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Validation of Digital Soil Map in Maize Growing Areas of Chitwan, Nepal

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ABSTRACT

National Soil Science Research Centre of the Nepal Agricultural Research Council (NARC) with technical support from the International Maize and Wheat Improvement Center developed Digital Soil Map (DSM), a web-based information system, in 2020 using the legacy data with a geospatial model using a random forest machine learning prediction approach. The map generated with the model predicted values besides geo-referenced points that require further validation. Since DSM was launched, no work has been done to validate the map. We sampled 452 points from all municipalities of the Chitwan district using a gridded sampling approach to validate the existing predicted values of the DSM. We found that the observed values such as soil texture, soil organic matter, and total nitrogen content were similar to the range values of DSM. Still, a discrepancy was found between the available potassium and phosphorous. In the majority of areas, the observed value of available soil potassium (20 – 450 kg K ha^{-1} ± 15 kg K ha^{-1}) was found lower compared to the DSM values (118 – 330 kg K ha^{-1}), however, available phosphorous (55 – 230 kg P ha^{-1} ± 10 kg P ha^{-1}) was found higher compared to DSM range values (11 – 139 kg P ha^{-1}). The maize growing area of Chitwan was found suitable with soil pH (6.4 – 6.8) and other nutrients except for available soil potassium. Most of the areas from Eastern and Western Chitwan reported potassium mining, which needs to be considered in balancing nutrients in field crops.

Keywords: Nutrient balance, potassium mining, soil polygon analysis, soil nutrients

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INTRODUCTION

Soil properties are spatially different and require high-resolution mapping to exhibit detailed soil information. A legacy coarse soil map in Nepal provides semi-detailed soil type information (Lamichhane et al 2021). The soil map of Chitwan is typically characterized by sandy loam texture with low to moderate soil fertility (Ojha and Panday 2021). These maps provide support to policymakers and land managers to effectively formulate land management programs and manage the inputs at the farm level (Arrouyas et al 2014), which requires a detailed mapping (Yang et al 2011). Various geospatial models and regressions are used to predict the spatial soil information based on legacy data and environmental covariates for preparing the digital soil map (Kempen et al 2009, Vincet et al 2018, Zeraatpisheh et al 2019). Nepal recently launched a digital soil map that mostly used legacy soil data at a higher resolution (NSSRC 2021).

Digital soil map (DSM) of Nepal provides spatial soil information relating to soil nutrient status, soil particle size distribution, soil pH, soil types, and cropping system information (NSSRC 2021). Digital soil information map is a web-based application developed by the collaborative effort of Nepal Seed and Fertilizer project, CIMMYT, and National Soil Science Research Centre (NSSRC), NARC. The legacy data were used to prepare the map, which was primarily collected from the National Land Use Planning Project. Other data sources such as the database of soil laboratories of NSSRC and Department of Agriculture (DoA) have also been used.

Collected data are then interpolated in a web-based Geographical Information System, which is now available in the web domain https://soil.narc.gov.np/.

The geospatial interpolation in DSM was done using a random forest machine learning approach. It is a supervised machine learning predictive model where a single result was obtained based on the combined output of multiple decision trees (Fawagreh et al 2014). The predictive values obtained from the model should be validated in the real ground scenario (Pikki et al 2021). The validation is done by calculating the mapping uncertainty after calculating the deviance between the real ground observed values and model predicted values. Certain measures like agreement analysis (compare the modeled range values with observed range values) and root mean square error (RMSE – calculate the distance between the observed and predicted values with reference to the best-fitted lines and are optimal for normal/Gaussian errors) were employed in this study (Hodson 2022). This map validation will provide us with the confidence of the certainty of the use of DSM values.

This information system requires validation considering the nutrient dynamism influenced by farm management practices and inputs used with the due course of time. The cropping system of Chitwan district is Rice and Maize based system, which are nutrient intensive systems. The input management particularly fertilizer and water primarily governs the soil fertility and is changing over time. The dynamism should be monitored regularly for providing precise information to the end-users, which should rely on the primary data. With an objective to validate and update the digital soil information map, National Maize Research Program (NMRP), Rampur, Chitwan was assigned to collect soil samples from Chitwan district.

METHODOLOGY

Chitwan district is one of the districts of Bagmati province with an elevation range from 121 to 1947 meters above sea level (Table 1). Topographically, Chitwan district lies in both the Siwalik and middle-Mountain physiographic regions of Nepal. There are seven municipalities and their respective area is given in Table 1.

