8" N	78° 44' 15.3" E	999-1042	Sandy clay loam	*Butea monosperma, Tectona grandis*
		Grazing Land*	25° 13' 41.2" N	78° 44' 55.5" E	943	Sandy clay loam	
	2	Arable land	24° 59' 30.5" N	78° 49' 47.3" E	1090	Clay loam	Sorghum bicolor + Soyabean
		Grazing Land*	24° 59' 24.9" N	78° 49' 50.2" E	1077	Sandy loam	

		Grazing Land*	24° 55' 22.8" N	78° 50' 23.8" E	1220	Sandy clay loam	
	3	Arable land	24° 52' 13.3" N	78° 49' 58.5" E	1140	Sandy clay loam	*Sorghum bicolor* (fodder)
		Forest	24° 50' 42.1" N	78° 52' 37.6" E	1220	Sandy clay loam	*Diospyros melanoxylon, Madhuca longifolia, Butea monosperma, Tectona grandis*
		Grazing Land*	24° 49' 11.7" N	78° 50' 0.4" E	1117	Sandy loam	
		Grazing Land*	24° 49' 7.2" N	78° 50' 30.9" E	1159	Sandy clay loam	
		Arable land	25° 9' 21.5" N	78° 44' 31" E	1047	Clay loam	*Zea mays* + *Vigna mungo*
Jalaun (7)	1	Arable land	26° 0' 50.6" N	79° 26' 6.4" E	451	Clay	*Sorghum bicolor* (fodder)
		Forest	26° 1' 12.2" N	79° 25' 41.9" E	457	Silty clay	*Prosopis juliflora, Dalbergia sissoo, Azadirachta indica*
		Degraded land	25° 58' 30.2" N	79° 25' 39.7" E	470	Clay	
		Grazing Land*	25° 58' 30.2" N	79° 25' 39.7" E	470	Clay loam	
	2	Grazing Land*	25° 50' 12.7" N	79° 25' 8.6" E	447	Silty clay	
		Forest	25° 50' 12.7" N	79° 25' 8.6" E	447	Clay loam	*Prosopis Juliflora*
		Arable land	25° 51' 48.4" N	79° 25' 25.6" E	461	Clay loam	*Sorghum bicolor* (fodder)
	3	Arable land	26° 1' 29.3" N	79° 25' 22.4" E	452	Clay loam	*Sorghum bicolor* (fodder)

		Forest	26° 1.0' 54.7" N	79° 25' 26.5" E	498	Clay loam	
		Grazing Land*	26° 1.0' 54.7" N	79° 25' 26.5" E	498	Clay loam	
Hamirpur (8)	1	Arable land	25° 20' 59" N	79° 15' 55.5" E	612	Clay	*Sorghum bicolor* (fodder)
		Forest	25° 19' 57.2" N	79° 16' 43.9" E	541	Loam	*Prosopis juliflora*
		Grazing land*	25° 20' 25.9" N	79° 16' 20.8" E	563	Clay loam	
		Grazing land*	25° 20' 6.1" N	79° 16' 40.5" E	586	Silty clay loam	
	2	Arable land	25° 32' 49.2" N	79° 18' 22.6" E	520	Silty clay	*Sorghum bicolor* + *Cajanus cajan*
		Forest	25° 35' 21.9" N	79° 21' 56.7" E	446	Clay	*Dalbergia sissoo, Azadirachta indica, Acacia arabica*, *Anogeissus Pendula*, *Shorea robusta*
		Grazing Land*	25° 32' 49.2" N	79° 18' 22.6" E	520	Clay	
		Grazing Land*	25° 33' 40.6" N	79° 23' 7.9" E	488-525	Clay	
	3	Arable land	25° 13' 41.3" N	79° 80' 4.5" E	634	Clay	*Sorghum bicolor* (fodder)
		Forest	25° 11' 9.3" N	79° 19' 50.3" E	667	Sandy clay loam	*Tectona Grandis*
		Grazing Land*	25° 12' 4.8" N	79° 19' 10.2" E	703	Sandy clay loam	
		Grazing Land*	25° 11' 40.7" N	79° 19' 22" E	683	Clay	

(*) – mixed grass stands of *Cechrus* sp., *Sehima* sp., *Hetropogon* sp., + scattered bushes of *Prosopis zuliflora*, *Zyzyphus* sp. *Casurina* sp., *Caalotropis sp.* etc. and weeds usually sprout in rainy season structure (porosity), availability of nutrients, water (soil moisture), environment (temperature, pH) and chemical composition and occupy almost all the niches in soil food chain, have potential to be developed as bio-indicators[28,24]which is more effective than traditional soil physical and chemical based approach of soil quality evaluation. These approaches are slower in response to changes in soil environment and often, changes are detectable after actual damage has been done. Soil fauna,especially microarthropods are thought to be useful indicators of soil quality because their response is quick towards changes in soil environment[42]. Hence microarthropod based soil indicators are very useful for fragile soil ecosystems.

In this regard a survey was planned to study soil microarthropods abundance of North-West Bundelkhand region. The soil ecosystem of this region is fragile. Erratic rainfall and barren degraded land scape lead to significant surface run-off makes the soil prone to erosion. Further, droughts are frequent and poor capacity of vegetation regeneration adds to the problem[32]. Because of this, the agrarian economy of the region is fully dependent on animal husbandry related activities, which are majorly dependent on community grazing lands. This delicate soil underlines the need for monitoring of soil quality and its maintenance for sustainable productive systems. In this study soil quality index (SQI) incorporating microarthropod population was

TABLE-2 : Descriptive statistics of soil properties

Soil Properties	Mean	St Dev ±	Skewness	Kurtosis	Minimum	Maximum
pH	8.05	0.96	-0.03	0.04	5.82	10.50
EC (mhos/cm)	0.12	0.19	4.06	16.68	0.02	1.09
CL (%)	34.41	10.22	0.45	-0.36	18.30	60.10
SI (%)	32.39	10.51	-0.18	-0.68	11.60	61.60
SA (%)	33.19	17.93	0.31	-1.10	3.30	69.20
Av N (kg/ha)	217.30	68.69	0.52	2.81	40.80	463.40
Av P (kg/ha)	10.97	4.76	1.27	1.33	4.45	26.63
Av K (kg/ha)	453.14	268.43	2.33	8.82	133.90	1858.20
TN (%)	0.05	0.03	1.23	1.33	0.01	0.13
TP (%)	0.05	0.02	0.12	-0.66	0.03	0.09
TK (%)	0.33	0.25	0.95	0.64	0.01	1.09
SM (%)	15.90	7.6	0.39	-0.19	2.77	37.38
MBC (mg C/g)	350.81	333.65	1.33	0.61	13.88	1388.26
SOC (%)	0.38	0.28	2.26	6.12	0.07	1.57

EC – Electrical Conductivity, CL - Clay, SI – Silica, SA – Sand, Av N – Available nitrogen, Av P – Available Phosphorus, Av K – Available Potassium, TN – Total Nitrogen, TP – Total Phosphorus, TK – Total potassium, SM – Soil moisture, MBC- Microbial Carbon, SOC – Soil Organic Carbon used with a view to develop as a bio monitoring tool for soil fertility assessment so that restoration issues could be handled timely.

