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Analysis of Soil and Water Quality Status among the Different Villages in Kashi Vidyapith Block of Varanasi District, Uttar Pradesh

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ABSTRACT

The current study was conducted from November, 2023 to June, 2024 in the villages of the Kashi Vidyapith block of Varanasi district, Uttar Pradesh (221 107), India to assess soil and water quality status. We have collected forty GPS (Global Positioning System)-based soil samples from depths of 0–15 cm and thirty water samples from the villages. The collected soil and water samples underwent analysis for physicochemical characteristics. The coefficient of variation for available nutrients fluctuated, with values for available nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium recorded at 24.85%, 22.13%, 13.53%, 14.87%, 16.87%, and 16.40%, respectively. The nutritional index in the identified samples indicated that the amounts of available nitrogen, phosphorus, potassium, and sulphur were generally low. The water analysis revealed that the range of pH (7.6–8.8), electrical conductivity (EC) (0.56–2.33 dS m^{-1}), chlorides (0.4–1.2 Meq l^{-1}), carbonates and bicarbonates (0.4–1.2 Meq l^{-1} and 7.6–18.8 Meq l^{-1}), while calcium and magnesium (5.8–75 Meq l^{-1}). Additional, parameters such as permeability index (PI) range from 5.9–53.8 exceed permissible limits, whereas sodium (0.17–0.78 Meq l^{-1}), potassium (0.02–2.89 Meq l^{-1}), sodium adsorption ratio (SAR) (0.03–0.17 Meq l^{-1}), soluble sodium percentage (SSP) (0.53–10 Meq l^{-1}), potassium ratio (KR) (0.003–0.037), and residual sodium carbonate (RSC) (-60.6–4.6 Meq l^{-1}) remain within permissible limits. Derivated from specific factors, the water quality index ranges from 153.43–444.23, suggesting a marginally unsustainable water quality. The integrated use of biofertilizers, bioinoculants, and site-specific nutrient management is essential for improving soil health and enhancing nutrient availability for plants.

KEYWORDS: GIS, GPS, nutrient index, soil quality, water quality

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

The sustainability of crops relies on the evaluation and surveillance of soil and water quality (Yadav et al., 2022). Plants can extract carbon and hydrogen, two prevalent plant nutrients, from the atmosphere and water. The other categories of nutrients are primary and secondary macronutrients, micronutrients (Khadka et al., 2019; Verma et al., 2023). Therefore, it surely demonstrates that soil is the primary source of nutrients for crops and it contributes to the plant's development in distinct ways (Delsouz et al., 2017). Therefore, we must conduct a comprehensive soil study to identify nutrient deficiencies and supply appropriate quantities of nutrients to plant. Soil testing provides us data on nutrient availability which helps us in giving fertilizer recommendations to crops. The meticulous regulation of pH, organic carbon, available N, available P, and available K has garnered interest because of its potential to augment economic returns in crop production while mitigating environmental impacts (Singh et al., 2021). A previous technological limitation was that, prior to the advent of GPS and Geographic Information System (GIS) solutions, it was challenging to articulate the spatial variability of soil fertility within the region (AbdelRahman et al., 2020). It is advisable to utilize the Global Positioning System for soil sampling when developing thematic soil fertility maps. Mishra et al. (2016) asserted that precise application maps for site-specific fertilization are essential in the context of precision agricultural technology. Therefore, regional variability maps depicting pH, organic carbon, nitrogen, phosphorus, and potassium levels in soil will facilitate a reduction in fertilizer usage, associated costs, and the ensuing detrimental effects on the environment. Yao et al. (2004) characterize geo-statistics as a method for estimating soil property values in unsampled or inadequately sampled regions. As explained by Yadav et al. (2022), this project will use GIS and remote sensing to show and explain the results of soil analysis done in the field using thematic soil maps that show the physicochemical features of the study area. Prajapat et al. (2023) experimented to assess the fertility level of soil in several villages within the Depalpur Block of Indore District, Madhya Pradesh, India. Water is vital for existence, and groundwater functions as a principal source of drinkable water. The progress of contemporary civilization, industry and urbanization has led to the rapid decline of groundwater quality (Gupta et al., 2019). The quality of surface water in inland water bodies substantially affects the groundwater table and the quality of neighboring aquifers due to their direct interaction (Papatheodorau et al., 2006). Thus, both natural processes and anthropogenic activities, affect the quality of surface and groundwater (Prajapati and Bilas, 2018). Pollution from industrial effluents and municipal waste is a substantial issue in metropolitan regions and industrial hubs in India. The discharges adversely affect the physicochemical of the river, and future projections indicate a worsening of the situation (Singh et al., 2024). The civilians of Kashi Vidyapith neighborhood in Varanasi are entirely reliant on groundwater source from the Ganges River. The parameters essential for assessing water quality include, sodium absorption ratio, residual sodium carbonate, permeability index, soluble sodium percentage, and Kelly's ratio. The objective of this study was to assess the soil and water quality status of certain features in several villages of the Kashi Vidyapith block in Varanasi district, Uttar Pradesh, and to propose ways for enhancing soil and water quality.

2. MATERIALS AND METHODS

2.1. Site description of study area

The present investigation was performed in the Kashi Vidyapith block of Varanasi district located in the geographic coordinates of 25°31N–82°81E Uttar Pradesh, India (Figure 1) during November-2023 to June-2024. The climate condition of the study area is sub-humid with the minimum temperatures 4°C, maximum temperature of 40°Cand average 32°C, whereas night temperature is below 8–10°C for almost entire December and January, occasionally it reaches down to 4°C (38°F) or 5°C (39°F). For the next five months, from November to the end of February, it has consistently pleasant windy days, clear skies, and cool nights. Winter starts in November and ends in February in Kashi Vidyapith block**.** Rain is expected to come in February with a rainfall intensity of 1000–1400 mm. The crops presently cultivated in this block are rice, wheat, sugarcane, mustard and seasonal vegetables, etc.