Soil sample point determination

Soil samples from each municipality were taken in a 1 km^2 grid. One sample in each grid was assigned considering only the cropland image taken from the Google Earth satellite image. The total number of samples in each municipality is given in Table 1 and the overall distribution of the soil samples in the Chitwan district is shown in Figure 1 extracted from GoogleEarth. Soil samples were taken using a hand-held auger from 0–20 cm depth. A composite soil sample of three sub-samples at each sampling point was taken using a diagonal approach. A total of 452 samples were taken from the cultivated area of each municipality of Chitwan district.

Table 1: Soil sample numbers taken in different municipalities of Chitwan districts respective to their area.

SN	Municipalities	Area, km^2	Sample numbers
1	Bharatpur metro-municipality	432.85	226
2	Ratnanagar municipality	68.68	32
3	Kalika municipality	149.08	42
4	Rapti municipality	212.31	30
5	Madi municipality	218.24	60
6	Khairahani municipality	85.55	30
7	Ikshyakamana rural municipality	166.73	32
	Total sample number		**452**

Laboratory analysis

Soil samples collected from different municipalities were brought into the laboratory of National Maize Research Program, NARC which was air-dried. After drying, samples were sieved using a 2 mm mesh size sieve during which roots, gravel, and undecomposed plant materials were removed. A portion of the air-dried sample is then placed in the oven at 105℃ for 12 hours to determine the oven-dry mass of the soil samples. The air-dried soil samples were then used for laboratory analysis. The standard operating procedure developed by DSM updating guidelines prepared by DoA and NSSRC was used to analyse soil parameters. Soil texture was analysed using hydrometer method (Bouyoucis 1927). Soil pH was determined using potentiometric method with soil to water ratio of 1:2.5. Wet oxidation method was used to determine soil organic matter (Walkley and Black 1934). Total nitrogen was determined using Kjeldahl method (Bremner and Mulvaney 1982), available phosphorous was determined using modified Olsen's bicarbonate method in double beam spectrophotometer (Olsen et al 1954), and available potassium was determined with ammonium acetate extraction method with digital flame photometer (Jackson 1967).