Materials and Methods

Study site details

Bundelkhand region is spread over 71602.50 km^2 area located between 23°8'N to26°31' N latitude and 78°11'E to 81°31'E longitude and administratively it covers seven districts of Uttar Pradesh and six districts Madhya Pradesh (Fig. 1). This study was carried out in river Betwa and river Dhasan catchment falling under Datia, Jalaun, Hamirpur and Tikamgarh districts of Northwest Bundelkhand region. The land use of these districts is represented by agriculture, forests, barren and uncultivated land, land under non-agricultural use, cultivated wasteland, land under miscellaneous tree crops and grass, permanent pastures and other grazing and fallow lands[1].Forest area (including degraded forest and open tree cover) of these four districts is classified as low forest cover *i.e.*, forest (>40% canopy) cover is hardly 11 per cent of area. Maximum grazing lands are available in Jalaun district (12.84%), and in Datia (6.73%)

TABLE-3 :Soil properties of different land uses

	Land use (locations sampled, no. of samples)			
	Arable Land (13, 39)	Forest (10, 30)	Grazing Land (18, 54)	Degraded Land (2, 6)
pH	8.28 ± 0.08 [a]	7.86 ± 0.11 [a]	7.76 ± 0.15 [a]	10.12 ± 0.25 [b]
EC (mhos/cm)	0.07 ± 0.01 [a]	0.08 ± 0.01 [a]	0.09 ± 0.02 [a]	0.79 ± 0.16 [b]
CL (%)	38.30 ± 1.69 [a]	33.88 ± 1.54 [a]	32.04 ± 1.42 [a]	33.07 ± 3.68 [a]
SI (%)	35.18 ± 1.63 [ab]	31.84 ± 1.49 [a]	29.71 ± 1.57 [a]	41.18 ± 1.50 [b]
SA (%)	26.51 ± 2.42 [a]	34.28 ± 2.76 [a]	38.23 ± 2.78 [a]	25.75 ± 2.94 [a]
Av N (kg/ha)	223.12 ± 5.55 [b]	262.79 ± 15.22 [c]	203.91 ± 6.96 [b]	72.52 ± 25.48 [a]
Av P (kg/ha)	12.75 ± 0.82 [b]	10.06 ± 0.83 [ab]	10.56 ± 0.62 [ab]	7.70 ± 0.56 [a]
Av K (kg/ha)	421.38 ± 24.25 [a]	634.76 ± 74.83 [b]	395.26 ± 26.85 [a]	272.33 ± 19.13 [a]
TN (%)	0.06 ± 0.00[bc]	0.07 ± 0.01 [c]	0.04 ± 0.00 [ab]	0.02 ± 0.00 [a]
TP (%)	0.06 ± 0.00 [ab]	0.05 ± 0.00 [ab]	0.05 ± 0.00 [a]	0.06 ± 0.01[b]
TK (%)	0.34 ± 0.04 [a]	0.38 ± 0.04 [a]	0.29 ± 0.04 [a]	0.32 ± 0.03 [a]
SM (%)	21.97 ± 1.03 [c]	16.95 ± 1.35 [b]	11.48 ± 0.71[a]	10.96 ± 1.93 [a]
MBC (mg C/g)	387.74 ± 51.77 [a]	340.08 ± 67.74 [a]	353.64 ± 45.54 [a]	139.07 ± 28.01[a]
SOC (%)	0.41 ± 0.02[bc]	0.58 ± 0.07 [c]	0.29 ± 0.03 [b]	0.10 ± 0.03 [a]

Duncan subset [abc] at alpha 0.05; EC – Electrical Conductivity, CL - Clay, SI – Silt, SA – Sand, Av N – Available nitrogen, Av P – Available Phosphorus, Av K – Available Potassium, TN – Total Nitrogen, TP – Total Phosphorus, TK – Total potassium, SM – Soil moisture, MBC- Microbial Carbon, SOC – Soil Organic Carbon while limited patches of grasslands are available in Hamirpur and Tikamgarh (2-3%) districts. Grazing lands of Datia, Jalaun and Hamirpur districts are badly affected by ravines and shrub infestations[27]. The soil fertility is in the low to medium range. Annual rainfall in the area varies from 750-900mm.

TABLE-4 : Microarthropods families observed in the study locations

	Collembola	Mites	
		Oribatida	**Others**
1	Onychiurus	Hermannidae	**Gamasida**
2	Sensiphorura	Plateremaeidae	11 Unidentified sp.
3	Paronellidae	Perlohmanniidae	**Actinedida**
4	Folsomia	Polypterozetidae	Calligonellidae
5	Isotomodes	Schlerobatidae	4 Unidentified sp.
6	Isotomurus	Damaeidae	**Acaridida**
7	Brachystomellidae	Hermanniellidae	Anoetidae
8	Hypogasturidae	Ameronothridae	2 Unidentified sp.
9	Mackenziellidae	Carabodidae	
10	Neelidae	Mesoplorphoridae	
11	Dicrytomidae	Epilohmannidae	
12	Sminthuridae	Phthiracaridae	
13	Lepidocrytus	Cepheidae	
14	Entomobryidae	Cercomegistidae	
15	Folsomides	Erythraeidae	
16	Neosminthurus	Galumanidae	
17	5 Unidentified sp.	Oppiidae	
18		Oribatulidae	
19		Neoliodidae	
20		18 Unidentified sp.	