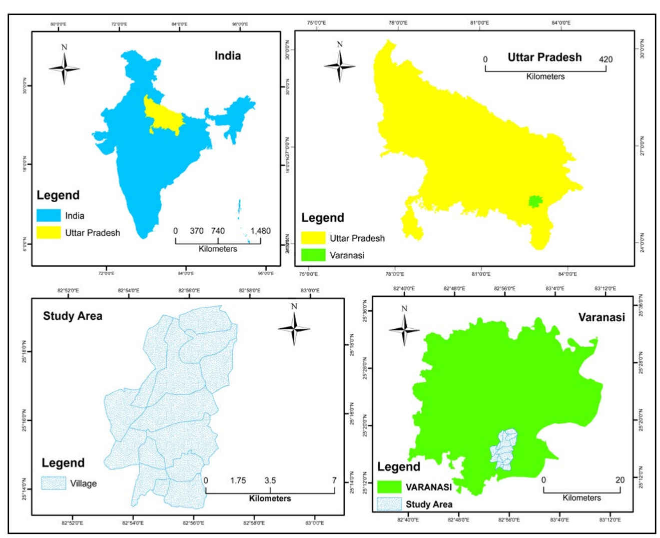

Figure 1: Representing study map of Kashi Vidyapith area

2.2. Soil sampling, processing and analysis of physico-chemical properties

In total 40 surface soil samples (0–15 cm depth) were collected before sowing of crops in January, 2024 at different villages of Kashi Vidyapith block of Varanasi which include Lohta, Kesaripur, Zafrabad, Jalalpatti, Ghatampur, Haridatpur, Mishirpur, Deora, Delhna, Khushipur, Bandepur and Aura (Figure 2). The soil samples were collected in zigzag manner from the different locations of crop field. The soil samples were collected with geo-coordinates which were recorded from each place with help of GPS tool. In the field soil samples of 500 g each were collected, then stored in the polythene bag. Samples of soil were collected from many polythene bags from different hamlets and labeled appropriately depending on the number of samples taken. When collecting the above soil samples, the following details of the farmer's field-crops planted area and fertilizers used were noted. Soil samples were let too dry at room temperature, then crushed by pounding them with a wooden roller on a wooden plank and finally passed through a 2 mm mesh size sieve. Thereafter, homogenized samples were put in polythene bags to enable the determination of the physico-chemical. Soil texture was done using a method developed by Bouyoucos (1962). The techniques used in measuring the bulk density and the particle density included pycnometer as described by Black (1965). Porosity was obtained from the mass of the soil sample relative to its dry bulk density as well as the particle density of the soil. In estimating water holding capacity of the samples, keen box method was used as recommended by (Piper, 1966). The pH was ascertained by using potentiometric method with a ratio of 1:2.5 soil water suspension whereas electrical conductivity was measured by using EC meter (Jackson, 1973). Total organic carbon was measured by the Wet oxidation method as given by Walkley and Black (1934). Nitrogen availability was determined by using alkaline potassium permanganate method described by Subbiah and Asija (1956) and nitrogen estimation was done with the help of Kjeldahl semi auto-analyzer. The available phosphorus was determined by Olsen's method by using a spectrophotometer instrument according to the procedure given by Olsen et al. (1954). Determination of available potassium was done by flame photometer with the help of extractant neutral normal ammonium acetate as prescribed by Hanway and Heidal (1952). Soluble calcium and magnesium were analyzed by Versenate titration method as described by Jackson (1973). Turbidimetric method using spectrophotometer was employed to estimate available sulphur as described by Chesnin and Yien (1950). All soil analysis that has to be done in the Department of Ag. Chemistry and Soil Science lab of C.C.R. (P.G.) College, Muzaffarnagar, Uttar Pradesh Following all the protocol.

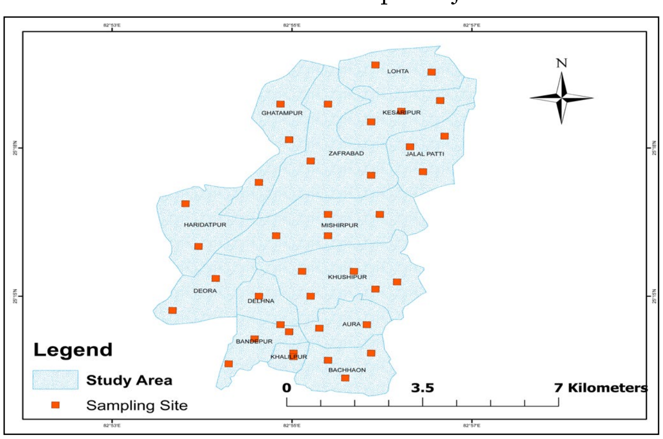

Figure 2: Representing soil sampling map of site area

2.3. Nutrient index evaluation

Data from the soil test summaries were used to determine the nutrient index values of the soils in the individual blocks whereby they were sorted into low, medium, and high based on the percentage distribution. The nutritional index was developed by Parker et al., 1951. Nutrient Index=[% in high category x3+% in medium category x2+% in low categoryx1]100, Against the nutrient index value less than 1.5 for low, 1.5–2.5 for medium and greater than 2.5 for high.

2.4. Water sampling and analysis of hydro-chemical properties

The 30 water samples collected were analyzed pH by using a Digital pH meter whereas Electrical conductivity was measured by using an EC meter and expressed in terms of units (dS m^{-1}). Potassium and sodium were estimated by using a flame photometer instrument described by (Anonymous, 1992) which was calibrated by using 1000 ppm of potassium and chloride (KCl). Calcium+Magnesium content in water samples was estimated by complexometric titration method using 0.01N EDTA solution and 3–4 drops of Eriochrome Black-T indicator and 0.5ml of ammonium hydroxide-ammonium chloride buffer and titrated until the colour changes from pink to blue. Alkalinity (carbonates and bicarbonates) was estimated by the Acidimetric titration method using 0.02N sulphuric acid solution and indicator of phenolphthalein for carbonates estimation until the pink tint faded and the acid volume was measured if pink colour appeared it indicated the presence of carbonates and in the same solution 2–3 drops of methyl orange was added as an indicator for estimation of bicarbonates and titrated with 0.02N sulphuric acid until yellow colour changes to rose red (Gupta, 2007). Calcium in water samples was estimated by using complexometric titration method and an indicator of Murexide or ammonium purpurate was used and titrated with 0.01N EDTA until the colour changed from orange-red to lavender purple.

2.5. *Analysis of irrigation water quality index parameters*

Sodium absorption ratio (SAR) is an index of alkali/sodium for crop risk. The following formula; SAR (Meq l^{-1}) (Richards 1954)=Na/√(Ca+Mg/2), The Residual sodium carbonate (RSC) is calculated by using the following formula: RSC (Meq l^{-1}) (Raghunath, 1987) (Meq l^{-1})=(CO_3^{2-}+HCO_3^{-})/(Ca^{2+}+Mg^{2+}), The Soluble sodium percentage (SSP) is calculated by using the formula: In fact, SSP (Meq L^{-1}) (Todd 1980)=Na+K/(Ca+Mg+Na+K). Water suitability for irrigation use is also analyzed using Kelly's ratio (Kelly, 1951). Kelly's ratio was calculated by using the following formula: Na/[Ca]^(2+)+[Mg]^(2+). Where, concentrations are given in Meq l^{-1}. It is considered unsuitable for the use in irrigation, if the value of kelly's ratio in more than one because alkali hazards and it was considered as suitable for irrigation use when the value of kelly's ratio was lesser than one (Karanth, 1987). The permeability index (PI) calculated by using the formula: Meq L^{-1} and is calculated as Na+√HCO_3/Ca+Mg+Nax100 as suggested by Doneen (1964).

2.6. *Irrigation water quality index (IWQI)*

The kind and amount of salts dissolved in irrigation water greatly influence its quality. The irrigation water quality index is used to calculate the basic water quality characteristics. The quality of irrigation water varies by location, area, country, and so on depending on soils, cropping pattern, etc (Babiker et al., 2007). The salinity and alkalinity of the irrigated region are important factors influencing water quality. Water quality is the most important aspect in guaranteeing long-term water use for irrigated agriculture. The various indices of water quality are used to evaluate the Water quality index. The IWQI model was applied to the data. This model was developed by (Meireles et al., 2010).

