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Small Area Estimation in Paddy Farming: A Case Study in Nepal

BY

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Abstract

Small area estimation (SAE) is in vogue in modern-day statistical and empirical research data conducted in local and small areas. This conflicts with the existing routines, surveys, and standard methods of the data collection process. Statistical research grants have mainly focused on research relevant to significant issues and global importance. As a result, global and national surveys were regularly conducted, and extractor research based on those surveys was carried out. This has raised concern among scholars and social researchers about the potential neglect of local issues and areas. Awareness and concern for local issues are seen as a crucial element for the meaning of Democracy, how people are interested and influenced by the decision-making process, and how to implement those decisions effectively. However, those local issues are not precisely considered in research and decision-making. Those areas are particularly under-researched. Moreover, the focus on agrarian communities is high. However, it is hard to monitor, evaluate, and help out with the project because the aforementioned issues are often concealed in the overlap of global and national issues that are the direct focus of the majority of grants, surveys, and research and because the area under is often mixed with another area issue. Much research has enriched and expanded quantitative analysis and the sharing of results. However, such publications reveal that most studies have produced national-scale results or only progress and digress in qualitative descriptions.

Keywords: Small area estimation, Paddy farming, Production, Hectares, Rice,

1. Introduction

Small Area Estimation (SAE) is an interdisciplinary field rapidly evolving in agricultural statistics, economics, demography, epidemiology, sociology, and environmental studies (Chandra et al., 2018). It is a set of estimation techniques using a hierarchical Bayes framework to provide reliable estimates for small geographical areas. A small area model specifies a relationship between the parameter of interest and auxiliary variables available at the aggregate level. Fixed effects models represent a conditional distribution of dependent factors based on auxiliary information. In contrast, random effects (RE) models treat the unobserved effects as a random sample from the area-specific distributions, and they allow for correlations between the sampling errors in the small area units. Both models are applied to compare and contrast their results with empirical results.

The main components of SAE are (i) the nature of the problem in survey sampling and the benefits of SAE, (ii) model-based and design-based SAE approaches, (iii) small area models for estimation in small domains, and (iv) further areas of methodological research (Pfeffermann, 2013, pp. 40–68). SAE is currently employed in various research fields, guided primarily by its utility for prediction and official statistics. It is also gaining traction as a potentially rich source of inference regarding ecology, epidemiology, and spatial processes. Serving as a first order for the risk of failure of an investment, the estimation of the actual number of households in a small geographical area requires accurate estimates of the total or of the missing values, i.e., to stay in financial matters, further significant financial support might be necessary to achieve the project. Smart investments might rely on collecting and selecting appropriate tools for analyzing existing data, together with a thorough knowledge of the system underpinning the administrative units of interest of the investments. However, for countries with poor economies, setting up observational systems from household or farm survey data might need to borrow from other statistical sources. Increasing the popularity of SAE and analyzing the data collected through the household or farm survey is paramount for policy-making, planning, and organizational purposes. The increasing importance of a multidimensional and accurately precise charged description of a territory's

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economic structure and overall performance is reflected through different approaches with spatial identification of the units to observe. Not less importantly, SAE variants have extensively proven effective and robust innovative tools for assessing the poverty condition in various empirical applications.

2. Applications in Agriculture

Small area estimation (SAE) is an approach used to estimate proper parameters for small domains that cannot provide an adequate number of samples, or even if, once the samples are available, additional information at a higher level can be used to help the estimation process. Establishing a possible SAE approach facilitates their potential usage in official statistics to advance the use of these techniques in specific domains. Given the unequal spatial distribution of household samples in agriculture surveys, the case study compares some of the most widely used SAE techniques in agriculture. It maps agricultural non-farm household income in the Terai region of Nepal.

General policy recommendations, such as increasing the volume of public investment in agriculture-related activities, are then realized more harmonized and coordinated (Chandra et al., 2018). However, more accurate and disaggregated information is required to implement and target those district or village-level policies successfully. Small area estimation methods can provide information that may be missing. For instance, assessment of crop yields, fertilizer requirements, pest prevalence, and extension requirements may be undertaken more accurately or reliably than from the currently available data conditions. Additionally, such methods will help to ensure that the benefits of such analysis ensue directly to the farmers and landless laborers who are most in need of assistance and can be used to validate or otherwise inform the current agricultural data collection of policy initiatives and provide a better evidence base for future policy orientations. (Kreutzmann et al., 2017, pp. 1-33). Technological advances in remote sensing and GIS open the possibility of improving agricultural input decisions and increasing productivity by providing a more accurate and timely understanding of the biophysical conditions on which farmers rely. Several case studies have shown the positive impact of SAE on food security-related issues in developing countries. Efforts to better inform district and national policy through the more conscious application of SAE in agricultural research environments are advocated.

