Assessing Soil Nutrient Dynamics and Their Impacts on Crop Yields: A Case Study of Janaki Rural Municipality, Banke, Nepal

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Abstract

This study represents .

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1 Introduction

Agriculture in Nepal is based on subsistence farming for the majority of the population and this can never be underestimated. The growth of Nepalese agriculture was low and very vulnerable in recent decades (Gyawali & Khanal, 2021). Despite the excellent production potential, farmers continue to face enormous challenges. Poverty, land degradation, low agricultural productivity, wrong use of budget and subsidies, shortage. The development of agriculture was hindered by the number of agricultural inputs, poor government support, etc. The challenge of maintaining food security was the simultaneous growth of the population on the one hand and the reduction of cultivated land on the other (Gyawali & Khanal, 2021). In Nepal's agriculture, coarse grains and pulses are crucial for food and nutritional security, the nitrogen economy, and job possibilities They serve a dual purpose in Nepal, playing a significant role in both trade and survival. Coarse grains and pulses are important components of the Nepalese diet, providing much-needed nutrients to the common people(Db et al., 2014). 1.1.2.2 Current Scenario: Out of Nepal's total land area of 147,181 square kilometers, cultivated agricultural land makes up 21% and uncultivated agriculture land makes 7% of total land use (MOALD, 2020). In the last few years, Nepal's agricultural growth has accelerated significantly. The remaining 75.9% of farmers do subsistence farming, while just 25.1% engage in commercial farming. Although grain, cash crop, and pulse output has greatly improved over the past few years, it still isn't enough to feed the growing population (Simkhada 2019). The majority of farms in Nepal (53%) are small-scale, with landholdings of no more than 0.5 hectares, while the remaining 20% are large-scale, with landholdings of more than 1 hectares. More than one-fourth (26%) of agricultural landowners in Nepal are women (FAQ 2020).

1.0.1 Agricultural Land Use

The land problem is one of the most common concerns of all nations. In Nepal, cultivation is still unplanned and uncontrolled and there has been a tremendous shift in land use from agriculture to other purposes where cultivation is more flourishing in the Terai region of Nepal. Demand for land-intensive crops is increasing in the rapidly developing South Asian region, including Nepal (Timilsina et al., 2019). A recent FRTC study (2019) showed that the cultivated land is 21.88 percent of the entire country. This shows the recent growth of cultivated area in Nepal. The average land holding per family in Nepal is less than 0.68 ha (CBS, 2013), which has gradually decreased over the last three decades. In addition, agricultural land is regularly fragmented for several reasons, especially in the Terai zone of Nepal (Shrestha, 2011). Land use for temporary and permanent crops grown show an opposite trend, with permanent crops increasing and temporary crops decreasing. The number of land parcels has significantly increased, supporting the fact about increased land fragmentation trend in Nepal. Today's growth in crop production in Nepal is due only to increased production area, however, the trend is to reduce agricultural land especially in the Terai due to urbanization and land fragmentation between 1989 and 2016 is a major obstacle to achieving food security in the country. So, the need is great increase the efficiency of land use to solve the problem of increasing food demand (Timilsina et al., 2019). 2.5 Fertilizers in Agriculture: More nutrients in the form of chemical fertilizers are needed to maximize high grain yields and meet the growing food demand of the majority of Nepal's population (Lamichhane et al., 2022). Chemical fertilizers are rich in nutrients; therefore, only a small amount is needed for productivity (Han et al 2016). A study carried by (Baral et al., 2020) in Nepalgunj, Banke found that different farm types, varietals, and irrigation systems have quite different fertilizer application procedures. Farmers utilized 55:39:15 kg N: P2O5:K2O ha-1 on average. The sources of these nutrients were urea, DAP, and MOP. Farmers' fertilizer usage was shown to be unbalanced overall. Amounts of N fertilizer used per hectare ranged from 0 kg to 138 kg. Compared to medium (57 kg ha-1) and small (41 kg ha-1) farmers, large farmers submitted applications at a greater rate (73 kg ha-1) (Baral et al., 2020). Although farmers have reported using more inorganic fertilizer over the previous five years, actual usage is still less than what the government advises. According to Takeshima et al. (2016), large farmers often use more nitrogen fertilizer than medium-sized and small-sized farms, perhaps because they have more financial resources and fewer organic inputs available. 2.8 Agricultural Land Use: Demand for land-intensive crops is increasing in the rapidly developing South Asian region, including Nepal (Timilsina et al., 2019). A recent FRTC study (2019) showed that the cultivated land is 21.88 percent of the entire country. This shows the recent growth of cultivated area in Nepal. The average land holding per family in Nepal is less than 0.68 ha (CBS, 2013), which has gradually decreased over the last three decades. In addition, agricultural land is regularly fragmented for several reasons, especially in the Terai zone of Nepal (Shrestha, 2011). Today's growth in crop production in Nepal is due only to increased production area, however, the trend is to reduce agricultural land especially in the Terai due to urbanization and land fragmentation between 1989 and 2016 is a major obstacle to achieving food security in the country. So, the need is great increase the efficiency of land use to solve the problem of increasing food demand (Timilsina et al., 2019). According to (Devkota et al., 2023) Nepalgunj had the highest coverage of agricultural areas; the proportion of agricultural areas in Nepalgunj was 95.38% (83.51 km2), 90.03% (78.82 km2) and 89.77% (78.6 km2) in the year 1990, 2000 and 2010 respectively.