2.7. *Computation of IWQI*

The WQI is computed following the three steps: First step: Assigning weight (w_i) to the selected water parameters like pH, HCO_3, Cl, EC, Na, K, etc. According to their relative importance in the overall quality of water, rating was given. Second step: Computation of relative weight (W_i) of the chemical parameter using the following equation: $W_i=w_i/\sum w_i$(i=1 to n). Where, W_i=is the relative weight, w_i=Weight of each parameter, n=Number of parameters. Third step: Assigning a quality rating scale (q_i) for each parameter, as below: $q_i=(C_i/S_i)\times100$. Where, q_i=quality rating, C_i=Concentration of each chemical parameter in each water sample in Meq l^{-1}, S_i=value of parameter given by (Anonymous, 1991). For the computation of WQI, the sub-index (SI) is first determined for each chemical parameter, given below: $Sl_i=W_i\times q_i$.WQI=($\sum$ Sl_i)–no of parameters ($\sum w_i$), Where, Sl_i=sub-index of i^{th} parameter, W_i=Relative weight of the parameter, q_i=Rating based on the concentration of the i^{th} parameter, n=Number of chemical parameters, ($\sum w_i$) is obtained by adding no of parameters.

2.8. *Statistical analysis*

Statistical analysis was done on all the observation data that was collected from all the subjects. The extent of relationship between different parameters, Measures of dispersion and mean of all parameters in the soil, Range of all the parameters in the soil, Standard deviation of all the parameters in the soil and co-efficient of variation of all the parameters in the soils were determined. Principal component analysis is multivariate method for extracting components from a group of variables. The PCs with greatest Eigen values were believed to be the most accurate representations of soil properties (Deka et al., 2016).

3. RESULTS AND DISCUSSION

3.1. *Physical properties of soil*

In the soils of Kashi Vidyapith block the sand silt and clay content of the samples varied from 61.0–86.0, 5.0–22.0 and 5.0–27.0% (Table 1) respectively. The ranged value of bulk density, particle density and porosity were from 1.19–1.64 g cm^{-3}, 2.03–2.95 g cm^{-3}, 22.27–52.21%. Lowest measured bulk density was S_{36} and S_{27} from the villages of Delhna and Bachhaon, it might be so due to high organic carbon content. The bulk density had significant and negative relationship with the organic carbon (r=-0.109) and Porosity (r=0.767) (Figure 5), Similar result was observed by Khadka et al. (2019) in the Agricultural Research Station, Vijayanagar, Jumla, Nepal. Out of all the Mishirpur village samples S_{40} had the highest particle density while Aura village samples S_{24} had the lowest particle density. The second analysis indicated that the Particle density had a small but rather negative relationship with the organic carbon (r=0.144) (Figure 5). The finding of Deoli et al. (2020) was similar for the Saheshpur block of Dehradun also, the graphs on the distributions of physical properties shown in Figure 3.

Table 1: Status of physical properties of different villages of Kashi Vidhyapith block of Varanasi district

Parameters	Min.	Max.	Mean	S.D.	S.E.	C.V. %
Sand (%)	61	86	74.95	0.91	5.73	7.64
Silt (%)	5.0	22	11.85	0.54	3.44	29.02
Clay (%)	5.0	27	13.2	0.64	4.07	30.84
BD g cm^{-3}	1.19	1.64	1.43	0.02	0.11	7.37
PD g cm^{-3}	2.03	2.95	2.25	0.03	0.18	8.07
Porosity (%)	22.27	52.31	35.4	0.99	6.27	17.7
WHC (%)	21.15	43.21	31.77	1.03	6.5	20.47

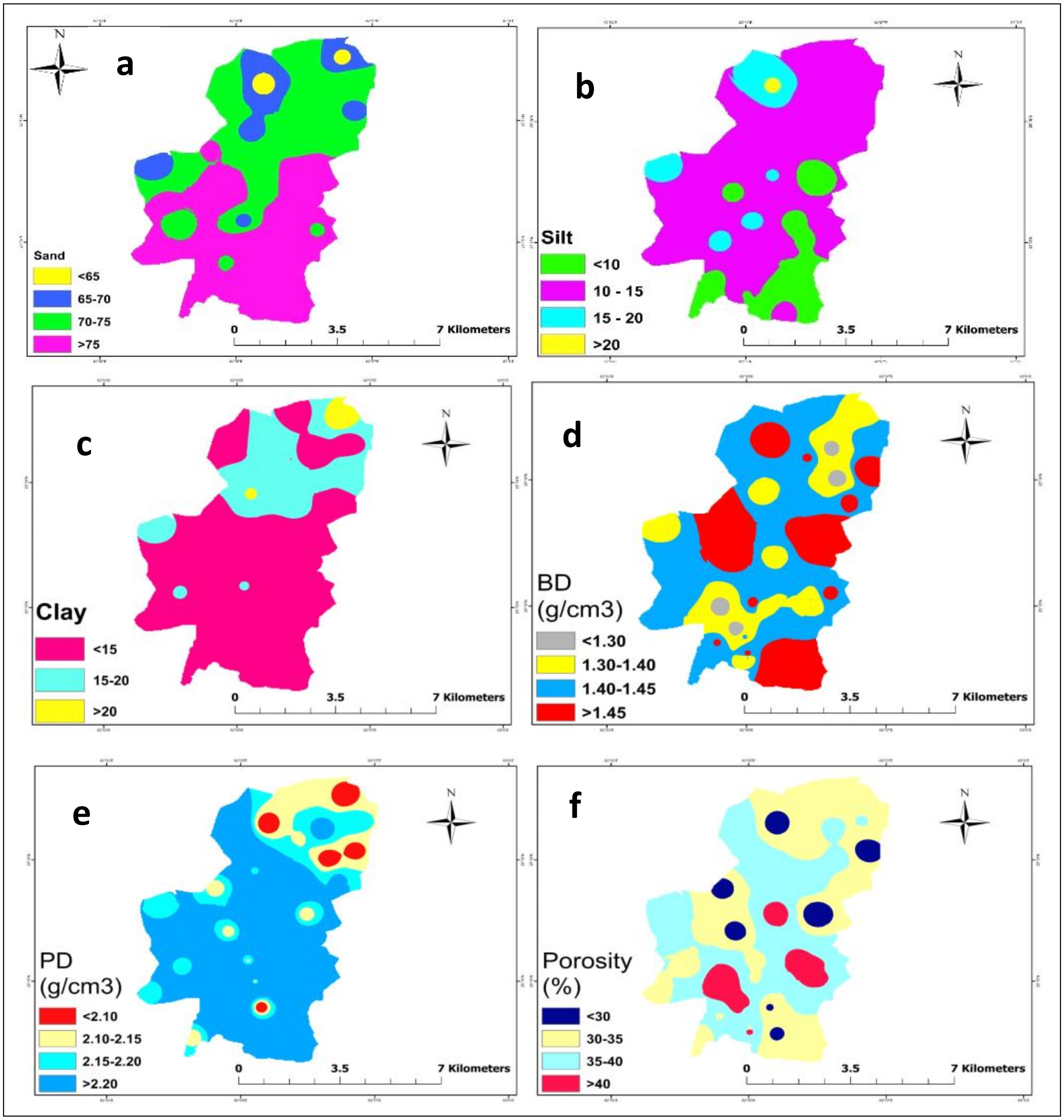

Figure 3: Spatial variability maps of soil physical properties in Kashi Vidyapith block of Varanasi district

