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Spatial variability of soil potassium fractions in the alluvial soils of North Bihar

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Abstract
The investigation was carried out at Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, to evaluate the spatial variation in different forms of potassium (K) in the soils of North Bihar. The study area extends between 83°54′18.02″ and 88°17′17.04″ E longitudes and 25°29′58.17″ and 27°17′4.44″ N latitudes, covering nearly 52,925 km². The soils of this region are primarily alluvial in nature—calcareous soils have developed from the sediments of the Gandak, Budhi Gandak, and Bagmati rivers. In contrast, non-calcareous soils originate from the alluvium deposited by the Kosi, Adhwara, and Kamala Balan rivers. A total of 121 representative soil samples were collected and analyzed to determine the content of water-soluble, exchangeable, non-exchangeable, and total potassium. The concentrations of these K fractions exhibited considerable variability, with water-soluble K ranging from 3.5 to 67 ppm, exchangeable K from 12 to 274 ppm, non-exchangeable K from 65 to 2101 ppm, and total K from 469 to 22,471 ppm. The dominance of different K forms followed the sequence: total K > non-exchangeable K > exchangeable K > water-soluble K. Distinct spatial variability in K distribution was observed among the districts, which may be attributed to variations in parent material, topography, and land management practices. The results highlight the need for site-specific potassium management strategies to promote efficient nutrient utilization and maintain soil fertility in the intensively cultivated areas of North Bihar.

Keywords: Soil properties, forms of K, spatial distribution, K fertilisation, sustainable fertilisation

Introduction

Potassium (K) ranks as one of the three primary macronutrients required by plants, following nitrogen (N) and phosphorus (P). It is essential for several physiological and biochemical processes, including enzyme activation, biomass accumulation, and the enhancement of plant resistance to both biotic and abiotic stresses. In soil, potassium is present in four distinct forms: solution K, exchangeable K, non-exchangeable or fixed K, and structural or mineral K, which remain interconnected through a dynamic equilibrium. The equilibrium among these fractions ensures a steady availability of potassium to meet crop requirements. Of these, the solution and exchangeable forms constitute the readily available potassium fraction, while the non-exchangeable form serves as a reserve that gradually releases K to the available pool as plants absorb it. Although the total potassium content in soils is generally high, most of it is locked within mineral structures and, therefore, not directly accessible to plants.

Continuous cropping without adequate K fertilisation leads to depletion of exchangeable and non-exchangeable reserves, resulting in reduced yields and nutrient imbalance. The availability of non-exchangeable potassium does not depend on its amount, but on the rate of release and the amount of potassium that can be converted into its exchangeable form (Shakeri, S. (2018)) [20]. Despite being essential, K fertilisation often receives less attention than N and P, creating a nutrient imbalance in many parts of the country. Given this context, assessing the distribution of various K forms is crucial for optimising fertiliser recommendations and maintaining soil fertility.

Geographic Information Systems (GIS) provide an efficient means to visualise and analyse the spatial variability of soil nutrients. Mapping the distribution of K pools helps identify nutrient-deficient zones and supports precision nutrient management.

This study aims to assess the spatial distribution and relationships among different K pools in the soils of North Bihar to guide sustainable K management strategies.

Materials and Methods

Toposheet and Base Map: The soil map of Bihar at a scale of 1:500,000, prepared by NBSS&LUP in association with Rajendra Agricultural University, Sabour (1988), served as the foundational reference for the study. Using GIS techniques, soil sampling grids measuring 40 × 40 km were generated, and a total of 34 grids representing the North Bihar region were chosen for soil sample collection.

GPS and Sampling: Sampling points were located using a Magellan Mobile Mapper CX GPS device. At each point, surface soil samples (0-15 cm depth) were collected before the monsoon season from different land situations—upland, midland, and lowland. In total, 121 composite samples were obtained, air-dried, sieved (<2 mm), and properly labelled for analysis.

GIS Analysis: Spatial mapping was performed using TNTmips GIS software (Version 2010). Digitisation of rivers, district boundaries, and sampling points was carried out using vector tools. The digital layers were overlaid to create thematic maps that illustrate the spatial variation in K pools.