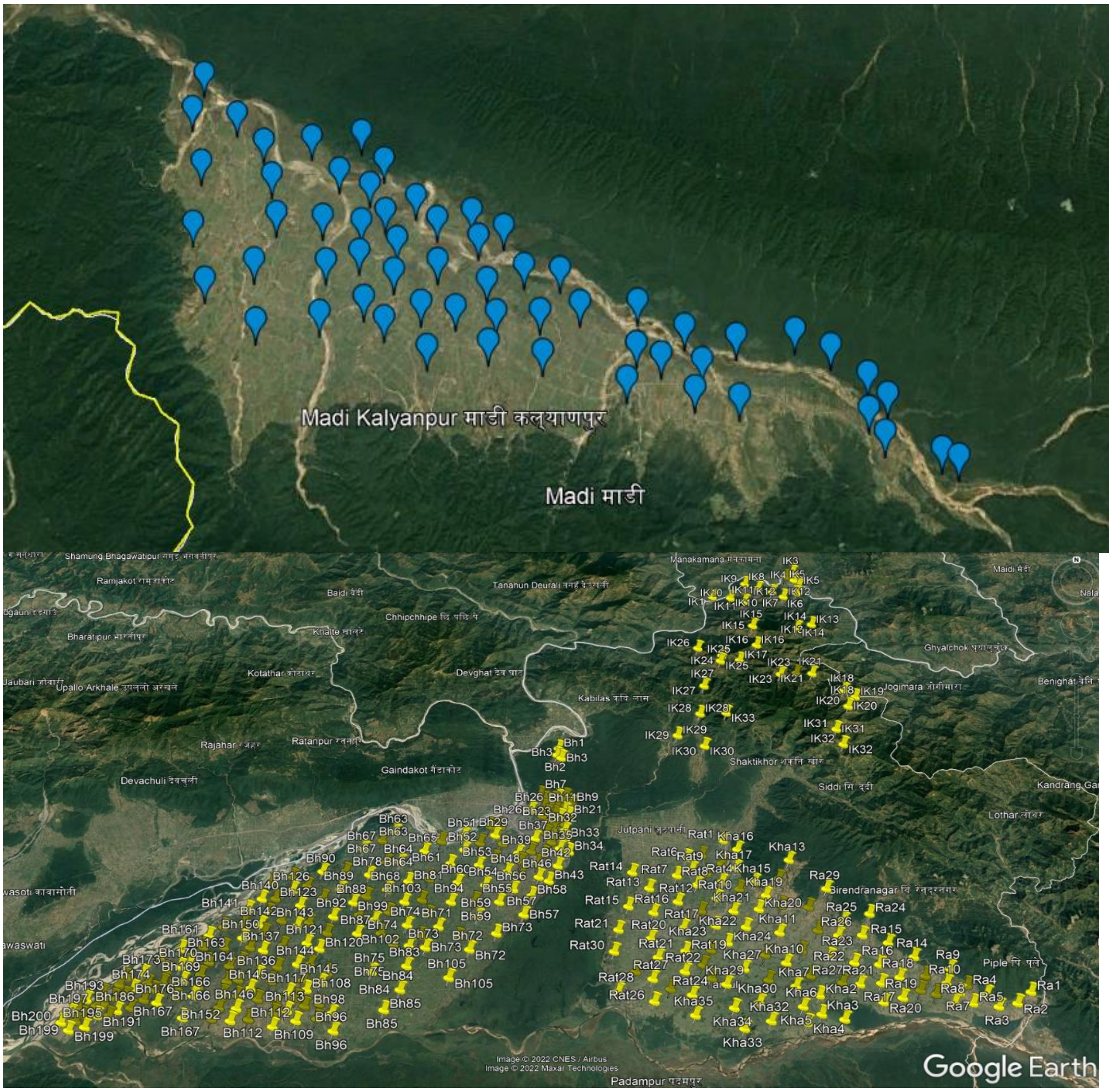

Figure 1: Soil sample points distribution in seven municipalities of Chitwan district (n = 452)

Statistical analysis

The range values (minimum, mean, and maximum) of the observed values were calculated with summary statistics. The range values for each municipality were extracted from DSM using polygon analysis feature of the respective municipality. The Bland-Altman plot was used to analyze the agreement of the observed range values with DSM predicted values. Similarly, the root mean square error (RMSE) was calculated to check the predictive accuracy of models used in DSM with the ground observed values using equation 1. All the analyses were done in R studio (Rstudio team, 2020).

$$RMSE = \sqrt{\frac{\Sigma(yi-\hat{y}i)^2}{N-P}} \text{ …………… Equation 1}$$

Where,

y_i = actual value for the i^{th} observation

$\hat{y}_i$ = predicted value for the i^{th} observation

N = number of observations.

P = number of parameter estimates, including the constant.

Lower the RMSE value (near to zero), the best is the validation between the observed and predictive values. Larger RMSE value indicate the larger uncertainties between the values.

RESULTS

Agreement analysis (Range agreement)

The maximum, minimum, and mean range values of observed soil parameters was compared with the DSM extracted range values (Figure 2 and 4).

Table 2: Summary statistics showing mean and 95% confidence interval (CI) of the observed values of the soil parameters sand, silt, clay, and soil pH in Chitwan district, Nepal

Location	Sand, %	Sand 95% CI	Silt, %	Silt 95% CI	Clay, %	Clay 95% CI	Soil pH	Soil pH 95% CI
Bharatpur	75.80± 0.45	74.91–76.69	16.06±0.37	16.06–16.06	8.14±0.17	8.14–8.14	6.72±0.06	6.72–6.72
Ikshyakamana	74.00± 1.04	71.96–76.04	16.45±0.89	16.45–16.45	9.55±0.37	9.55–9.55	6.54±0.12	6.54–6.54
Kalika	65.98± 1.35	63.33–68.62	22.79±0.98	22.79–22.79	11.23±0.61	11.23–1.23	6.72±0.12	6.72–6.72
Khairahani	64.83± 0.70	63.45–66.21	24.52±0.55	24.52–24.52	10.66±0.53	10.66–0.66	6.66±0.14	6.66–6.66
Madi	72.59± 1.03	70.58–74.61	16.24±0.66	16.24–16.24	11.17±0.47	11.17–1.17	6.69±0.13	6.69–6.69
Rapti	71.15± 1.14	68.92–73.38	19.00±0.91	19.00–19.00	9.85±0.47	9.85–9.85	6.48±0.17	6.48–6.48
Ratnanagar	65.69± 0.53	64.64–66.73	23.78±0.46	23.78–23.78	10.53±0.41	10.53–0.53	6.84±0.14	6.84–6.84