Selection of sampling sites

Graticules and multiple layers overlay techniques. IRSP6L3 satellite data and ERDAS Imagine and Arc-info workstation software were used for this study. Land use/ Land cover (LU/LC) classes were extracted from IRSP6L3 image using geo-processing tools of ArcInfo Workstation. The sample sites are truly representative of bio-physical entity of the Bundelkhand region. Different thematic layers *viz.,* LU/LC, relief, drainage, rainfall, Irrigation, major soil types and landform were used for the selection of site. A total of 17 potential sample sites were identified based on thematic layers. Again, to avoid the similarity of topography and land cover eight potential sites were considered. Finally, for the present study only four representative sites located in Betwa catchment were selected (Fig. 1 A & B). From each site three locations, each covering 2-4 LU/LC classes, were selected for the final soil sampling (Fig. 1C).Based on this, 43 locations soil was sampled (Table 1).

Soil sampling

The representative soil samples (0-15cm) were collected with core-sampler from 43 geo-referenced locations selected to represent major land uses of the districts. Number of sampled land uses varied depending on the approachability from motorable roads. The geographical coordinates, latitude, longitude, and altitude were recorded by hand-held Global Positioning System. From each location, three samples were collected, approximately 100m apart from each other thus total 129 samples were collected. Soil samples were sealed in plastic bags and processed in laboratory. A part of samples was dried in air, pulverized, and passed through a 2mm sieve for physico-chemical analysis. The remaining part was used for microarthropod extraction.

Soil physico-chemical analysis

The soil texture was measured by modified hydrometer method[12].The soil reaction or pH was estimated by glass electrode pH meter(1:2.5 soil: water suspension) and electrical conductance (EC) was measured by using a conductivity bridge. The bulk density was determined by the core method and soil water holding capacity was estimated by Keen Rackzowski box following the procedures. The oxidizable soil organic C carbon (SOC) was determined by the Walkley and Black method. Total nitrogen was estimated by Kjeldahl's digestion and distillation procedure. Ammonium (NH_4^+) and nitrate (NO_3^-) nitrogen was determined by steam distillation of ammonia using heavy MgO for NH_4^+;then reduction with Devarda's Alloy followed by steam distillation in the same for NO_3^-. The available phosphorus in soil was estimated colorimetrically (nm) after extraction with 0.5M $NaHCO_3$. Total phosphorus content was analysed by $HClO_4$-digestion method described by. Exchangeable potassium was determined by extraction with 1N CH_3COONH_4(1:5 soil-solution ratio) followed by estimation on a flame photometer.Soil microbial biomass C was measured by the fumigation-incubation method, from the relationship $Bc = F_C/k_C$, where F_C= [(CO_2-C evolved from fumigated soil, 0-10 days) - (CO_2-C evolved from non-fumigated soil)] and kc, the proportion of microbial C evolved as CO_2 = 0.45 for 10-day incubations at 25°C[16].

Soil microarthropod extraction

To quantify fauna population in soil, the samples were collected using a Cylindrical Core Sampler (diameter 5 cm). All plant material was removed from the land surface and samples were drawn from 10 cm depth of soil. After this, each core was carefully sealed in a separate polythene bag and transported to laboratory for processing. Modified Berlese-Tullgren Funnel method was followed for extraction of microarthropods. The samples were placed on sieve (pore size H" 2mm) and were heated from above by an ordinary lamp bulb (25 W), suspended about 20 cm above. The organisms

TABLE-5 Diversity of microarthropods observed in studied land uses

Land Use	Shannon-Wiener	Margalef's	Richness	Evenness	Simpson's Dominance
Arable Land	2.40^{ab}	2.83^{ab}	18.46^{ab}	0.88	0.15
Forest Land	2.63^{b}	2.92^{b}	19.80^{b}	0.91	0.09
Grazing Land	2.03^{a}	2.15^{a}	12.72^{a}	0.89	0.21
Significance	0.05	0.04	0.04	ns	ns

(Degraded land data was not analysed due to very low population) moved down and got collected into the specimens' tube filled with 50% polyethylene glycol (200 LR). They were then separated by means of a fine camel hairbrush with the help of an ordinary binocular stereo- zoom microscope. After sorting, the soil microarthropods were preserved in 70% alcohol (9 parts) and glycerol (1 part) for identification and further studies. Samples were prepared for identification by using temporary mount consisting of a cavity slide, cover slip and lactic acid as the mounting medium. Some permanent mounts were also prepared in Hoyer's medium. The samples were identified and categorized under an inverted compound microscope. The major groups of soil microarthropods were classified using available keys[15,20]. Population (per m^2) was estimated as per following equation[31] (Where, *X* is the number of organisms per sample and *d* diameter of sampler). However, before calculation population count was transformed (n+1) to counteract zero counts recorded in some of the samples for ease in statistical calculation.

$$Population/m^2 = \frac{10000\ \mathrm{X}}{0.785\mathrm{d}^2}$$

Diversity indices (Shannon index, Simpson's dominance, Evenness, Marglef's index, and richness were calculated by using Biodiversity professional version 2 software.

Soil quality index

Soil quality index (SQI) was calculated for developing arthropod abundance as a tool for monitoring sustainable land uses. Minimum soil data set (MDS) were selected for SQI by principal component analysis (PCA) and based on available literature[41]. The index value was used as a representative value of the overall assessment of soil quality of the study area. Principal component analysis (PCA) was employed to give weights to the selected quality attributes. Components having high Eigen values (>1) and variables with high factor loading were assumed to be best represented attribute. Percentage of variance explained by each PC divided by the total percentage of variance explained by all PCs provided weighted factor for chosen indicator variable under a given PC. For SQI weighted variable score was summed up for each observation as per equation :-

$$\mathrm{SQI} = \sum_{i=1}^{n} Wi Si$$

where *Wi* is assigned weight of each indicator deduced from PCA, *Si* is the score of subscripted variable and n is the number of indicators in the final minimum data set[33]. The correlation analysis was done to determine relation among the indicator variables and mesofauna abundance. Regression between SQI and population was used to find out the possibility of using microarthropod population as bio indicator of fertility.