This study focuses on understanding the impact of climate change on agriculture and food security in Janaki Rural Municipality, Banke, with a particular emphasis on nutrient dynamics, fertilizer use, and land-use changes. Climate change has disrupted soil nutrient availability and fertilizer efficiency, thereby affecting crop yields. Additionally, shifting land-use patterns, such as the conversion of agricultural lands for non-agricultural purposes, have further diminished the area available for cultivation. Analyzing the status of soil fertility and irrigation, along with changes in cultivated land over the past 20 years, is critical to addressing the challenges posed by climate change. By evaluating these factors and their relationship to food security, the study aims to provide insights that will guide sustainable agricultural practices and strategic planning to mitigate climate impacts on food production in the region.

1.1.5.2 Fertilizers/ Nutrient: More nutrients in the form of chemical fertilizers are needed to maximize high grain yields and meet the growing food demand of the majority of Nepal's population (Lamichhane et al., 2022).One of the most important inputs for agricultural output is fertilizer. According to APP, higher fertilizer usage accounts for nearly half of the incremental production and it has been determined that a key contributing factor in the poor production and productivity of agricultural commodities is farmers' inadequate access to seed and fertilizer (Pandey et al., 2017). Chemical fertilizers are used to correct plant nutrient deficiencies, providing large amounts of nutrients to help plants withstand stress, maintain optimal soil fertility, and improve crop quality. Because the nutrients in chemical fertilizers are already soluble in water, they promote the rapid development of plants and are effective quickly and effectively. Chemical fertilizers are rich in nutrients; therefore, only a small amount is needed for productivity (Han et al 2016). Chemical fertilizers have been found to increase yields for a few years, but are ineffective in the long term and contribute to soil degradation. Chemical fertilizers accelerate the decomposition of organic matter in the soil, which weakens the soil structure and reduces soil aggregation. As a result, nutrients are easily lost from the soil through fixation, leaching and gassing, reducing the effectiveness of fertilizers (Alimi et al 2007). Higher doses of chemical fertilizers not only reduce the microbial population (Gruhn et al 2000) but also causes an imbalance of soil nutrients, which can lead to soil acidity and reduced yields (Ojeniyi 2002).