3.2. *Chemical properties of soil*

The pH of Kashi Vidyapith block on average was found to vary in between 6.44–8.77 (Table 2). Out of 40 soil samples, 57.5% soil samples under neutral category, 7.5% samples under slightly acidic category and 35% of the total samples were under moderately saline category (Table 3). Similar findings were reported by Kumar et al. (2018) in other blocks of Rampur district Uttar Pradesh. The electrical conductivity of the analyzed soil sample was between 0.03–0.51 dS m^{-1}. The coefficient of variation and standard deviation were 69.73% and 0.08, respectively. Delhna village obtained the highest value of 3.5 in S_{19} whereas, Bachhaon had the lowest value in S_{26} of 0.9. Since, most of the formed groups had EC<2.0 dS m^{-1}, according to the limits suggested by Muhr et al. (1963) for the evaluation of the salt problem of soils, all samples could be considered as normal. The soils under

Table 2: Status of chemical properties of different villages of Kashi Vidhyapith block of

Parameters	Varanasi district					
	Min.	Max.	Mean	S.D.	S.E.	C.V.
Soil reaction (pH)	6.44	8.77	7.26	0.08	0.5	6.91
EC (dS m^{-1})	0.03	0.51	0.12	0.01	0.08	69.73
O.C. (%)	0.24	1.18	0.76	0.04	0.23	30.86
Av. N (kg ha^{-1})	132.12	472.23	300.39	11.8	74.66	24.85
Av. P (kg ha^{-1})	16.33	40.23	25.8	0.9	5.71	22.13
Av. K (kg ha^{-1})	145	250	185.16	3.96	25.06	13.53
Av. S (kg ha^{-1})	10.3	18	14.48	0.34	2.15	14.87
Av. Ca(cmol (P+) kg^{-1})	3.8	8.21	5.56	0.15	0.94	16.87
Av. Mg (cmol (P+) kg^{-1})	2.12	4.12	2.85	0.07	0.47	16.4

study had varying percentages of organic carbon which ranged between 0.24–1.18% (Table 2). From the above results, it was noted that both the S_{18} and S_{30} Deora and Bandepur village showed maximum organic carbon. On the other hand, S_{20} of Kushipur village contains a comparatively lower extent of organic carbon. Furthermore, 5.0% of the soil samples showed low organic carbon content followed by 35% medium organic carbon content while 52% had high organic carbon content (Table 3). Similar events have also been reported by Sonkar et al. (2023) in the Sakaldiha block located within the industrial area of Chandauli District of Uttar Pradesh. The distributions of chemical properties are as follows in Figure 4.

3.3. *Primary and secondary available nutrient properties*

The available nitrogen in the studied soils ranged from 132.12–472.23 kg ha^{-1}. Amongst the study areas, the Haridatpur village (sample S_{13}) had the highest per cent nitrogen and the village Delhna (sample S_{19}) had the lowest per cent nitrogen,by using classification by Subbiah and Asija (1956). 35% of the samples were lower than 280 kg ha^{-1}, and 65% of samples falling between 280–560 kg ha^{-1} (Table 3). There is a significant positive correlation established between nitrogen and organic carbon (r=0.775) (Figure 4) (Amara et al., 2017; Kumar et al., 2018; Bharteey et al., 2023). Another factor was available phosphorus that was obtained in the soil of the research region with the variation from 16.33–40.23 kg ha^{-1}. In the study, therefore, it was realised that the number sample (S_{36}) which is from Delhna village showcased the highest value of phosphorus at 40.23 kg ha^{-1}. In addition, it came to light that 60% of the sites have Medium P_2O_5 (kg ha^{-1}) content and 40% of the sites of the study area have High content of P_2O_5 (kg ha^{-1}) (Table 3). The significant negative correlation between P_2O_5 and pH (r=-0.306) (Figure 5). The similar results were also found by Maurya et al. (2024) in Arajiline block of Varanasi district. The range values of available potassium content in these soils were as follows; 145.0–250.0 kg ha^{-1}. No. S_{37}, S_{39} village Khalilpur, Mishirpur have the highest value of potassium and No. S_3 village Kesaripur has the lowest value of potassium. Concentrations of soil samples contents: In all forty content samples, 100%is present. The significant positive relationship between potassium and pH (r=0.273) (Figure 5). Singh et al. (2016) also observed an almost similar soil fertility status in Arajiline block Varanasi district Uttar Pradesh. It was estimated that sulphur content of this block of soils of Kashi Vidyapith varied from 10.30–18.00 kg ha^{-1}. Sample No. S_{33} collected from the village Khushipur has the highest sulphur content while sampled No. S_{35} collected from the village Jalalpatti has the lowest level of sulphur content. Rai et al. (2018) also observed similar results in black soil of Varanasi district of eastern Uttar Pradesh. The following Map illustrates the status and availability of primary and secondary nutrients in the study area (Figure 5). The available calcium of studied soils was ranged from 3.80–8.21 cmol(p+) kg^{-1} (Table 2). The lowest availability of calcium was observed in Aura village whereas; the highest availability was the Mishirpur village. Sharma et al. (2013) also reported the similar finding with average available calcium of 1764 ppm in the vegetable growing soil of Varanasi district. The amount of the available magnesium among the taken samples ranged from 2.12–4.12 cmol (p+) kg^{-1}, Maximum concentration of Mg^{2+} was found in Aura village sample No. S_{25} while minimum concentration of Mg^{2+} was found in Delhna village sample no. S_{36}. These samples imply that the Total samples are in good stead concerning the proportions in the availability of Mg^{2+}. A similar observation is made by Sharma et al. (2013) as well.

3.4. *Nutrient index value of study area*

The nutrient Index value (NIV) of available primary nutrients i.e. N, P, K and S of Kashi Vidyapith block in Varanasi district were mentioned below in Figure 6. It was analysed that NIV for N, P, K and S was 1.20, 0.8, 0.8 and 0.98 were low. In respect of the nutrient index value <1.5 for low, 1.5–2, for high greater than 2 those values were calculated. There are comparative values of high, according to Singh et al. (2016).

Table 3: Percentage wise distribution of soil chemical and nutrient properties of Kashi Vidhyapith block (Ramamoorthy and Bajaj, 1969)

Parameters	Range	Class	Total number of samples	Percentage of samples
pH	6.0–6.6	Slightly acidic	3	7.5
	6.7–7.3	Neutral	23	57.5
	7.4–8.0	Moderately saline	14	35.0
EC (dS m^{-1})	<2.0	Negligible effect of salinity	40	100
	2.0–4.0	Sensitive crop affected	-	-
	4.0–8.0	Most crops are affected	-	-
	8.0–16.0	Only salt-tolerant crops grow satisfactory	-	-
	>16.0	Very salt-tolerant crops grow satisfactory	-	-
O.C. (%)	<0.5	Low	5	12.5
	0.5–0.75	Medium	14	35.0
	>0.75	High	21	52.5
Av. N (kg ha^{-1})	<280	Low	14	35
	280–560	Medium	26	65
	>560	High	-	-
Av. P (kg ha^{-1})	<12.5	Low	-	-
	12.5–25	Medium	24	60
	>25	High	16	40
Av. K (kg ha^{-1})	<135	Low	-	-
	135–335	Medium	40	100
	>335	High	-	-
Av. S (kg ha^{-1})	<10	Low	-	-
	10–20	Medium	40	100
	>20	High	-	-
Av. Ca (cmol (P+) kg^{-1})	<1.5	Deficient	-	-
	>1.5	Sufficient	40	100
Av. Mg (cmol (P+) kg^{-1})	<1.0	Deficient	-	-
	>1.0	Sufficient	40	100

3.5. Network analysis of soil physico-chemical properties

The colour band (based on 'r' values) in the network among different soil physico-chemical and nutrient properties depicts the strength of association. The broader lines indicate a strong correlation (both positive and negative) and the narrow lines suggest a weak correlation (Figure 6). A notable positive relationship between available nitrogen and organic carbon and Bulk density and porosity negative relationship are dependable metrics for obtaining information on current or projected erosion-prone areas.