Chemical Analysis for pools of Potassium (K)

Water-soluble K

Water-soluble potassium in the soil samples was measured by extracting the soil with distilled water in a 1:5 soil-to-water proportion, followed by shaking for 30 minutes. After filtration, the potassium concentration in the extract was quantified using a flame photometer in accordance with the procedure outlined by USSLS (1954).

Exchangeable K

Exchangeable potassium in the soil samples was determined from the leachate obtained after equilibrating the soils with 1N neutral ammonium acetate. The potassium content in the extract was then measured using a flame photometer following the procedure described by Hanway and Heidel (1952).

Non-Exchangeable K

Non-exchangeable potassium in the soil samples was determined by boiling the soil with nitric acid in a 1:10 soil-to-acid ratio for 10 minutes, followed by estimation of potassium using a flame photometer according to the standard method outlined by Wood and De Turk (1940).

Total K

Total potassium in the soil was estimated by digesting the samples with a mixed acid solution of H_2SO_4, $HClO_4$, and HF in a platinum crucible at 220-225 °C, followed by potassium determination using a flame photometer as per the standard procedure described by Jackson (1973).

Spatial analysis

Spatial distribution maps of various potassium pools and their possible combinations were generated using TNTmips GIS software (Version 2010).

Results and Discussion

The findings of the study are illustrated using graphs and thematic maps, representing the various forms of potassium present in the soils.

Figures 1-3 illustrate the distribution of different potassium fractions in upland, midland, and lowland soils of North Bihar. Available K ranged from 26-330 ppm in uplands, 20.50-256.50 ppm in midlands, and 17-311.50 ppm in lowlands, with mean values of 82.37, 81.40, and 77.99 ppm, respectively. Water-soluble K showed lower concentrations, varying from 3.50-67.00 ppm across landforms, with an overall mean of 18.26 ppm.

Exchangeable K ranged from 2-274 ppm, with comparable mean values across upland (62.97 ppm), midland (63.26 ppm), and lowland (60.70 ppm) soils. Nitric acid-soluble K exhibited wide variability, ranging from 126-2431 ppm, while non-exchangeable K varied from 65-2101 ppm, indicating substantial reserve pools of potassium in the soils. Total K showed the widest range (469-22,471 ppm), with higher contents generally observed in lowland soils. Overall, finer soil fractions, particularly clay, contributed a major share of total potassium compared to sand and silt fractions.