Statistical analysis

Descriptive statistics like mean, maximum, minimum, standard error of mean, kurtosis and skewness and one way ANOVA for diversity indices, Correlation, linear regression and factor analysis using PCA were carried out by SPSS ver. 20.0. Regression analysis curve between SQI and population of 33 georeferenced location (data of ten locations showing

TABLE-6 : Correlation matrix among variables

	MBC	Moist	pH	EC	SOC	Av N	Av P	Av K	TN	TP	TK	CL	SI	SA	Pop
MBC	1.00														
Moisture	.290**	1.00													
pH	-.435**	0.04	1.00												
EC	-0.17	-0.07	.517**	1.00											
SOC	.480**	.301**	-.346**	-.238**	1.00										
Av N	.324**	0.13	-.446**	-.486**	.783**	1.00									
Av P	.212*	0.10	-0.17	-.198*	0.17	0.14	1.00								
Av K	-0.15	0.16	.231**	-0.03	0.14	0.08	0.08	1.00							
TN	0.13	0.17	-0.15	-.207*	.450**	.395**	.195*	.343**	1.00						
TP	-0.12	-0.07	.318**	0.15	0.13	0.04	0.05	.266**	.382**	1.00					
TK	-.316**	0.08	.524**	0.11	-.221*	-.208*	-.400**	.468**	0.04	.207*	1.00				
CL	-.328**	.186*	.474**	0.07	-0.14	-0.08	-.217*	.332**	-0.02	.205*	.496**	1.00			
SI	-.219*	.212*	.646**	.214*	-.204*	-.247**	-.289**	.436**	0.00	.329**	.661**	.488**	1.00		
SA	.317**	-.231**	-.651**	-0.16	.200*	.191*	.294**	-.445**	0.01	-.310**	-.671**	-.858**	-.866**	1.00	
Pop	.194*	.230**	-.181*	-0.11	.362**	.213*	0.06	.302**	0.10	0.13	-0.09	.209*	-0.03	-0.10	1.00

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

EC – Electrical Conductivity, CL - Clay, SI – Silt SA – Sand, Av N – Available nitrogen, Av P – Available Phosphorus, Av K – Available Potassium, TN – Total Nitrogen, TP – Total Phosphorus, TK – Total potassium, Moist – Soil moisture of sample, MBC- Microbial Carbon, SOC – Soil Organic Carbon, Pop – Microarthropod population extreme fluctuation were removed based on population abundance ± standard deviation) was drawn by Excel (Microsoft Office 15) package.

Results and Discussion

Soil properties

The soils of the study area were clay loam to sandy clay loam. An extensive variation in soil pH, EC, N, P, K, SOC, MBC were recorded (Fig. 2, Table2& 3). Distribution over space was highly skewed for MBC, EC, SOC, total N, available P, available K and microarthropod population. Kurtosis was also high for these parameters. Variability was recorded for EC (0.02–1.09) with mean (0.12 ± 0.02), skewness (4.06) and kurtosis (16.68). Highest EC was observed in the degraded land of Datia site (1.09) followed by Jalaun degraded sample site (0.68). The soil pH was in alkaline range with mean, 8.05 ± 0.08 with low skewness (-0.03) and kurtosis (0.04) value. The highest pH was found in the barren highly degraded land scape (10.12) in Datia and Jalaun sites and lowest pH (5.82) was found only at one location in ravine land area of Jalaun district.

As per rating chart of soil data soils were low in Av N and Av P while high in Av K, the average content of the nutrients being 217.3 ± 6.05, 10.97 ± 0.42 and 453.1 ± 23.63, respectively. Statistically higher Av N and Av K was recorded in Forest lands followed by arable land and grazing land whereas Av P was higher in arable land situation. The values for total N, P, K showed different trend. Significantly higher N but lowest P was recorded in the forest land. This may be attributed to more diverse vegetation in forests.

Soil moisture varied at sampling locations under different land use situations with 15.9 percent mean value. Lowest value was recorded in degraded land followed by grazing land situation which was significantly different from forest and arable lands. The pH and EC of degraded land were also significantly higher than all other land use situations. Earlier it[13] was reported that the soil in the Bundelkhand area comes under alfisol group with excessive permeability, very low moisture retention capacity and low inherent fertility. In this study similar results were found.

MBC values ranged from 13.88 to 1388.26 $mgCg^{-1}$ depending on the location. The mean MBC value (350.81$mgCg^{-1}$) was highly skewed (1.33 $mgCg^{-1}$). In general, there was no significant difference of MBC in arable land, forest, and grazing land uses. However, in Tikamgarh sites mean was significantly higher (697.71 ± 67.46$mgCg^{-1}$) than other sites. The site and land use had affected MBC values. Workers[38] reported that cropping reduced MBC content of soil in comparison to the nearby forested areas in dry tropical forest ecosystem. Previous workers[17] observed that sampling location and land slope affect MBC values in Central Iowa USA. They found that samples collected from potholes and toe slope positions had significantly greater

TABLE-7 : Principal component analysis of soil attributes

Rotated Component Matrix [a]

	Component			
	1	**2**	**3**	**4**
Eigen value	4.61	2.69	1.30	1.14
% of Variance	28.20	16.41	13.19	11.77
Cumulative %	28.20	44.61	57.80	69.57
Eigen vectors				
MBC	-0.36	0.19	0.00	**0.71**
Moisture	0.27	0.02	-0.02	**0.83**
pH	0.58	**-0.64**	0.14	-0.10
EC	0.04	**-0.82**	0.06	0.02
SOC	-0.15	**0.53**	0.42	0.52
Av N	-0.11	**0.78**	0.28	0.26
Av P	-0.44	-0.03	0.41	0.23
Av K	**0.53**	0.12	0.49	0.03
TN	0.02	0.34	**0.74**	0.11
TP	0.21	-0.19	**0.77**	-0.14
TK	**0.81**	-0.07	0.04	-0.15
CL	**0.81**	-0.02	0.00	-0.01
SI	**0.82**	-0.30	0.13	0.09
SA	**-0.94**	0.18	-0.07	-0.05