3.6. Principal component analysis of soil parameters

The physical-chemical data were analysed for 16 factors with eigenvalues greater than 1.5; the two first principal components contributing to their causes explained 37.01% of the variability in the soil parameters (Table 4). When the screen plot was graphed (Figure 7), it showed the relation of Eigenvalues to the numbers of the principal components. The analysis of the factor loading matrix of the soil parameters indicated that the following parameters loaded in the measure of a soil axis (P_1): Sand, Bulk density, Available potassium, available sulphur, available calcium, and available magnesium had positive loading values of P_1 while silt, clay, particle density, porosity, water holding capacity, pH, organic carbon, available nitrogen and available phosphorous had negative loading values on P_1. The first component or P_1 which was dominated by mechanical escrow aligns letting us the term 'chemical potential'. These parameters: sand, particle density, porosity, pH, electrical conductivity, organic carbon, available nitrogen, available potassium, available magnesium and available sulphur had all positive loadings on the second principal component (P_2). These parameters were significantly interrelated and count as a set of dependent factors as to the problem of "nutrient factor". Instead, silt, clay, bulk density, water holding, capacity, available phosphorous, and available calcium had a negative weighting in this factor. Consequently, this second factor is termed as 'physical Factor', the factor loadings of the soil parameters in P_1 and P_2 are presented below the figure as Figure 8, which confirmed that all the studied parameters were placed in the four quadrants.

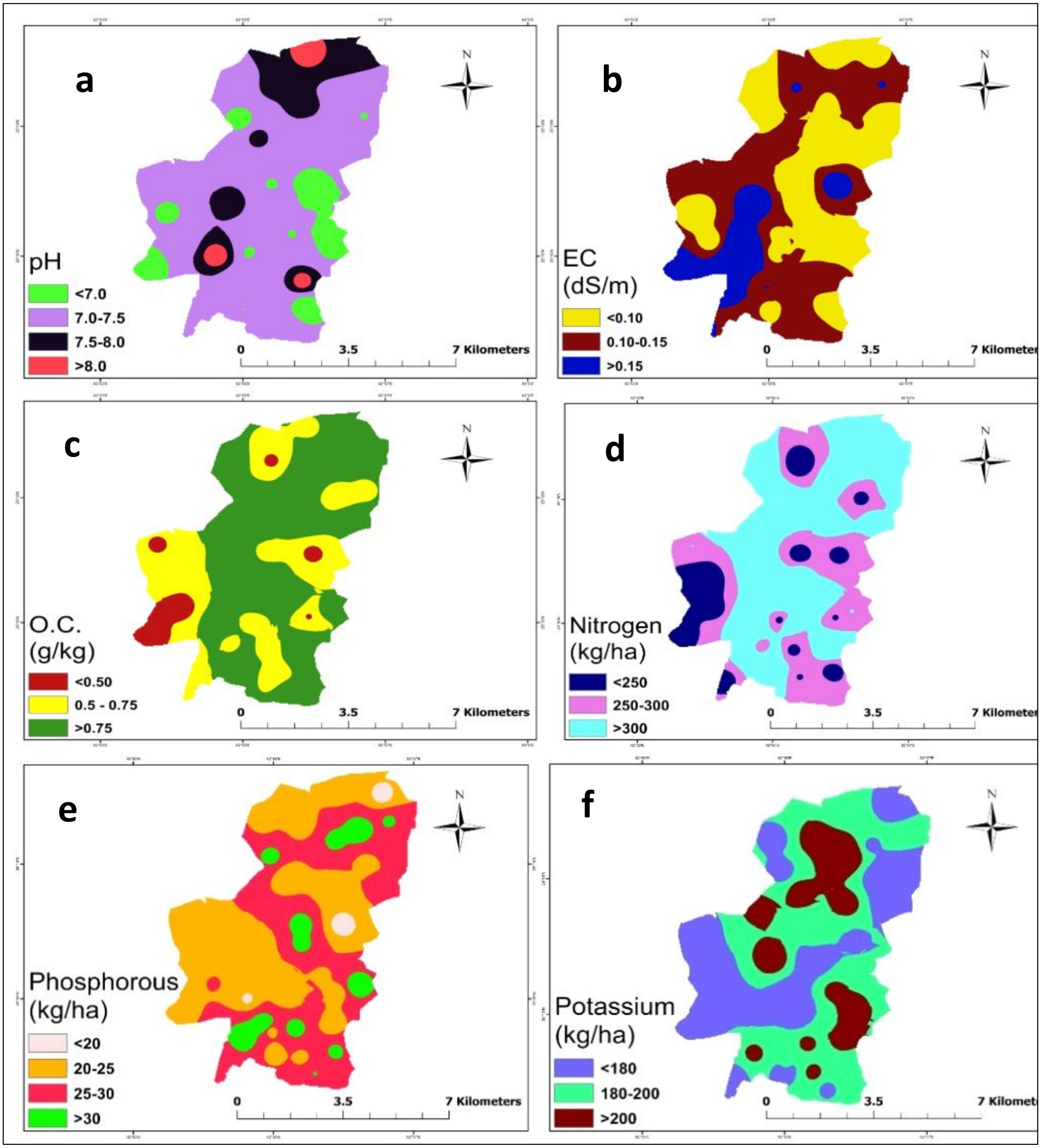

Figure 4: Continue...