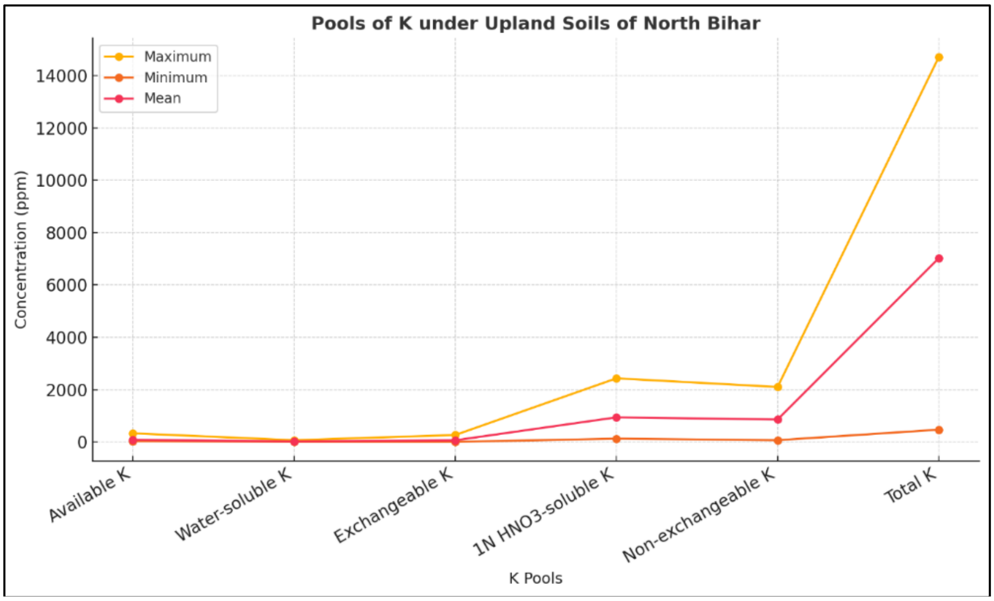


Fig 1: Graph of pools of K under the upland soils of North Bihar

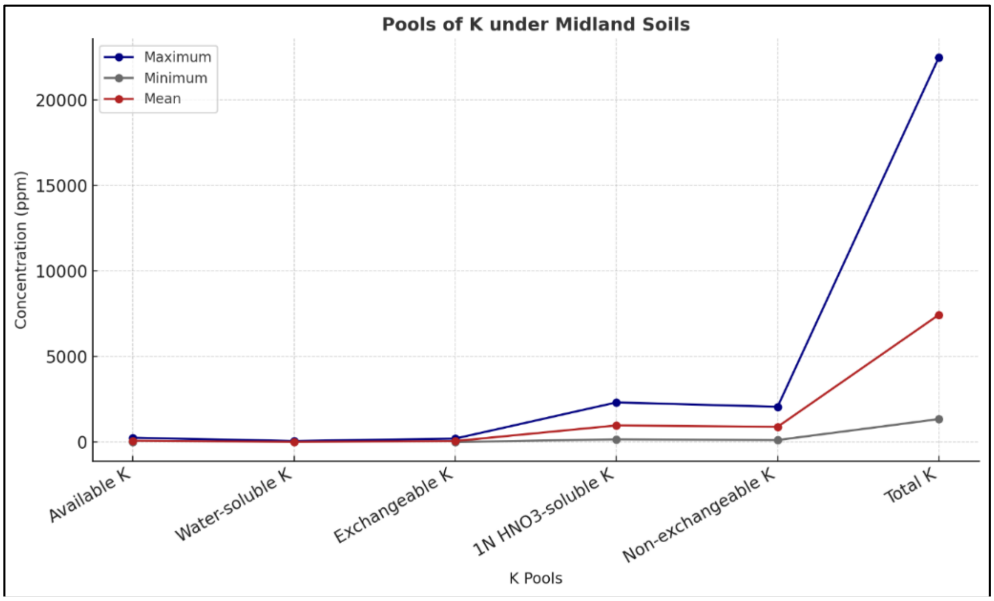


Fig 2: Graph of pools of K under midland soils of North Bihar

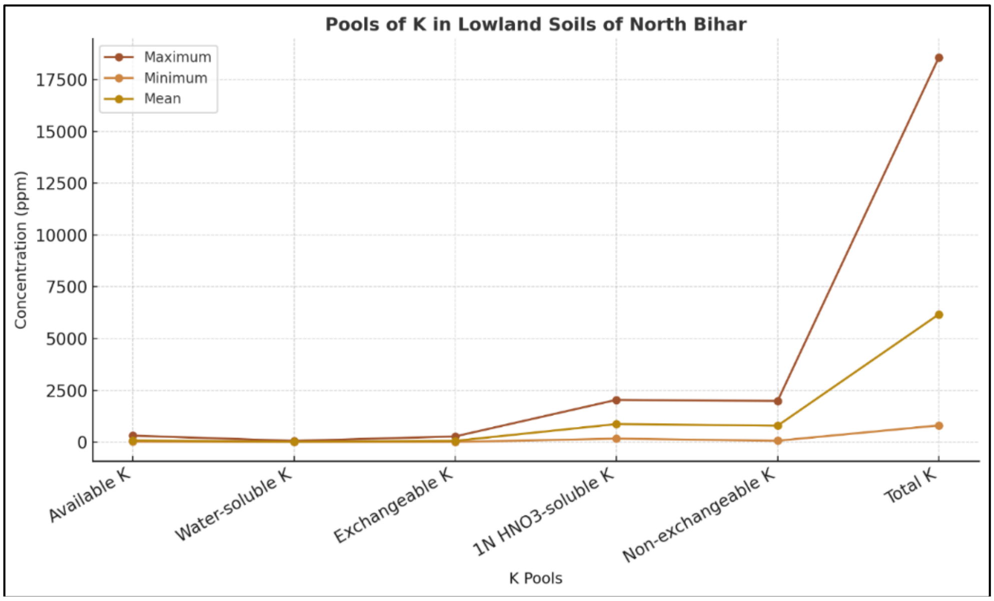


Fig 3: Graph of pools of K under lowland soils of North Bihar

GIS-aided maps for spatial distribution

The thematic maps (Maps 1-6) depict the spatial variability of different potassium fractions in the soils of North Bihar.