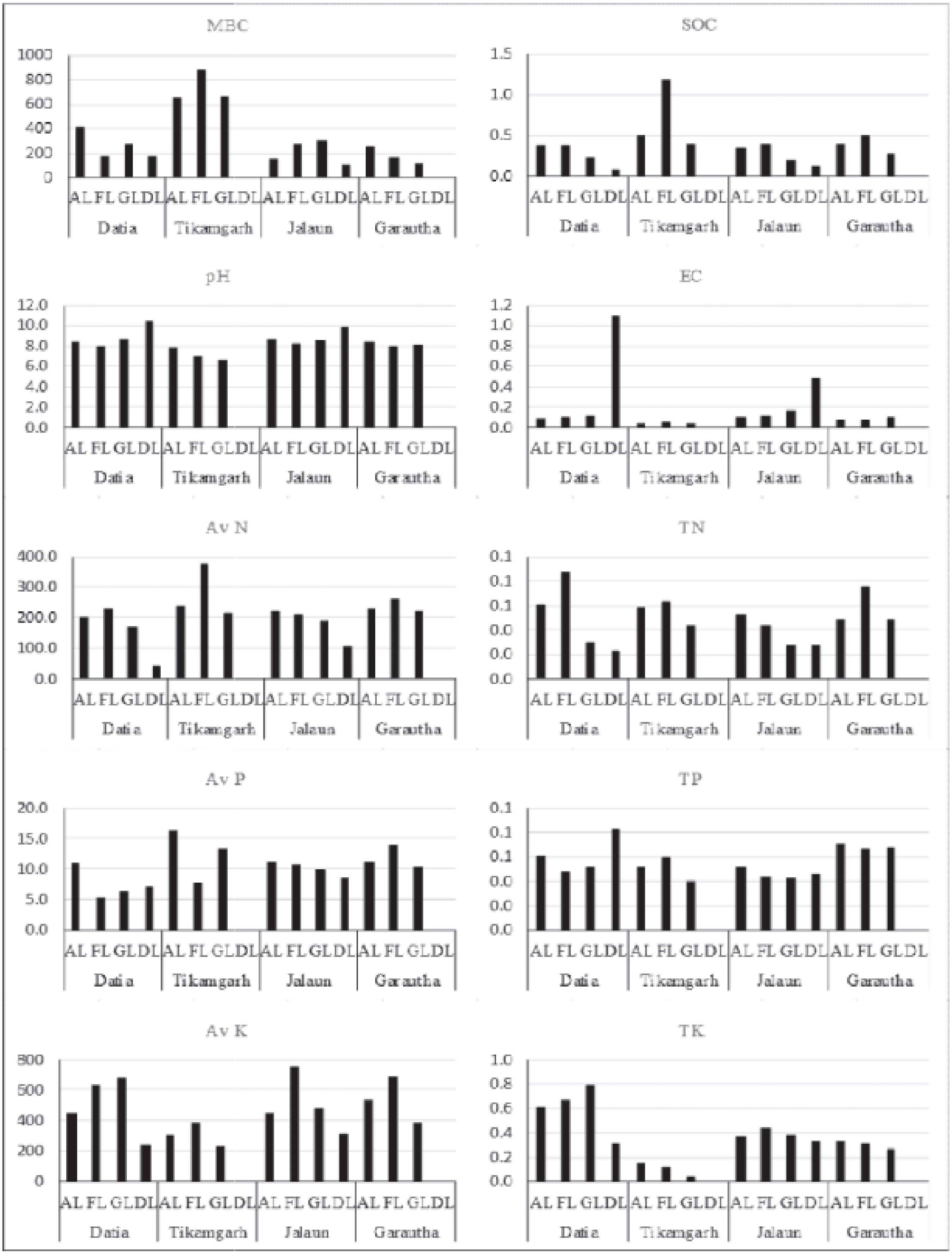

Fig. 1 : Soil properties at different locations/sites (AL = Arable land, FL = forest Land, GL = Grazing land, DL = Degraded land)

microbial biomass nitrogen and carbon, total carbon, total nitrogen and extractable organic carbon.

SOC showed wide variability (0.07 – 1.57%) with mean (0.38%). Highest SOC was recorded from forest areas (0.58%) followed by arable land (Table 3). Lower SOC in degraded land area was due to eroded soil devoid of much vegetation. Significantly higher organic carbon (1.18%) in Tikamgarh deciduous forest area was against India average of 0.2-0.5 percent. This may be attributed to high litter fall. Present finding agrees to earlier investigation[9] who reported high SOC values in forest ecosystems. Other workers[11] also reported that SOC build up was higher under tropical plantation crops and thick forests.

Microarthropod diversity and abundance

A total of 3281 number of specimens collected in this entire study. Out of these 1034 were collembolans and 2234 were mites and only 3 specimens were proturans. Collembolans belong to 16 families while mites fall under 22 families. However, some of the specimens could not be identified (Table 4).

Effect of land use was observed on the diversity indicators (Table 5). The greater species diversity and build-up of population in forest ecological systems as compared the arable land or grazing situation suggest that plant combinations/cover provide a congenial environment for soil mesofauna[2,22,35,37]. This study complements to the indication that landscape heterogeneity influence soil fauna species diversity[10,36,40].

The mean abundance across the land use and location was 134.55 × $10^2/m^2$ with confidence interval of ± 30.55 and inter-quartile range was 152.70 (Q1 =25.45, Q2 = 76.35, Q3 = 178.15). Abundance data showed high kurtosis value (11.43) indicating higher abundance at few locations under forest land use (Fig. 2 & 3). Despite of high variability of microarthropod community there was significant difference in abundance among sites and land uses. Forest lands harboured a greater number of arthropods (209.54× $10^2 m^{-2}$) compared to arable lands (170.32×$10^2 m^{-2}$), grazing lands (81.44 × $10^2 m^{-2}$) and degraded lands (5.09×$10^2 m^{-2}$). The population was rich in Hamirpur (177.58 ± 30.00), Tikamgarh (157.08 ± 19.68) and Jalaun (121.99 ± 47.53) locations. It was, however, significantly lower in Datia (61.08 ± 12.67). This is mainly due to the higher population of forest area samples.

Correlation among soil attributes and microarthropods

Correlation matrix showed significant positive corelation of MBC with soil texture attributes, NPK, SOC, and negatively correlation with pH. Total nitrogen and potassium strongly correlated with available NPK,while pH was strongly related to EC, available N and K and soil texture attributes. Microarthropods abundance was correlated with MBC, soil moisture, pH, SOC,available N and K and clay content (Table 6). These correlations indicate that microarthropod abundance was affected by soil physical chemical and biochemical attributes.