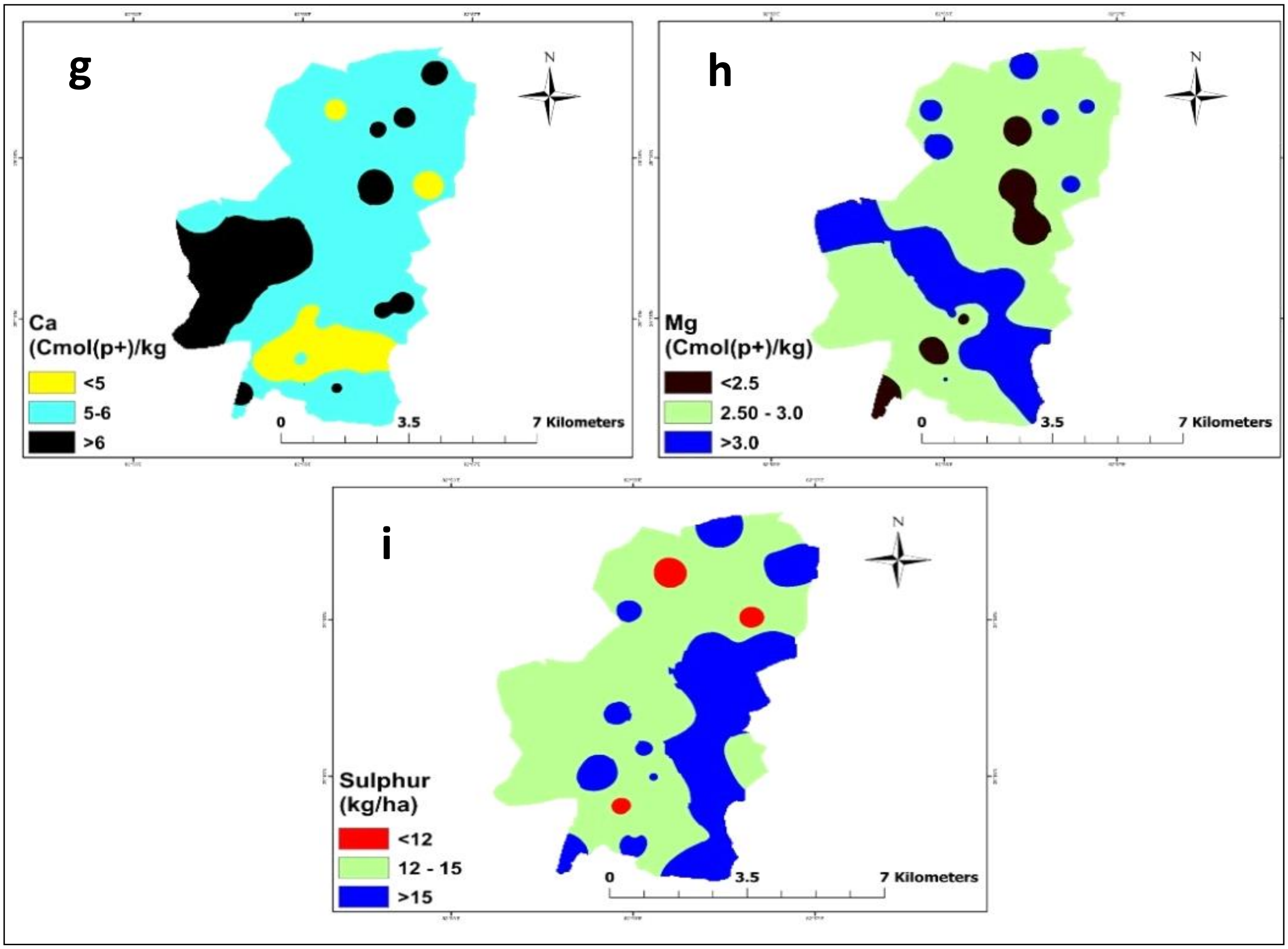

Figure 4: Spatial variability map of chemical and nutrient properties of Kashi Vidyapith block of Varanasi district

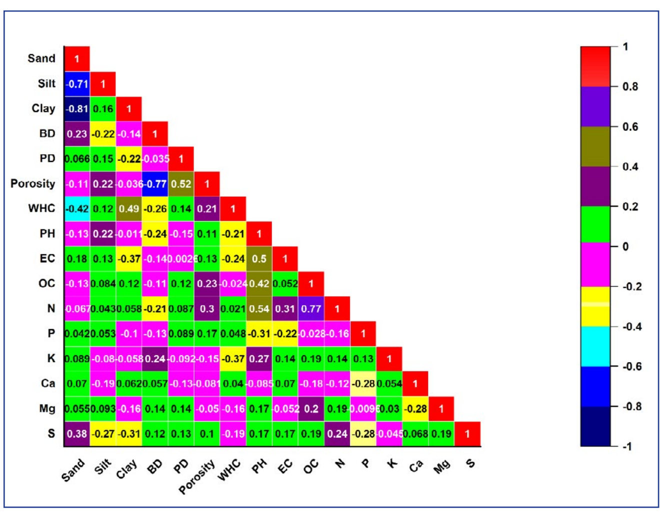

Figure 5: Correlation (p=<0.01; p<0.05) between soil physico-chemical properties of Kashi Vidhyapith block of Varanasi district

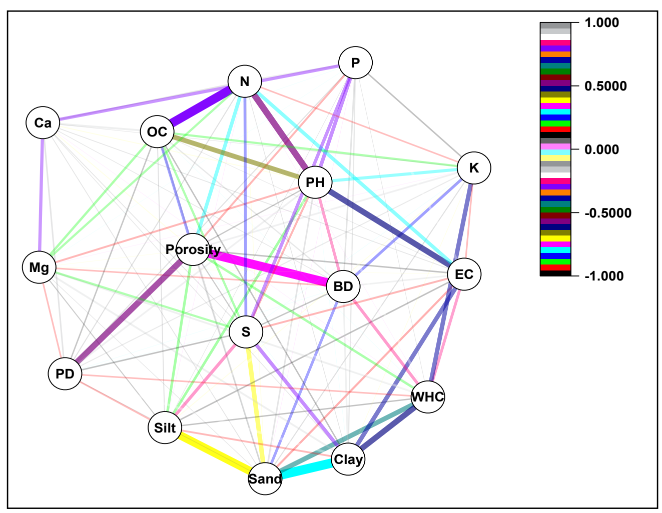

Figure 6: Network Analysis showing soil physico-chemical properties

Table 4: Eigenvalues, variance (%), cumulative variance (%) and matrix factor loading of soil parameters

Parameters	P_1	P_2
Eigenvalue	3.019	2.903
% of Variance	18.871	18.143
Cumulative variance (%)	18.871	37.013
Sand	0.787	0.358
Silt	-0.627	-0.048
Clay	-0.578	-0.464
Bulk density	0.645	-0.095
Particle density	-0.182	0.157
Porosity	-0.587	0.258
Water holding capacity	-0.522	-0.450
Soil reaction (pH)	-0.310	0.692
Electrical conductivity	0.007	0.598
Organic carbon	-0.420	0.590
Available nitrogen	-0.430	0.711
Available phosphorous	-0.049	-0.231
Available potassium	0.187	0.309
Available calcium	0.206	-0.126
Available magnesium	0.017	0.336
Available sulphur	0.263	0.536