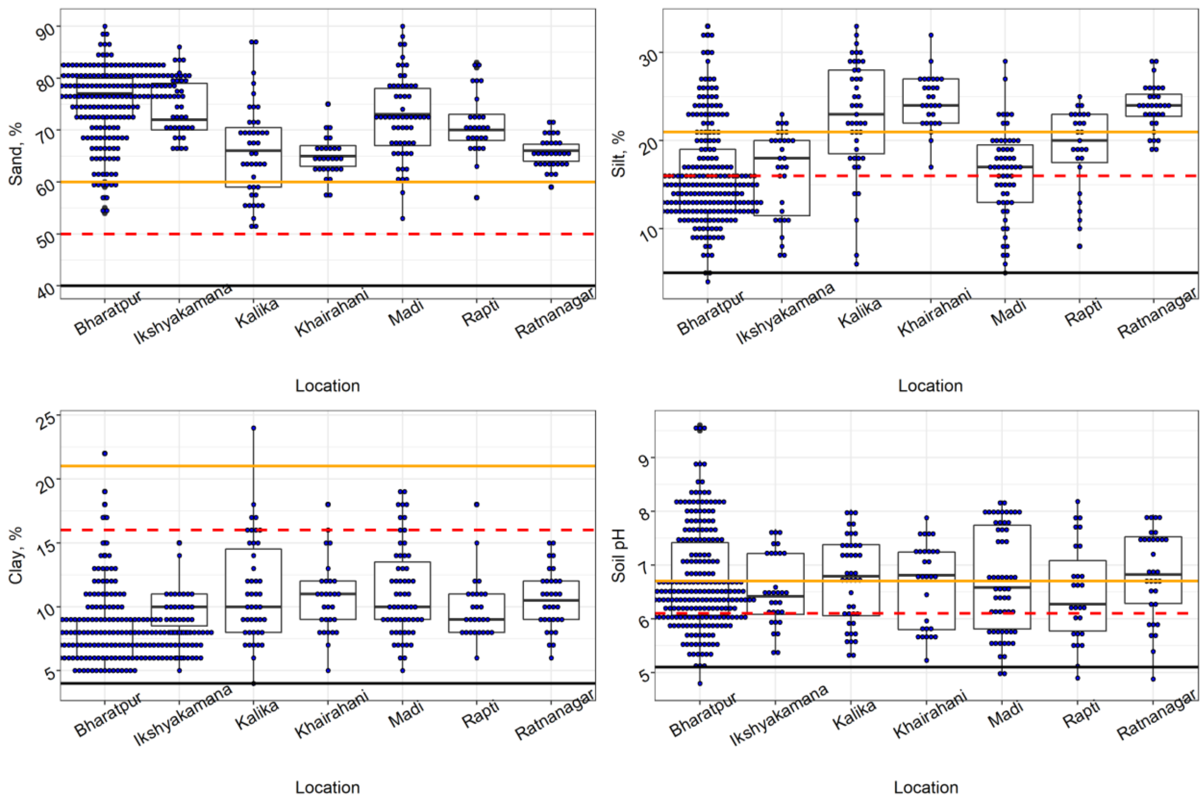

Figure 2. Agreement analysis (Bland-Altman plot) of sand, silt, clay content, and soil pH values in the soils of Chitwan district. Yellow, red (dotted), and black line represent maximum, mean, and minimum values, respectively extracted from Digital Soil Map

Summary of the observed values with their 95% confidence interval is shown in Table 2 and Table 3. Majority of the mean observed values of the sand content fell above the DSM maximum values. The mean silt content was found near to the mean values of the DSM mean values. However, all of the values of clay content fell within the DSM predicted values. Majority of the soil texture was found as loamy sand and sandy loam, which in line with DSM predicted values (Figure 3). Similarly, mean soil pH values were observed within the DSM predicted pH values.

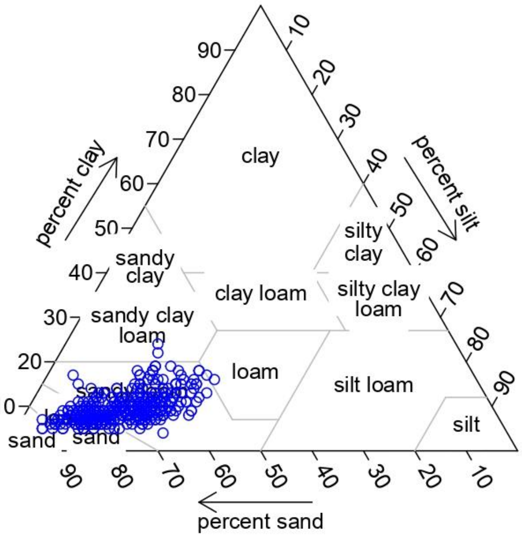

Figure 3. Soil texture distribution in different municipalities of Chitwan district (n = 452).