In a study[21] on microarthropod community under different trees and trampling management it was observed that the abundance was in general negatively correlated with soil pH, EC, and Bulk density while it was positively correlated with soil moisture and water-holding capacity. It was noticed[3] that total microarthropods, Acari and Collembola densities exhibited positive correlation with SOC and moisture.

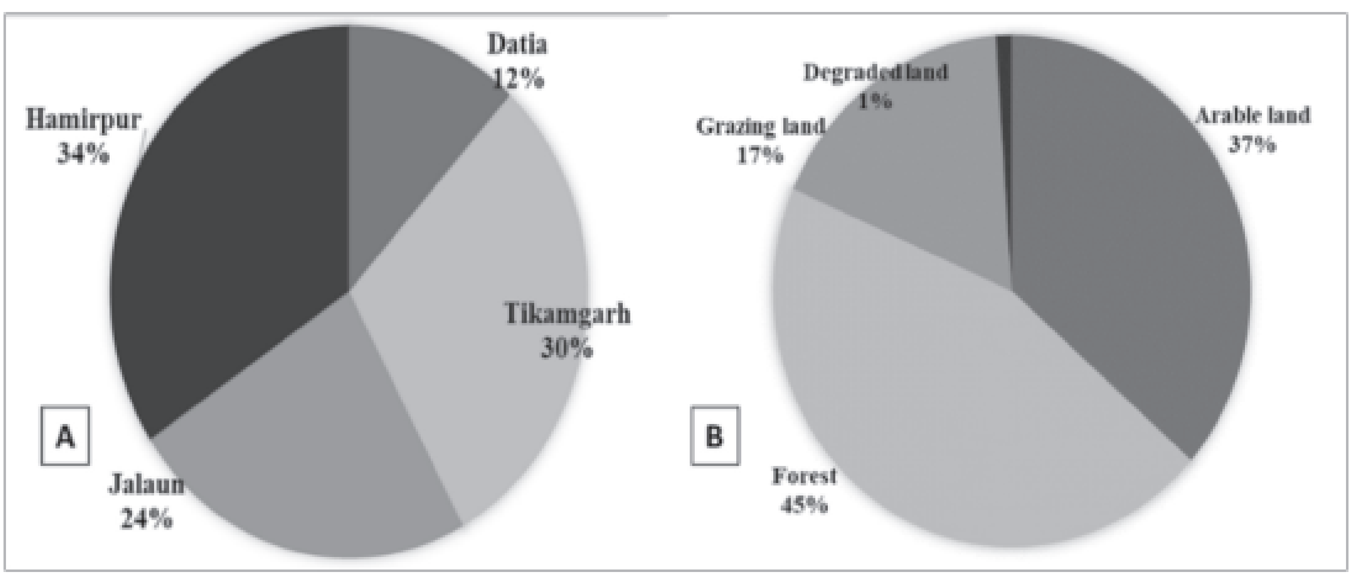

Fig. 2 : Mean microarthropod population under different sites (A) and land uses (B)

They were, however, negatively correlated with bulk density, pH and temperature of the soil.

Soil quality index

The impact of land uses and locations was assessed by deriving soil quality index (SQI). Four Principal component (PC) were identified with eigen values more than one from the fourteen soil attributes (Table 7). A total of 70 percent variance was explained by PC1 (28%), PC2 (16%), PC3 (13%) and PC4 (12%). First PC had five highly weighted variables (Av K, TK, CL, SI, SA), second PC had four highly weighted variables (pH, EC, SOC, Av N), third PC (TN, TP) and fourth PC had two variables (Moisture, MBC).

Since availability of nutrients in forest and grazing lands depends on the pool[29], it was categorical to use TN and TK values for soil quality index calculation. SOC is important to soil fertility parameter and is a strong indicator of a soil biological health[7]. MBC being a labile pool of organic matter acting both as source and sink of plant nutrients.Change in microbial biomass adversely affect cycling of soil organic matter, ecosystem stability and fertility[34]. Soil texture has effect on water holding capacity, nutrient retention and supply, drainage, and nutrient leaching. Coarse soils have a lesser ability to hold and retain nutrients than finer soils. Clay content is directly responsible for ion exchange and availability of nutrients and water retention attribute of soil[19].

Hence,soil variables *viz.,* SOC, MBC, TN, TK, and CL were used as data set for soil quality index calculation for this study (Table 7 shown as bold & underlined).The selected variables were well-thought-out beneficial parameters and were treated as more is better[33]. The SQI was calculated by giving weight to each variable through PCA results. The amount of variation explained by each PC divided by cumulative variation explained by all PCs was used to weight variables selected under a PC. After this all the weighted variables were summed up for each sample as per equations 1and2.

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold underline component loadings were MDS used in indicator.

MBC- Microbial Carbon, EC – Electrical Conductivity, SOC – Soil Organic Carbon, Av N – Available nitrogen, Av P – Available Phosphorus, Av K – Available Potassium, TN – Total Nitrogen, TP – Total