Water-soluble potassium (Map 1) was predominantly in the medium range (15-30 ppm), occupying about 59.40% of the area, mainly across central and eastern parts of the region, while lower levels (2-15 ppm) occurred in nearly 38.47% of the area, largely in western and north-western districts. High water-soluble K (>30 ppm) was limited to small pockets.

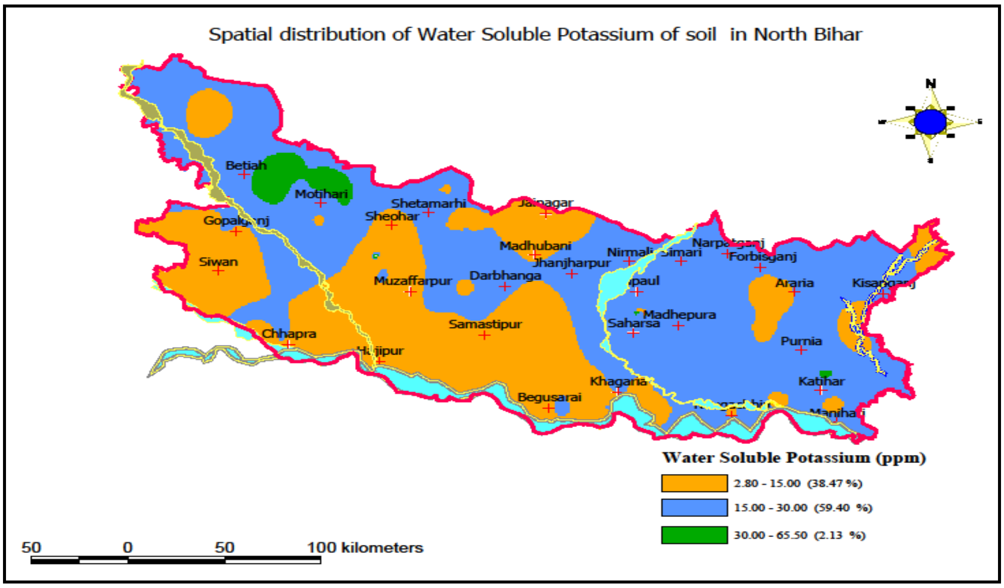
Available potassium (Map 2) showed a dominance of medium levels (61-121 ppm), covering 68.52% of the area, particularly in midland and lowland regions. Low available K (<61 ppm) was observed in about 22.56% of the area, mostly in upland tracts, whereas high available K (>121 ppm) was restricted to limited zones in parts of north-eastern North Bihar.

Exchangeable potassium (Map 3) followed a similar pattern, with 63.43% of the area falling under the medium category (50-120 ppm). Lower exchangeable K (<50 ppm) was mainly associated with upland areas, while higher values (>120 ppm) occurred only in localized pockets.