The observed values of the total nitrogen and soil organic matter in the Chitwan district were found within the range of predictive DSM values (Figure 4). The observed mean values of available phosphorous was found near the maximum values of the DSM predicted values. However, majority of the available potassium observed values were found below the minimum values of DSM values.

Table 3: Summary statistics showing mean and 95% confidence interval (CI) of the observed values of the soil parameters soil organic matter (SOM), Phosphorous (P), Potassium (K), and Total Nitrogen (TN) content in Chitwan district, Nepal.

Location	SOM, %	SOM 95% CI	P, kg/ha	P 95% CI	K, kg/ha	K 95% CI	TN, %	TN 95% CI
Bharatpur	4.16± 0.13	3.91–4.42	119.18± 3.34	119.18–119.18	75.54±5.34	75.54–75.54	0.09±0.00	0.09–0.09
Ikshyakamana	1.75± 0.15	1.46–2.05	164.77± 8.74	164.77–164.77	276.52±38.72	276.52–276.52	0.13±0.01	0.13–0.13
Kalika	3.99± 0.25	3.50–4.48	118.24± 6.39	118.24–118.24	293.07±17.24	293.07–293.07	0.16±0.01	0.16–0.16
Khairahani	3.32± 0.18	2.96–3.67	112.19± 6.07	112.19–112.19	85.10±5.62	85.10–85.10	0.09±0.01	0.09–0.09
Madi	2.07± 0.17	1.74–2.39	92.82± 4.28	92.82–92.82	76.27±6.14	76.27–76.27	0.06±0.00	0.06–0.06
Rapti	3.87± 0.21	3.46–4.28	119.49± 7.51	119.49–119.49	117.70±14.21	117.70–117.70	Na	na
Ratnanagar	3.73± 0.24	3.26–4.20	85.11± 7.00	85.11–85.11	383.44±42.12	383.44–383.44	0.07±0.01	0.07–0.07

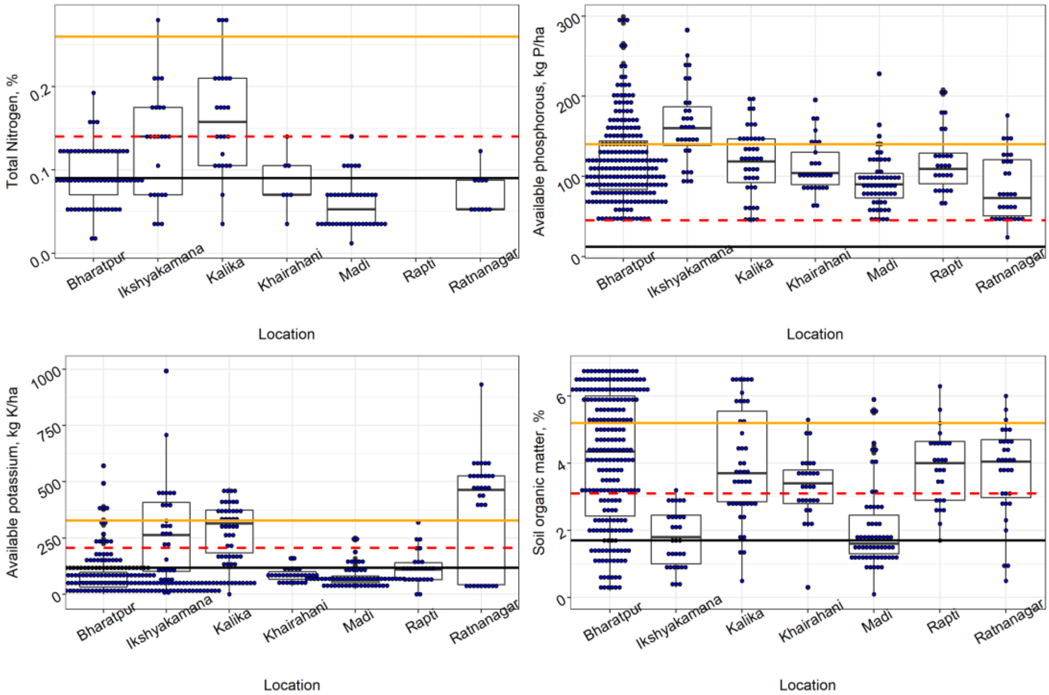

Figure 4. Agreement analysis (Bland-Altman plot) of total nitrogen, available phosphorous, available potassium, and soil organic matter content in the soils of Chitwan district. Yellow, red (dotted), and black line represent maximum, mean, and minimum values, respectively extracted from Digital Soil Map.