2 Study area, Data and Methods

2.1 Study Area

The study was conducted in Janaki Rural Municipality, Banke, Nepal. The study area is located in the mid-western region of Nepal. The study area is situated between 28° 00' 00" N to 28° 15' 00" N latitude and 81° 45' 00" E to 82° 00' 00" E longitude. The study area is located at an altitude of 200 to 500 meters above sea level. The study area is characterized by a subtropical climate with a mean annual temperature of 25°C and a mean annual rainfall of 1500 mm. The study area is characterized by a monsoon climate with a wet season from June to September and a dry season from October to May. The study area is characterized by a hilly terrain with steep slopes and deep valleys. The study area is characterized by a dense forest cover with a variety of flora and fauna. The study area is characterized by a diverse population

3 Results and Discussion

4 Nutrient and Fertilizers

4.1 Nutrient

The analysis of soil properties based on Soil and Fertilizer data revealed that the majority of soil samples exhibited neutral pH levels (79.2%). Additionally, organic matter content was predominantly medium to high, with 83.3% falling within the medium range and 12.5% classified as high. Nitrogen levels varied, with a significant proportion (45.8%) in the medium range, conducive to healthy plant growth. Phosphorus levels were notably high, with 50% of samples classified as high and the remaining 50% as very high, suggesting adequate phosphorus availability for plant nutrition. Potash levels also demonstrated a diverse distribution, with the majority falling within the medium to high range. These results enhance our understanding of soil quality by highlighting subtle differences in important agricultural metrics that can guide targeted actions for optimal crop management (Table 1).

Table 1: Soil Properties and Their Interpretation

Variables	**Scale**	**Interpretation**	**Percent (%)**
pH	1–6.5	Acidic	20.8
	6.5–7.5	Neutral	79.2
	7.5–14	Basic	0
Organic Matter	<0.1	Very Low	0
	1.1–2.5	Low	4.2
	2.6–5	Medium	83.3
	5.1–10	High	12.5
	>11	Very High	0
Nitrogen	<0.05	Very Low	0
	0.051–0.10	Low	4.2
	0.11–0.20	Medium	45.8
	0.21–0.4	High	50
	>0.41	Very High	0
Phosphorus	<10	Very Low	0
	11–30	Low	0
	31–55	Medium	0
	56–110	High	50
	>110	Very High	50
Potash	0–55	Very Low	0
	56–110	Low	0
	111–280	Medium	41.7
	281–500	High	54.2
	>501	Very High	4.2

Descriptive statistics of soil nutrients (pH, Organic Matter, Nitrogen, Phosphorus, and Potash) are presented in Table 2, showing the Minimum, Maximum, Mean, and Standard Deviation of each nutrient. This table complements the findings of Table 1 by providing measures of central tendency and variability for each soil nutrient.

Table 2: Descriptive statistics of soil nutrients and total yield

Variable	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
pH	5.200	7.500	6.746	0.687
Organic Matter (%)	1.930	6.100	4.019	0.941
Nitrogen (%)	0.090	0.300	0.195	0.049
Phosphorus (ppm)	60.000	589.000	200.167	175.676
Potash (ppm)	116.000	608.000	277.667	94.304
Total Yield (kg/ha)	3000.00	19571.53	6372.066	3639.386

4.2 Nutrient and Production

Correlation analysis revealed significant correlations between pH, organic matter, nitrogen levels, and crop yield (Table 3). Negative correlations between pH, organic matter, nitrogen, and yield indicate that yield tends to decrease as these components increase. This inverse association may result from imbalances caused by excessive amounts or restrictions on nutrient availability. Notably, no significant association was found between yield and phosphorus and potash, indicating that these elements might not have a substantial impact on yield variability. Overall, managing pH, organic matter, and nitrogen levels in soil management techniques is crucial for increasing crop productivity and yield potential.