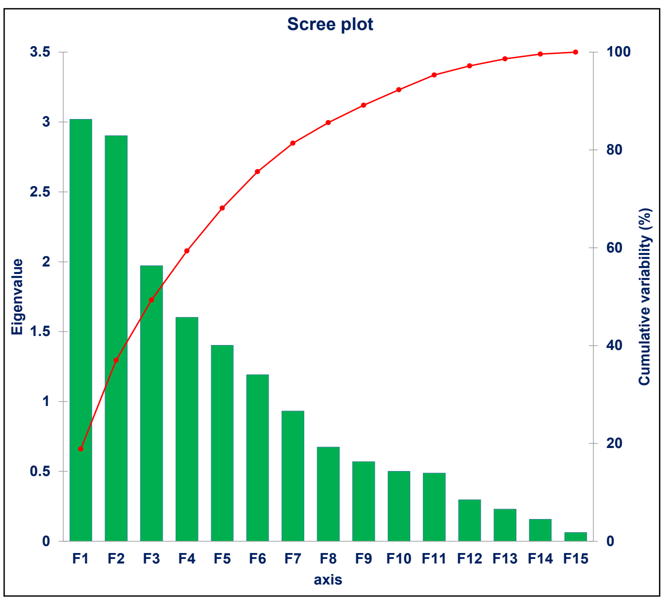

Figure 7: Scree plot showing relation between eigen values and PC numbers

3.7. *Hydro-chemical properties of water*

The results of the physic-chemical properties of irrigation water samples from different villages of Kashi Vidhyapith block in Varanasi district are given in Table 5. The pH of the water samples ranges from 6.2–9.0 with an average value of 7.5 (Table 5). Sample no. 9 of Jalalpatti village reported the highest pH value (9.0) whereas sample no. 15 of Mishirpur village reported lowest pH value (6.2). Out of 30 water samples, 26 samples (6.67%) were found suitable for irrigation while the rest 86.66% of the samples were moderately suitable for irrigation purposes. The pH had positive correlation with EC and potassium (Figure 10). Higher pH is server to crops (Ayers and Westcot, 1985) and reduces the effectiveness of some nitrogenous fertilizers through irrigation (Hopkins et al., 2007). Similar results were reported by (Naidu et al., 2020) in various mandals of Nellore district in Andhra Pradesh. The electrical conductivity in water samples varied from 0.5 to 1.1 dS m^{-1} with an average value of 0.6 dS m^{-1}. The S.D. and C.V. value of water samples were 0.15 and 22.83% respectively (Table 5). The highest electrical conductivity value (1.1 dS m^{-1}) and lowest electrical conductivity value (0.5 dS m^{-1}) both were reported in Zafrabad village of sample no. 7 and 2, respectively. Out of 30 water samples, 25 samples (83.33%) are in the suitability range for irrigation, and 5 samples (16.67%) are in the moderate suitability range for irrigation.

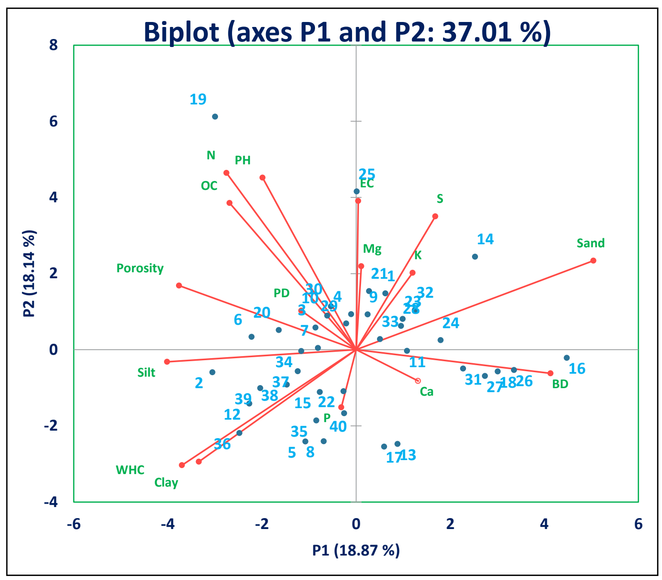

Figure 8: PCA biplot (biplot show both PC scores of the samples and loading of variables)

Higher electrical conductivity concentration indicates more amounts of total dissolved salts which affect the mobility and solubility of oxygen in water (Kumar et al., 2011). The carbonate concentration in water samples of Kashi Vidhyapith block is nil. The concentration of bicarbonate in water samples ranged from 7.50–15.00 Meq l^{-1} with an average value of 11.45 Meq l^{-1}. The S.D. and C.V. value of the samples were 1.79 and 15.68%, respectively (Table 5). Sample no. 18 of Deora village reported the lowest (8.0 Meq l^{-1}) concentration of bicarbonate while Sample no.

20 of Khushipur village reported the highest (15.5 Meq l^{-1}) concentration of bicarbonate. According to Ayers and Westcot (1985), carbonate concentrations greater than 0.1 Meq l^{-1} and bicarbonate concentrations greater than 10 Meq l^{-1} are not recommended for irrigation purposes. The result shows that 100% of the samples are in not suitable range for irrigation purposes (Table 5). Weathering of carbonate and/or alumino-silicate minerals is the primary source of HCO_3^- in groundwater, with a secondary contribution from carbon dioxide gas dissolution. Furthermore, the dissolution of carbonates and the weathering of silicate minerals may result in the formation of bicarbonate (Tiwari and Singh, 2014).. Calcium concentration in water samples ranged from 4.5–9.5 Meq l^{-1} with an average value of 7.1 Meq l^{-1}. The value of S.D. and C.V. for calcium was 1.4 and 19.9%, respectively. The highest (9.5 Meq l^{-1}) and Lowest (4.5 Meq l^{-1}) concentrations of Ca^{2+} were found in samples no. 29 and 7 of Khalilpur and Zafrabad villages respectively (Table 5). Magnesium concentration in water samples ranged from 1.5–7.0 Meq l^{-1} with an average value of 4.8 Meq l^{-1}. The value of S.D. and C.V. for calcium was 1.5 and 31.6%, respectively. The highest Mg was found in sample no. 24. Potassium values in analyzed water samples varied from 0.0–0.5 Meq l^{-1} with an average value of 0.2 Meq l^{-1}. The value of S.D. and C.V. for potassium was 0.2 and 77.4%, respectively (Table 5). Sample no. 5 and 25 of Zafrabad and Aura village, samples no. 12 and 22 of Haridatpur and Khushipur village and sample no. 5 and 25 Zafrabad and Aura village were reported the lowest (0.0 Meq l^{-1}) potassium values of while sample no. 12 and 22 of Haridatpur and Khushipur village was observed highest (0.5 Meq l^{-1}) potassium value. According to Anonymous, (1994), the range for potassium concentration in water samples is 0–2.0 Meq l^{-1}. According to this result, potassium content is moderately suitable for irrigation purposes in groundwater samples in the city of Kashi Vidhyapith block. Sodium concentration in water samples varied from 0.2–0.8 Meq l^{-1} with a mean value of 0.4 Meq l^{-1}. The value of S.D. and C.V. for sodium was 0.2 and 47.2%, respectively. The lowest value (0.2 Meq l^{-1}) of Na^+ was seen in sample no. 10, 13, 15, 17, 18, 20, 23, 24 and 29 of Ghatampur, Haridatpur, Mishirpur, Deora, Khushipur, Bandepur, Aura, and Khalilpur villages while the highest value (0.8 Meq l^{-1}) of Na^+ was reported in sample no. 11 of Ghatampur village. The result shows 63.33% in the range of moderately suitable while none of the samples was in the range of not suitable 36.67% which means the water quality of KashiVidhyapith block is suitable for irrigation purposes (Table 5).