Root mean square error (RMSE)

Root mean square error values of sand and silt content were found higher than clay and soil pH (Figure 5). A greater RMSE value was observed in available potassium and phosphorous, whereas the values remained lowered for total nitrogen and soil organic matter (Figure 6).

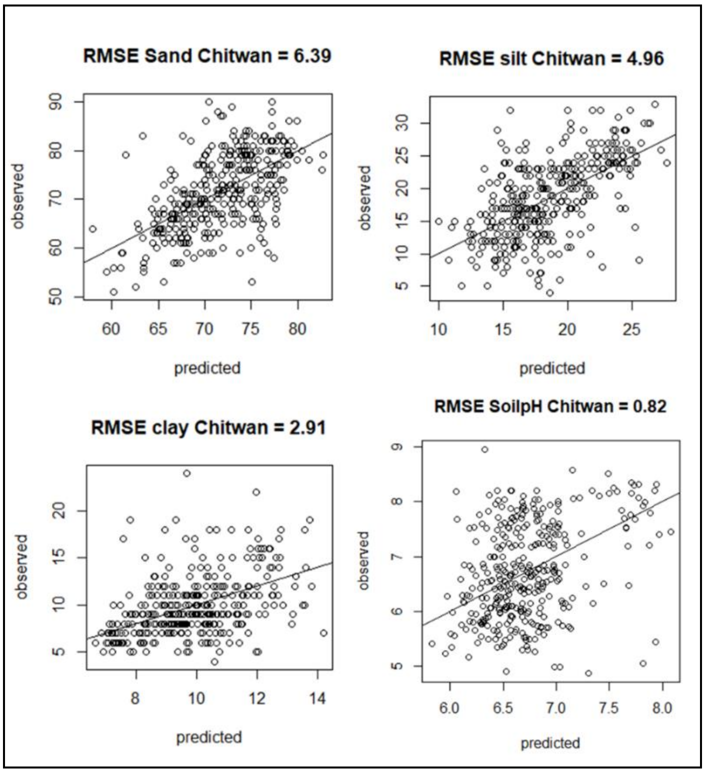

Figure 5. Root mean square error between observed and DSM predicted values of sand, silt, clay, and soil pH in Chitwan district.

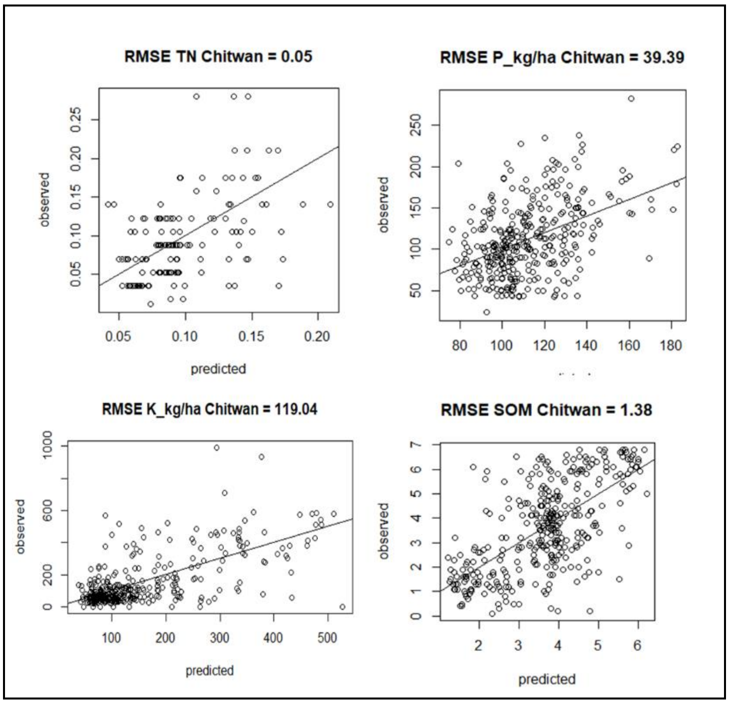

Figure 6. Root mean square error between observed and DSM predicted values of total nitrogen, available phosphorous, available potassium, and soil organic matter in Chitwan district.