Table 3: Correlation between yield and soil nutrients

Variable	**pH**	**Organic Matter**	**Nitrogen**	**Phosphorus**	**Potash**
Yield (kg/ha)	-0.289*	-0.203*	-0.368*	-0.018	0.200
p-value	0.055	0.017	0.038	0.466	0.175

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

5 Model Summary for Nutrient and Crop Yield

Table **??** represents the model summary for nutrient and crop yield in the study area. With an R value of 0.822, the model summary indicated a significant positive correlation, showing a strong relationship between the independent and dependent variables. The R^2 value of 0.675 suggested that 67.5% of the variability in average yield was explained by these independent variables. After adjusting for the number of predictors, the independent variables accounted for approximately 58.5% of the variance in crop production. The model's significance level (p-value) of 0.001

suggested that at least one of the independent variables significantly affected crop output, implying a substantial and strong overall impact on crop productivity.

Table 4: Linear Regression Model Summary for Nutrients and Crop Yield

Dependent Variable	Yield
Adjusted R^2	0.585
Model	Linear Regression
R	0.822
Significance (p-value)	0.001
F-statistic	7.484
R^2	0.675
Predictors	Potash, Phosphorous, pH, Organic Matter, Nitrogen

5.1 Coefficient Table

Table 5: Coefficient Table for the Model

Model	Unstandardized Coefficient	Std. Error	Beta	t	Sig.
(Constant)	15263.881	5559.539	-	2.746	0.013
pH	-1451.159	719.515	-0.274	-2.017	0.059
Organic Matter	10554.882	2253.806	2.728	4.683	0.000
Nitrogen	-222409.190	42458.901	-3.021	-5.238	0.000
Phosphorous	-1.166	2.993	-0.056	-0.390	0.701
Potash	7.169	5.221	0.186	1.373	0.187

The high coefficients of organic matter and nitrogen showed their strong influence on the expected yield. Although phosphorus and potash are essential for plant growth, their smaller coefficients suggested a lower impact on yield. pH had a moderate impact by influencing nutrient availability.

The linear regression equation from the analysis explains the variability in crop yields based on soil nutrients:

$$\text{Yield} = 15263.881 - 1451.159(\text{pH}) + 10554.882(\text{Organic Matter}) - 222409.190(\text{Nitrogen}) - 1.166(\text{Phosp} \tag{1}$$

6 Fertilizers and Production

Farmers used fertilizers to enhance crop yield. The major inorganic fertilizers used were urea, di-ammonium phosphate, and potash (Annex 6.3). Descriptive statistics between average yield and fertilizer use showed that the mean average yield observed was 5612.85 kg/ha with a standard deviation of 2659.38 kg/ha. The average amount of fertilizer used was 102.5218 kg with a standard deviation of 48.47575 kg (Annex 6.4).

Table 6: Correlation Between Average Fertilizer Use and Crop Yield

Yield (kg/ha)	0.349**
Significance (p-value)	¡0.001

The model's combined predictive value was demonstrated by the significant F-statistic ($p < 0.001$), supporting the explanation of 11.5% of the variability in crop production by fertilizer use.

The regression equation for fertilizers and yield is given by:

$$\text{Yield} = 3648.185 + 19.163 \times (\text{Fertilizers}) \tag{2}$$

7 Land and Irrigation Details

Table **??** presents the landholding and irrigation characteristics of the study area. The majority (54.5%) of families held between 5-15 Katha of land, followed by marginal landholders (28.4%) with less than 5 Katha.

8 Land Use Change Analysis

Land use change analysis for Janaki Rural Municipality and Banke District was conducted using ICIMOD data. The results are presented in Table **??** and Figure **??**.