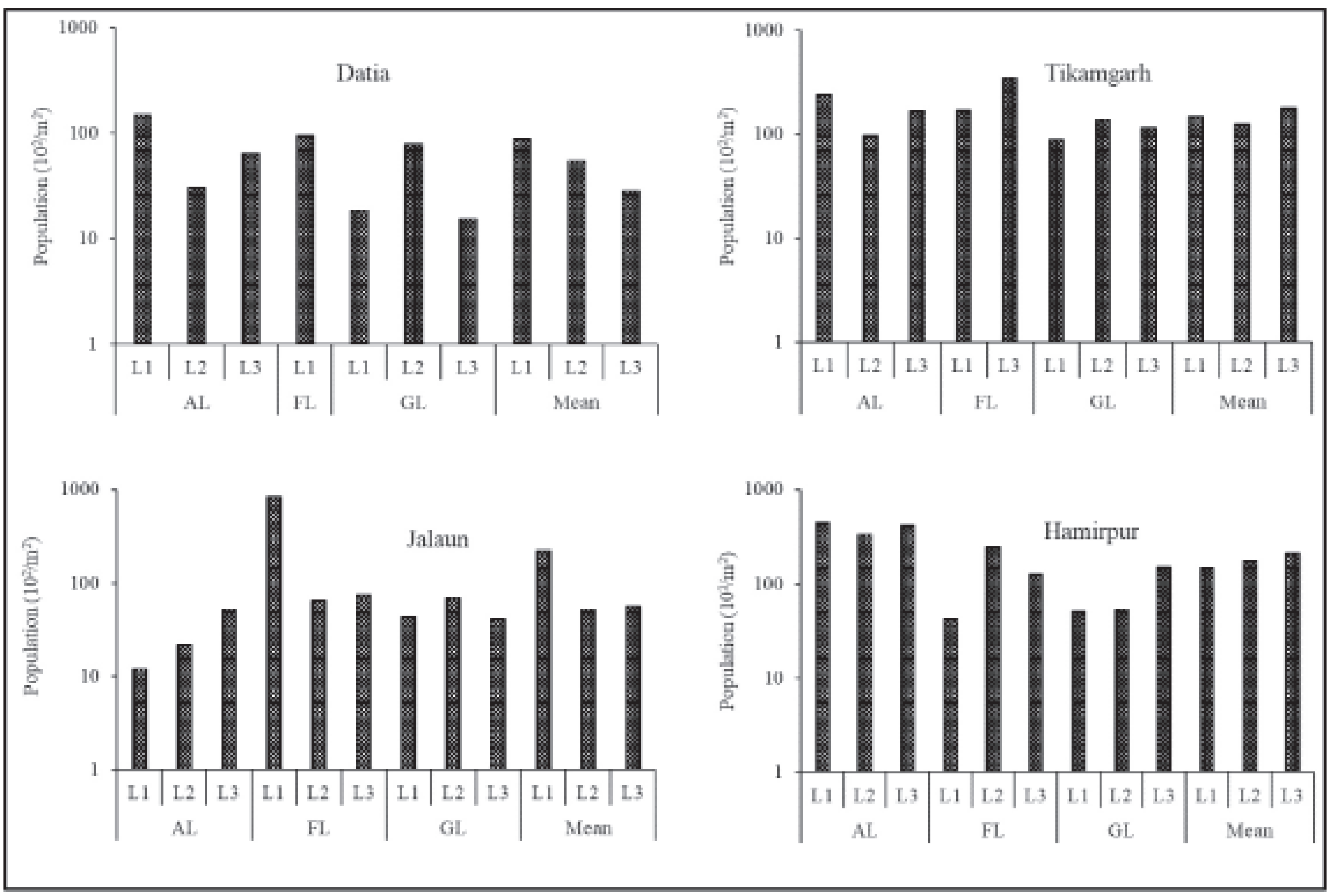

Fig. 3 : Microarthropod population under different land uses from different locations.
(AL = Arable land, FL = forest Land, GL = Grazing land)

Phosphorus, TK – Total potassium, CL - Clay, SI – Silt, SA – Sand.

$$SQI = \frac{0.14S \quad +0.14S \quad +0.16S \quad +0.13 \quad +0.12S}{0.70} \text{ ------(1)}$$

$$SQI = 0.20_{TK}+0.20_{CL}+0.24_{SOC}+0.19_{TN}+0.17_{MBC} \text{ ------(2)}$$

Highest SQI was recorded for AL (73.75), FL (64.82), GL (66.66) and significantly low for DL (30.35). When different locations were compared Tikamgarh samples showed significantly higher value (123.88) followed by Datia (55.50), Jalaun (46.52) and Hamirpur (34.68) (Fig. 5).

Microarthropods population *vs* soil quality index

This relationship was further supported by the significant regression statistics of SQI with population (R^2 = 0.26; $F_{1,36}$=12.51; p =0.001) of 37 georeferenced locations (Fig. 5).

Microarthropods as SQI approach is preferable on account of their quick response to changes in soil environment. This is because of their sedentary life, intricate relationship, and the stability of community composition at a specific site. Several ways like, species ratio, dominance structure, diversity indices, feeding types, life history patterns, *etc.,* have been defined to characterize soil microarthropod fauna to use as indicator of soil fertility/quality. A worker[39] had reviewed and evaluated different aspects of community structure based on specificity and resolution. He concluded that a combination of physio-type classification and multivariate statistical analysis are good enough for evaluation or developing soil microarthropods as bio-indicator. Many recent studies highlighted similar results. Previous scientists[28] developed an integrated approach through summing up a simplified functional trait score, the eco-morphological index (EMI) of soil arthropods, for assessment of soil quality. Abundance and diversity of soil fauna as an indicator of physical, chemical, and microbiological properties of soil was used by many workers[23,26].

There was found a good relationship with abundance based faunal index (FAI) values with soil quality and the functional trait method could be generalized into a flexible abundance-based measurement[42]. In their multiple taxa method, FAI measured biological quality of soil faunal community in explicit function. There was done assessment[4] of different land uses in the Mid Hills of Nepal based on the density, diversity, and soil biological quality index (QBS-ar) of microarthropods. In another comprehensive assessment[30] of soil quality in South Tyrol, biological soilquality index (BSQ) Italy used. The study results showed that BSQ reacted sensitively to land use hence can serve as indicator for sustainable land use practices.