DISCUSSION

Both the range agreement analysis (Figure 2, 4) and RMSE result showed the discrepancy in available P, available K, sand, and silt content between the observed values and DSM predicted values (Figure 5, 6). However, other observed parameters such as total nitrogen, soil organic matter, clay content, and soil pH values were found within the DSM predicted range. These similarities and discrepancies found between the observed values and predicted values might result due to the dynamic nature of soil properties (Yesilonis et al 2022) and levels of land management practiced by land managers over time (Arévalo-Gardini 2015). The data used in DSM were taken from national land use planning project which were sampled in 2012 in Chitwan district (NLUPP 2022). The observed values were sampled in 2022. In the due course of 10 years it is expected that the soil properties vary with the level of farm input management or possible land use changes (Jin et al 2021, Shrestha and Kafle 2020, Panday et al 2019).

Higher values of available P were observed than DSM predicted values (Figure 4) which might be due to the extensive use of diammonium phosphate (DAP). It is evident that urea has been in shortage in the Nepalese market for a long time (MoALD 2022), DAP supplies both phosphorous and nitrogen and farmers prefer to use DAP in place of urea. Furthermore, soil was sampled during the maize growing period which was near to the harvesting stage. During soil sample collection, farmers said that they had used DAP in place of urea during maize plantation. The input management temporarily affects the soil available P levels. It is necessary to assess the P stock in the cropping areas of Chitwan district.

Lower values of available K were observed than DSM predicted values which might be due low use of potassic fertilizer. Previous fertilizer recommendation recommends a very low rate of potassium because of the high soil test value of potassium (Joshy 1997). Recently, National Soil Science Research Centre along with National Seed and Fertilizer Project, CIMMYT realised that the K level is declining in Nepal and suggest to revise the previous recommendation and increasing K level in rice-maize-wheat cropping system (NSSRC 2023). In addition, Ojha et al (2021) identified the K level is declining in the context of Nepal due to low K input and degeneration of K-mineral (mica). This phenomenon has been observed in the maize and rice growing areas of Chitwan district.

Soil particle sizes such as sand and silt content (Table 2) were found higher than DSM values (Figure 2, 3). However, clay content was found within the range. Soil textural distribution did not vary between the observed and DSM values suggesting that their proportionate distribution over the spatial extent did not change. Soil physical properties like soil particle sizes are unlikely to change over the decade time (Eppes and Johnson 2022). Soil particle size analysed in the laboratory using hydrometer method. The difference in the sand and silt content might resulted from variations in measurement methods. This issue can be resolved following the standard operating procedure and periodic lab accreditation.

CONCLUSION

Comparing the results of range agreement analysis and RMSE, the output suggests the reliability of using DSM is true for clay content, soil pH, total nitrogen, and soil organic matter. The range values fall beyond the DSM predicted values in the case of sand, silt content, available phosphorous, and potassium content, which also corroborates with the higher RMSE values of respective parameters. It is recommended that the DSM values in case of Chitwan district can only be certain for clay content, soil pH, total Nitrogen, and soil organic matter. Soil texture information can also be used from DSM, however, caution is necessary to take while referring to sand, silt, phosphorous, and potassium DSM values. Sandy loam soil dominates most of Chitwan district's cultivated areas and some with sand, loam, and sandy clay loam soil. Overall, Chitwan soil's fertility status is low to moderate with lower values of total nitrogen, available potassium, and soil organic matter. Phosphorus source management is crucial as it showed a high to very high range in most areas. Soil pH is not a limiting factor in nutrient availability and crop production. A focus on balanced fertilization based on soil test value is necessary to promote in the district. So, an update is suggested for these parameters to use DSM values with greater certainty for sustainable soil management.

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AUTHOR’S CONTRIBUTION

RB Ojha: Project re-designing, Field sampling design, soil sample collection, soil analysis guidance, original draft preparation, and editing
K Khatri: Field sample collection, full laboratory analysis, and reviewing lab results
P Adhikari: Project planning, Field sample collection, and reviewing manuscript
SP Vista: Project conceptualization, reviewing, and editing manuscript
S Sapkota: Part of statistical analysis, reviewing, and editing manuscript

CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest regarding the publication of this manuscript.

REFERENCES

Arévalo-Gardini E, M Canto, J Alegre, O Loli, A Julca and V Baligar. 2015. Changes in soil physical and chemical properties in long term improved natural and traditional agroforestry management systems of cacao genotypes in Peruvian Amazon. PloS one. Jul 16;**10**(7):e0132147.

Arrouays D, N McKenzie, AR de Forges, J Hempel and AB McBratney. 2014b. GlobalSoilMap: Basis of the Global Spatial Soil Information System. CRC Press/ Balkema, Leiden.

Bouyoucos GJ. 1927. The hydrometer as a new method for the mechanical analysis of soils. Soil Science. **23**(5): 343-354.

Bremner JM and RD Hauck. 1982. Advances in methodology for research on nitrogen transformations in soils. Nitrogen in agricultural soils. **22**: 467-502.