Table 5: Chemical properties of water of different villages of Kashi Vidhyapith block, Varanasi district

Parameters	Anonymous (2017)	Anonymous (2012)	Study area samples		
	Acceptable limit	Acceptable limit	Min.	Max.	Mean
pH	6.5–8.5	6.5–8.5	6.2	9.0	7.5
EC (dS m^{-1})	0.7–3.0	-	0.5	1.1	0.6
HCO^{3-} (meq l^{-1})	1.25–8.50	-	7.5	15	11.45
Ca & Mg (Meq l^{-1})	-	-	8	15.5	11.8
Ca (Meq l^{-1})	75	75	4.5	9.5	7.1
Mg (Meq l^{-1})	50	30	1.5	7	4.8
K (Meq l^{-1})	12	-	0	0.5	0.2
Na (Meq l^{-1})	200	-	0.2	0.8	0.4
K (ppm)	-	-	1.2	19.5	8.1
Na (ppm)	-	-	4.8	18	8.9

3.8. Irrigation water quality index parameters

The sodium adsorption ratio of water samples varied from 0.15–0.40 Meq l^{-1} with a mean value of 0.23 Meq l^{-1}. The value of S.D. and C.V. for the samples was 0.28 and 24.34%, respectively (Table 6). The lowest value (0.15 Meq l^{-1}) of SAR is seen in sample no. 10, 13, 14, 17, 20, 23, 24, 27, and 29 of Ghatampur, Haridatpur, Mishirpur, Deora, Khushipur, Bandepur, Aura, Bachhaon and Khalilpur village, sample no. 1, 12 of Lohta, Haridatpur village and Sample no. 30 of Bandepur village while highest value (0.40 Meq l^{-1}) of SAR seen in sample no. 1, 12, 30 of Lohta, Haridatpur, Bandepur village. It was noticed that 100% of the samples are within allowable limits and belong to class S_1, indicating that there is no sodium hazard and that groundwater samples are within a suitable range for irrigation. A similar result was reported by Aher and Gaikwad (2017) in Nandgaon block of Nashik district, Maharashtra. The soluble sodium percentage of water samples varied from 2.02–9.93% with an average value of 4.90%. The value of S.D. and C.V. of the samples were 1.88 and 38.37%, respectively (Table 6). Sample no. 24 from Aura village had the lowest SSP value (2.02%), while sample no. 12 from Haridatpur village had the highest SSP value (9.93%). It was observed that 60% of the samples are in the acceptable range and fit for irrigation purposes. Residual sodium percentage of water samples varied from -0.70–0.10 Meq l^{-1} with a mean value of -0.39 Meq l^{-1}.

Parameters	Min.	Max.	Mean	S.D.	S.E.	C.V.
Sodium absorption ratio (Meq l^{-1})	0.15	0.4	0.23	0.28	0.12	24.34
Soluble sodium percentage (Meq l^{-1})	2.02	9.93	4.9	1.88	0.34	38.37
Residual sodium carbonate (Meq l^{-1})	-0.7	-0.1	-0.39	0.16	0.03	-41.72
Kellay ratio (Meq l^{-1})	0.01	0.07	0.03	0.02	0	50
Permeabilty index (Meq l^{-1})	25.22	34.48	29.24	2.23	0.41	7.62
Irrigation water quality index (Meq l^{-1})	15.94	30.91	24	3.48	0.63	14.48

Table 6: Irrigation water quality index parameters of water of different villages of Kashi Vidhyapith block of Varanasi district

The values of S.D. and C.V. of the samples were 0.16 and -41.72%, respectively (Table 6). The lowest RSC value (-0.70 Meq l^{-1}) was observed in sample no. 25 of Aura village where whereas the highest RSC value (-0.10 Meq l^{-1}) was observed in sample no. 27 of Bachhaon village. The result showed that 100% of water samples are in the range of suitable (Figure 9 and Table 7). Kelly's ratio in the water sample ranged from 0.01–0.07 with a mean value of 0.03.

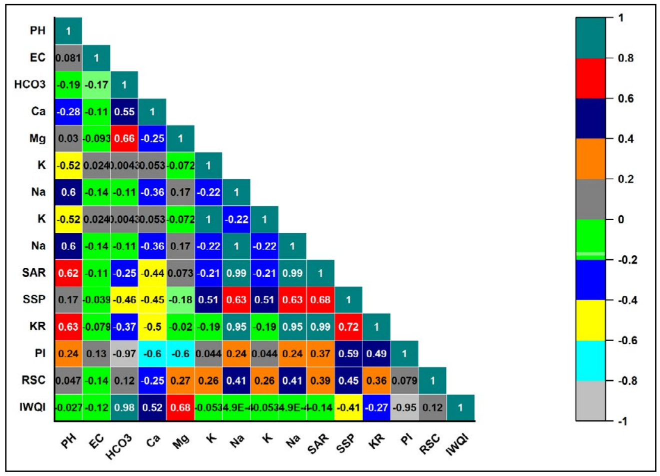

Figure 9: Correlation (p=0.01; p=0.05) between hydro-chemical properties of Kashi Vidhyapith block of Varanasi district

Table 7: Percentage-wise water quality index parameters of Kashi Vidhyapith block of Varanasi district

Irrigation water quality indices	Range	Class	Total number of samples	% of samples
Sodium absorption ratio (Meq l^{-1})	<10	Low hazard	-	-
	10–18	Medium hazard	14	46.67
	18–26	High hazard	7	23.34
	>26	Very High hazard	9	30.0
Soluble sodium percentage (Meq l^{-1})	<50	Good	18	60.0
	>50	Not suitable	12	40.0
Residual sodium percentage (Meq l^{-1})	<1.25	Low hazard	30	100
	1.252.25	Medium hazard	-	-
	>2.25	High hazard	-	-
Kellay ratio (Meq l^{-1})	<1.0	Good	30	100
	>1.0	Not suitable	-	-
Permeability index (Meq l^{-1})	>75	Excellent	-	-
	25–75	Good	30	100
	<25	Not suitable	-	-
Irrigation water quality index (Meq l^{-1})	<50	Excellent	30	100
	50–100	Good	-	-
	100–200	Poor	-	-
	200–300	Very poor	-	-
	>300	Unsuitable	-	-

The S.D. and C.V. of the samples were 0.02 and 50.0%, respectively (Table 6). The highest KR value (0.065) was seen in sample no. 12 of Haridatpur village while the lowest KR value (0.014) was seen in sample no. 20 of Khushipur village. It was observed that 100% of the samples are within the allowable range and suitable for irrigation (Table 7). The data of permeability index in water samples varied from 25.22–34.48 with an average value of 29.24. The S.D. and C.V. of the samples were 2.23 and 7.62%, respectively (Table 6). The highest value (34.48) of PI was reported in sample no.18 of Deora village whereas the lowest value (25.22) was reported in sample no. 20 of Khushipur was a village. The results revealed that 100.0 % of samples are in the range of moderately permissible (Table 7). The range of the Irrigation Water Quality Index of samples varied from 15.94–30.91 with a mean value of 24.00. The S.D. and C.V. value of samples for IWQI was 3.48 and 14.48%, respectively (Table 7). The highest value of IWQI was found in sample no. 20 of Khusipur village respectively. Out of the total number of water samples, 100% of the samples are suitable for irrigation (Table 7). Similar findings were reported by (Kant et al., 2015) in the lahar block of Bhind district, Madhya Pradesh and (Raju, 2007) in Cuddapah district, Andhra Pradesh.

4. CONCLUSION

The soil of Kashi Vidyapith block, Varanasi, varies from sandy loam to silt clay loam, with a normal pH and varied organic carbon levels. The nutrient indices for accessible N, P, K, and S were low, emphasizing the need for biofertilizers and bio-inoculants to improve fertility and crop nutrition. Irrigation water quality ranged from unsuitable to acceptable, with indices indicating appropriateness for irrigation. These findings highlight the need of improving irrigation procedures and soil fertility management in order to promote sustainable agriculture.

5. ACKNOWLEDGEMENT

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