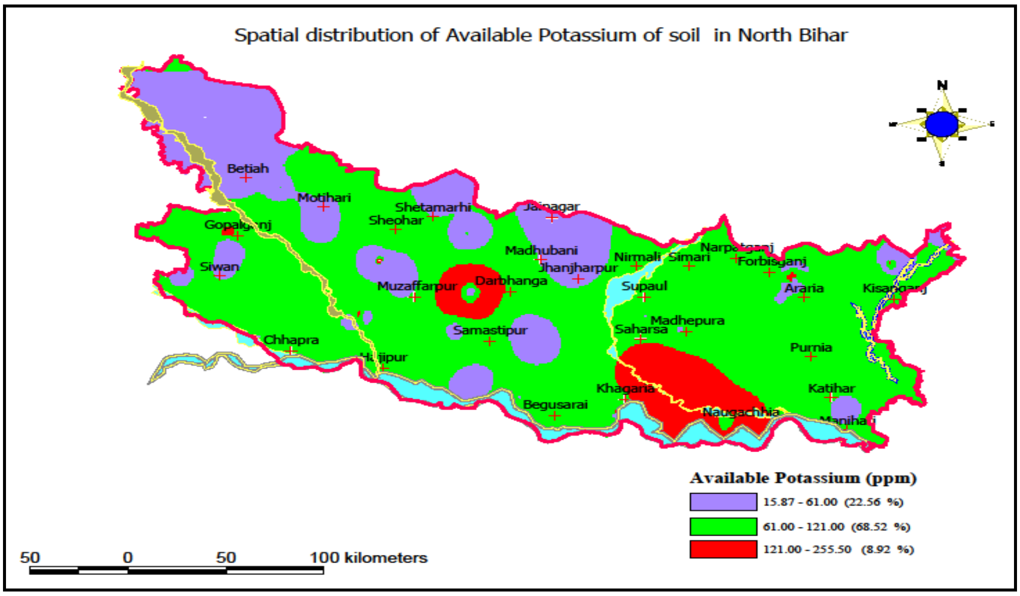
Non-exchangeable potassium (Map 4) was high (>600 ppm) over a major portion of the region (82.64%), indicating substantial reserve K in the soils. Moderate levels (300-600 ppm) were confined to small areas, while low non-exchangeable K (<300 ppm) occurred only sporadically.

Nitric acid-soluble potassium (Map 5) was largely in the medium range (750-1500 ppm), covering about 74.05% of the area, whereas lower values (<750 ppm) were observed mainly in upland zones. High HNO_3-soluble K (>1500 ppm) was limited to very small areas.

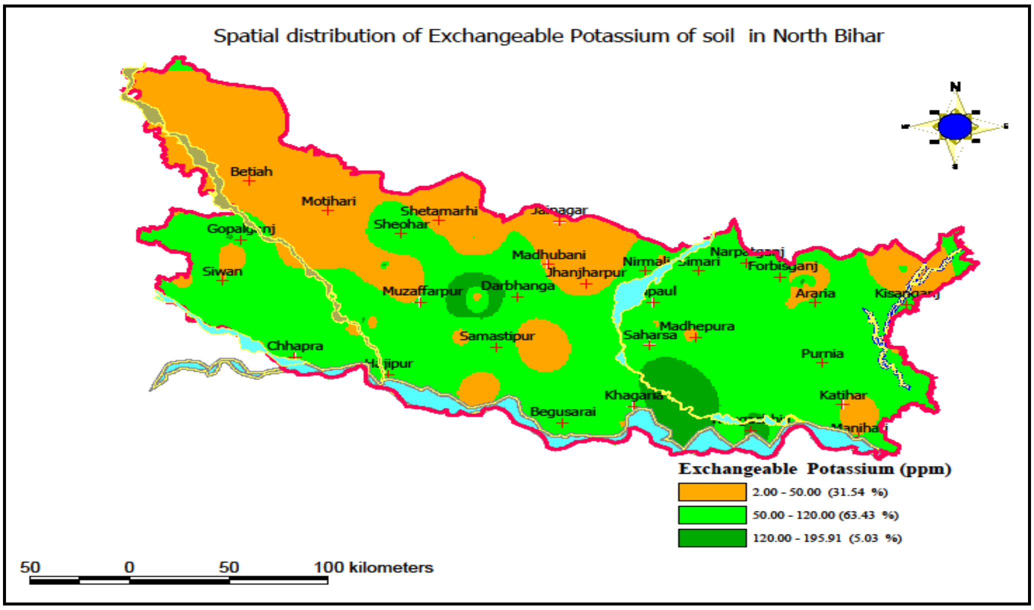
Total potassium distribution (Map 6) revealed that most soils (78.17%) contained medium total K (5000-10,000 ppm), particularly in midland and lowland landscapes. Low total K (<5000 ppm) was confined to a few upland pockets, while high total K (>10,000 ppm) occurred in limited areas.