Eppes MC and BG Johnson. 2022. Describing Soils in the Field: A Manual for Geomorphologists. **3**:450-479. https://doi.org/10.1016/B978-0-12-818234-5.00180-2

Fawagreh K, MM Gaber and E Elyan. Random forests: from early developments to recent advancements. Systems Science and Control Engineering: An Open Access Journal. 2014 Dec 1; **2**(1):602-9.

Hodson TO. 2022. Root-mean-square error (RMSE) or mean absolute error (MAE): When to use them or not. Geoscientific Model Development. **15**(14): 5481-5487.

Jackson M. 1967. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd.

Jin J, L Wang, K Müller, J Wu, H Wang, K Zhao, F Berninger and W Fu. 2021. A 10-year monitoring of soil properties dynamics and soil fertility evaluation in Chinese hickory plantation regions of southeastern China. Scientific Reports. Dec 7;**11**(1):23531.

Joshy D. Soil Fertility and Fertilizer Use in Nepal. 1997. Nepal Agriculture Research Council, Khumaltar, Lalitpur, Nepal. **1**, 80.

Kempen B, DJ Brus, GBM Heuvelink and JJ Stoorvogel. 2009. Updating the 1:50,000 Dutch soil map using legacy soil data: a multinomial logistic regression approach. Geoderma. **151** (3–4): 311–326.

Lamichhane S, L Kumar and K Adhikari. Updating the national soil map of Nepal through digital soil mapping. Geoderma. 2021 Jul 15;394:115041.

MoALD. 2022. Fertilizer use and consumption database. Ministry of Agriculture and Livestock Development, Singhdurbar, Kathmandu, Nepal.

NLUPP. 2022. Land use database. National Land Use Planning Project. Survey Department, Ministry of Land management, Cooperatives and Poverty Alleviation. Minbhawan, Kathmandu, Nepal.
NSSRC. 2021. Digital Soil Map of Nepal (Booklet). National Soil Science Research Center, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal.
NSSRC. 2023. Site specific fertilizer recommendation in rice, wheat, and maize in Nepal. National Soil Science Research Center and National Seed and Fertilizer Project, CIMMYT, Khumalatar, Lalitpur, Nepal.
Ojha RB and D Panday (Eds). The soils of Nepal. 2021. Springer Nature, Berlin/Heidelberg, Germany: Springer International Publishing. https://doi.org/10.1007/978-3-030-80999-7
Ojha RB, S Shrestha, YG Khadka and D Panday. Potassium nutrient response in the rice-wheat cropping system in different agro-ecozones of Nepal. PloS one. 2021 Mar 18;**16**(3):e0248837.
Olsen S, C Cole, F Watanbe and L Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington DC: Government Printing Office.
Panday D, RB Ojha, D Chalise, S Das and B Twanabasu. 2019. Spatial variability of soil properties under different land use in the Dang district of Nepal. Cogent Food and Agriculture. Jan 1;**5**(1):1600460.
Piikki K, J Wetterlind, M Söderström and B Stenberg. 2021. Perspectives on validation in digital soil mapping of continuous attributes—A review. Soil Use and Management. **37**(1):7-21.
RStudio Team .2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.
Shrestha S and G Kafle. 2020. Variation of selected physicochemical and hydrological properties of soils in different tropical land use systems of Nepal. Applied and Environmental Soil Science. Sep 14; 2020:1-6.
Vincent S, B Lemercier, L Berthier and C Walter. 2018. Spatial disaggregation of complex Soil Map Units at the regional scale based on soil-landscape relationships. Geoderma. **311**: 130–142.
Walkley A and I Black. 1934. An examination of direct method for determining organic matter and the proposed modification of the chromic acid titration method. Soil Science Society of America Journal. **37**: 29-38.
Yang L, Y Jiao, S Fahmy, AX Zhu, S Hann, JE Burt and F Qi. 2011. Updating conventional soil maps through digital soil mapping. Soil Sci. Soc. Am. J. **75** (3): 1044–1053.
Yesilonis I, V Giorgio, Y Hu, R Pouyat, K Szlavecz. 2022. Changes in soil chemistry after 17 years in urban and rural Forest patches. Frontiers in Ecology and Evolution. Feb 21.**10**:786809.
Zeraatpisheh, M, S Ayoubi, CW Brungard and P Finke.2019. Disaggregating and updating a legacy soil map using DSMART, fuzzy c-means and k-means clustering algorithms in Central Iran. Geoderma. **340**: 249–258.