Table 7: Frequency Table for Land and Irrigation Data

Characteristics	Variables	Percentage
Total Land Holding	Small (¡5 Katha)	28.4
	Marginal (5-15 Katha)	54.5
	Large (¿15 Katha)	17.2
Land Type	Lowland	80.6
	Both	19.4
Land Adequacy	Yes	97.8
	No	2.2
Soil Type	Clay	100.0
Soil Fertility Rating	Good Quality	26.9
	Medium	67.9
	Not Good Quality	5.2

Table 8: Slope of Land Cover Change (2000-2019) in Banke District

Land Cover	Slope
Forest	264.8
Other Wooded Land	111.7
Grassland	-279.3
Cropland	-210.4
Built-up	92.3
Waterbody	15.6
Riverbed	5.4

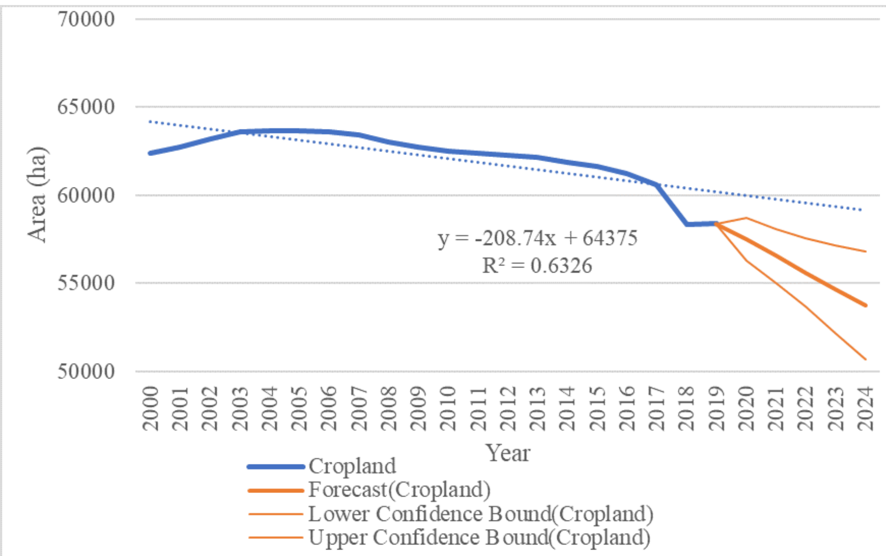

Figure 1: Land Use Change Trend in Banke District (2000-2019)

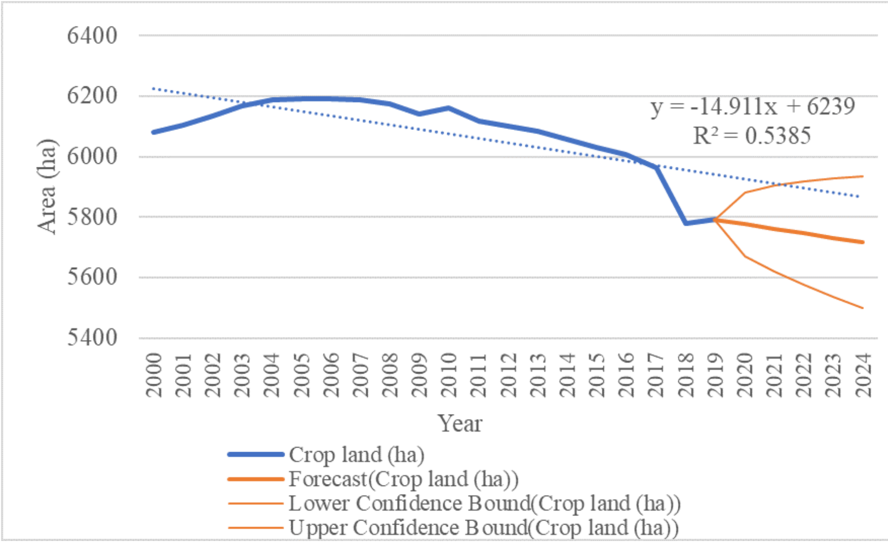

Figure 2: Land Use Change Trend in Janaki Rural Municipality (2000-2019)

9 Discussion

10 Summary

References

References

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