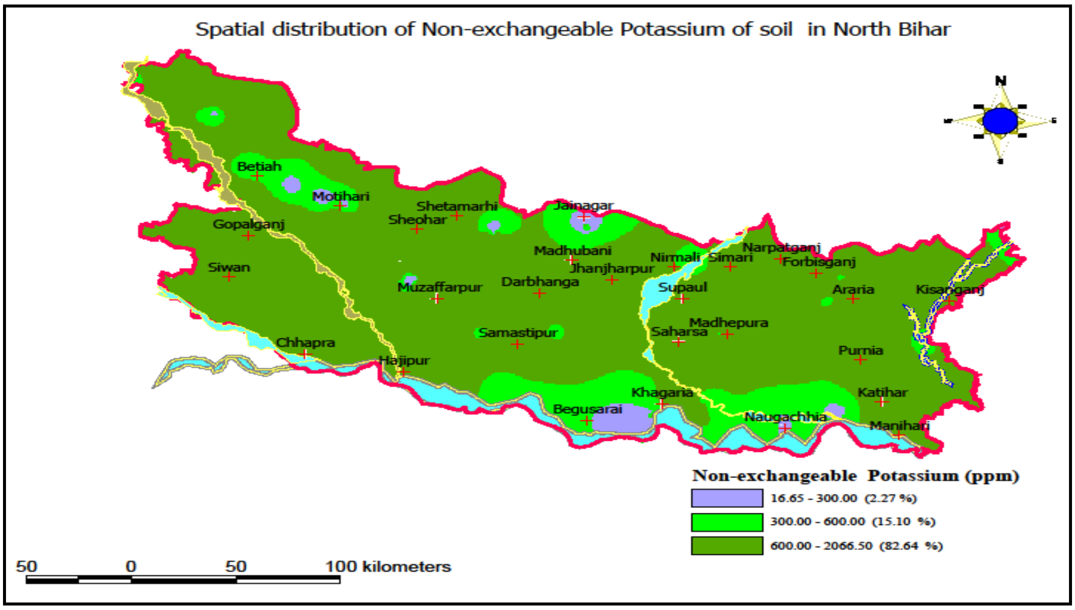
Map 1: Spatial distribution of water-soluble K of soils of North Bihar



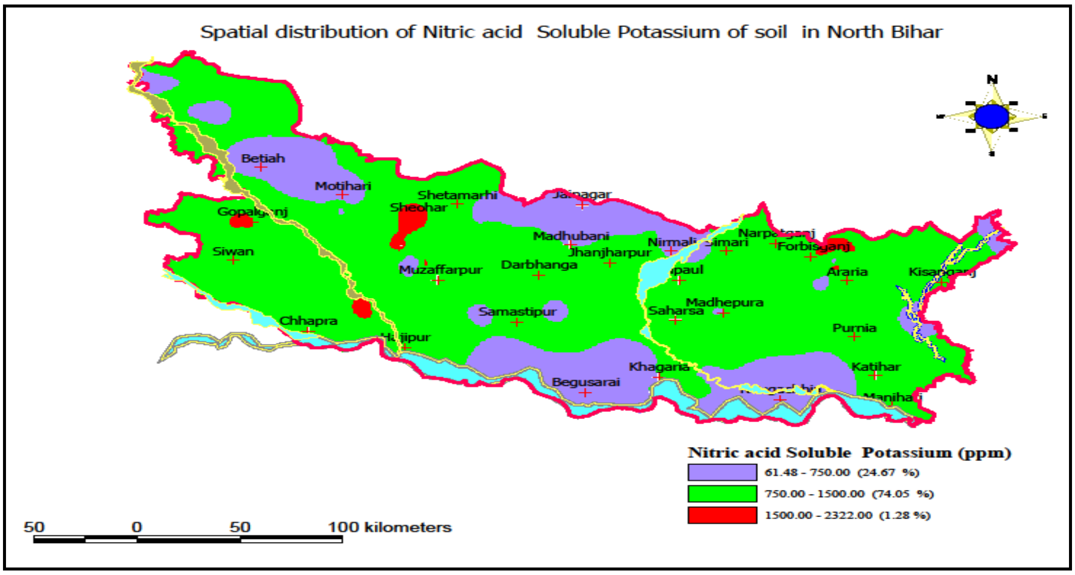
Map 2: Spatial distribution of available K of soils of North Bihar