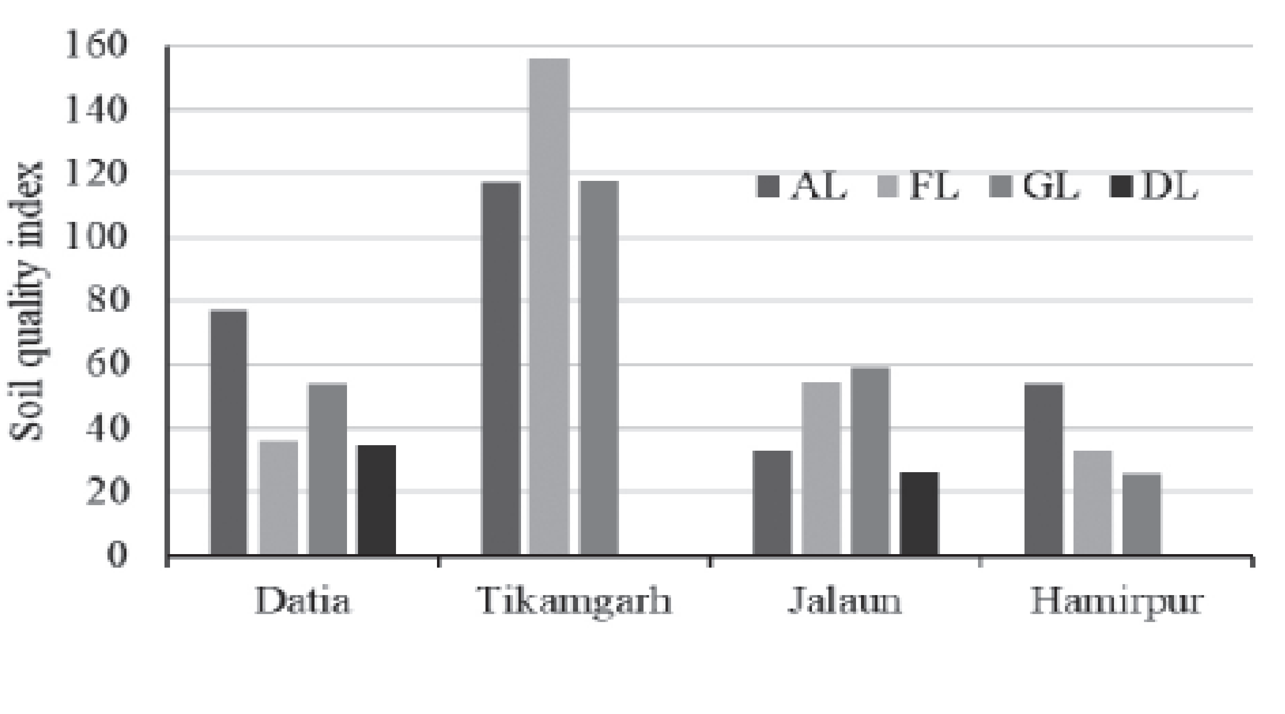

Fig.4 : Soil quality index (SQI) in different locations and land uses
(AL = Arable land, FL = forest Land, GL = Grazing land, DL = Degraded land)

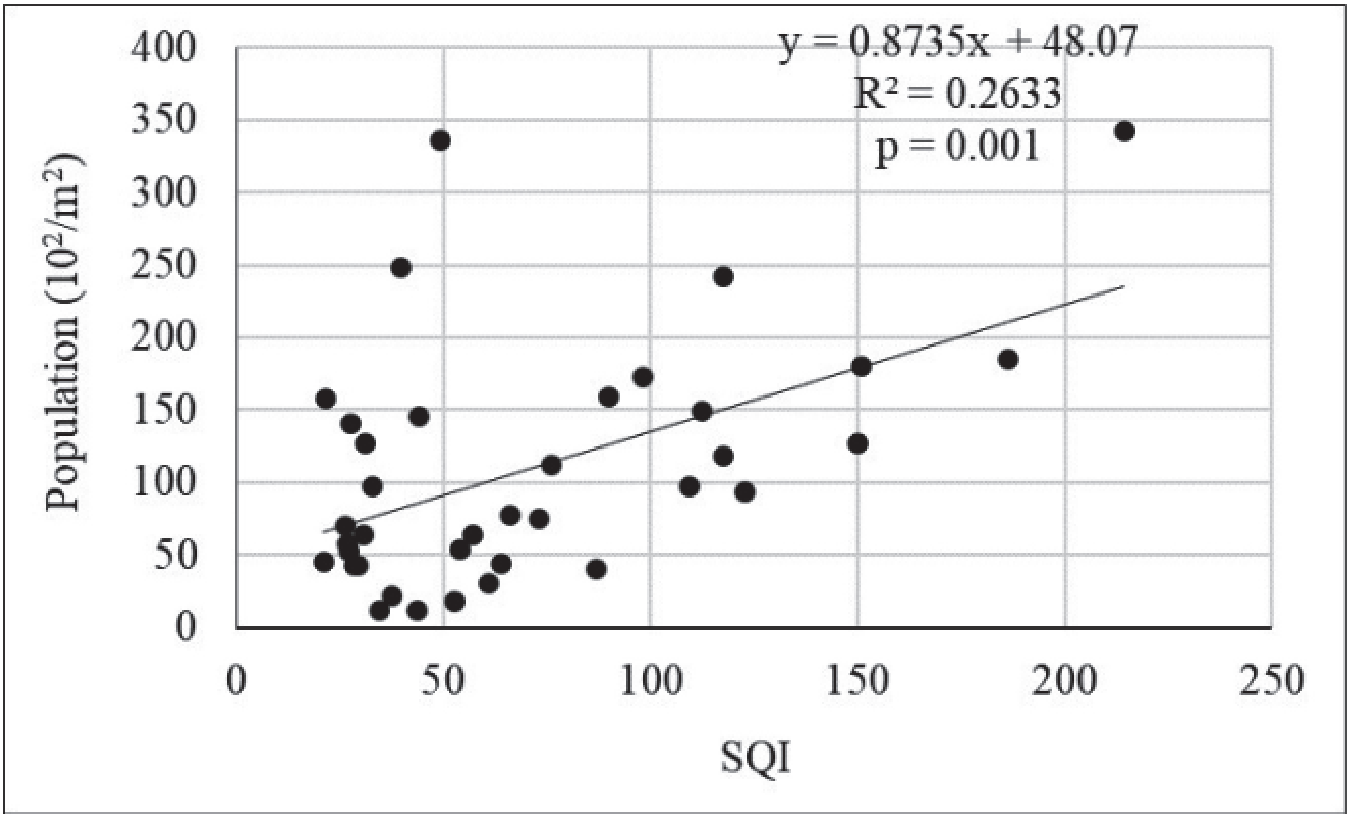

Fig. 5 : Relationship between soil quality index and microarthropod population

Some workers[14] selected soil arthropod abundance as one of the parameters for monitoring impact of rubber plantation on soil quality in Southwest China.

Conclusion

In this study a relationship is evident between microarthropod abundance and soil quality attributes. High SQI was found in arable land followed by forest, grazing land. Tikamgarh district exhibited significantly high value of SQI when compared to other districts possibly due to a very high area under forests in this district.The study conclusively addresses the role of soil microarthropods abundance as an important component in assessingsoil quality as indicator. Such an approach has merit over traditional SQI that relies on soil chemical parameters only. Abundance of microarthropods may be used for soil quality monitoring as they are consequence of cumulative impact of soil physical, chemical, and microbial parameters. The superiority of indicator lies in terms of early detection (time efficient), cost effective and in ease of operations. It may be very useful for monitoring and evaluation of various types of agricultural, development and other projects in both short and long run.

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