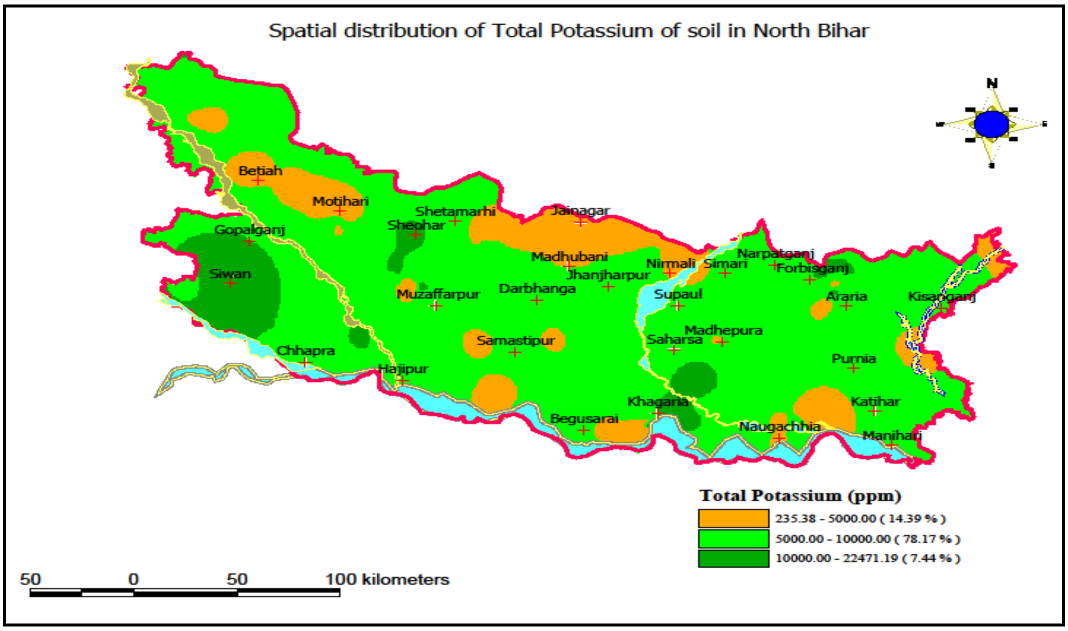
Map 3: Spatial distribution of exchangeable K of soils of North Bihar



Map 4: Spatial distribution of non-exchangeable K of soils of North Bihar



Map 5: Spatial distribution of nitric acid-soluble K of soils of North Bihar



Map 6: Spatial distribution of total K of soils of North Bihar

Conclusion

The present investigation revealed pronounced spatial variability among the different forms of potassium (K) in the soils of North Bihar. The dominance pattern of total K > non-exchangeable K > exchangeable K > water-soluble K indicates that a major portion of the soil potassium exists in forms unavailable to plants. The comparatively higher concentrations of total and non-exchangeable K in lowland areas reflect the influence of finer soil texture and mineral composition, while upland soils showed relatively lower K levels, suggesting nutrient depletion through continuous cropping and insufficient K fertilisation.

The use of Geographic Information Systems (GIS) proved effective in identifying zones with varying potassium fertility across districts, thereby providing a practical tool for precision nutrient management. The significant share of non-exchangeable K in total soil potassium highlights its role as a buffer source, maintaining the available pool under high cropping intensity.

Overall, the study underscores the importance of integrating potassium management into balanced fertilisation programs. Continuous monitoring of soil K pools, supported by GIS-based mapping, is essential for formulating location-specific nutrient recommendations and for ensuring long-term soil fertility and sustainable agricultural productivity in the alluvial soils of North Bihar.

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Authors' contributions

Sneh Prabha has collected the soil samples and conducted all laboratory work; SS Prasad has planned the research and guided. Sonal and BK Vimal have contributed to the final version of the manuscript.

Compliance with ethical standards

Conflict of Interest: The Authors declare that they don't have any conflict of interest.

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