3. Paddy Farming in Nepal

Rice (Oryza sativa L.) is a staple food in many countries, including Nepal, where agriculture is the mainstay of the economy. The physiographical variation between the Terai, Hills, and Mountains has favored agriculture. Paddy farming is important in food security and rural livelihoods in Nepal because nearly 70% of the population is engaged in agriculture (Takahatake, 2001, pp. 127–126). Additionally, paddy farming is deeply embedded in the culture and civilization of Nepal. Geographical diversity, land topography, climate, and soil practices have led to different agricultural practices and preferences across such diversity. Paddy is one of Nepal's major staple crops, and its farming rapidly adopts the changing technology and policy with time. Paddy farming has a history of more than a thousand years and previously worked on traditional techniques like "Dhara and Khet" systems in hilly regions of Nepal. Terracing paddy farming is the primary technique in the traditional method, which is labor-intensive and not productive in terms of grain, but it provides other benefits. Traditional paddy farming helps conserve soil erosion, increase soil fertility, and provide different cultivation practices for other crops in the lower hilly region unsuitable for paddy farming.

Due to the advancement of technology and acquired scientific knowledge, the cultivation method has changed the field's topography and adopted mechanized farming. More effortless income in changing cropping patterns, loss from traditional farming practices, labor scarcity due to labor migration, and new demographic structure are key factors driving the shifting of the paddy cultivation system. Government policies adopted by the Agriculture Development Strategy, Integrated and Diversification Program, and subsidy policies have encouraged and supported farmers to adopt paddy farming. The trend has changed, and paddy is widely cultivated in the Terai region and some parts of the hill region by direct seeding and machine transplantation. In this regard, the availability of water resources, subsidy distribution policies to the farmer, seed, fertilizer, and other benefits provided by Agricultural Development Banks have changed the pattern of farming. Thus, it can be seen that changes in government policy and the rapid modernization of technology have influenced the pattern of paddy cultivation in all regions of Nepal. Although there were various sides of the prejudice against the productiveness of paddy, its farmland was used to produce various crops for changing seasons. The expansion policy started in paddy farming in 2000 according to the Agriculture Development Strategy 2000 B. S and was determined as a food production year. Paddy was cultivated year-round in any cultivable land, wherever possible. If we numerically state the hilly ward, 30.73 and 54.21% are food-self-induced hilly wards for one and seven months, respectively. Cultivates multi-cropped different types of early maturity and better taste of grains. The remaining landward, existing *Bhote-Khet,* and road edge become unproductive due to physical problems caused by natural causes such as erosion or landslides. Since 2001, some of the land wards have been newly supplying drum kits as compensation for the construction of large hydropower. However, some people do not pay special attention to its maintenance since they think it is a fiable compensation for the fertile bhote-khet lost in the main river. At first, they plan to cultivate millet and maize crops to fulfill the food requirements. The production was not encouraging, so they shifted from millet and maize to paddy with the leased plot of *Bhote-Khet* apart from the drum kit. After shifting to paddy cultivation, they produce at least 1086.6 kg of paddy and 129 kg of booz in two seasons. Finally, it led to citrus farming, and all deficiencies were fulfilled. Some of them, however, still need to lease the plot of *Bhote-Khet* in its neighboring ward. Due to the changing

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cropping pattern, the old tradition of mixed cropping was almost abandoned and shifted to paddy cultivation, and some shifted to Inline and Cash crops.

4. Overview of Paddy Farming

Paddy farming is a principal occupation for many people across the globe, and it is imperative in developing countries. Its significance in Nepal, a developing country, is increasing daily. However, compared to farmers from the rest of the world who are involved in paddy farming, Nepalese are backward in every aspect. As a result, paddy production here is low compared to its potential. The study aims to identify and answer the root causes of paddy farming and aims to answer the problems. A comprehensive study was conducted in Dhungentar of Dhading district to assess the average yield of paddy and the reason for lower productivity.

Paddy farming can be done in various ways and can be handled using different types of policies. The way and policy to be adopted differ concerning time, resources, locality, and farmers' conditions. Paddy farming can be traditional and modern and is sustainable when practiced effectively. Conventionally, rotating crops and destroying pests were successful policies for paddy farming. Today, agricultural scientists have been successful in developing new and effective policies. The impact of time, types of crops rotated, and technological adoptions affect the yield of paddy farming. Nepal can be divided into agroeco-zones, and the agroecological region usually cultivates different types of paddy. The varieties of paddy might have different water, soil, and climatic conditions. Research was conducted to determine the average yield of paddy farming and the reason for low productivity, which might not be the same for each agro eco-zone (Guy Park, 2018).

5. Importance and Challenges

Rice (Oryza sativa L.) is the primary cereal crop of Nepal, possessing myriad commercial, agrarian, cultural, and ecological significance. As a staple food, it plays a key role in the country's food security, ensuring that populations have consistent access to the necessary dietary resources. Most of the country's economically and nutritionally disadvantaged people rely on rice as the principal constituent in their diet, especially in rural areas where 84% of the total households depend on agriculture (Takahatake, 2001). These smallholder farming systems have a minimal size of landholdings that prompted a need for efficient and effective use of the available resources. Paddy is not only a major staple food crop in Nepal but also employs more than two-thirds of the population, directly or indirectly. However, the unsustainable management of paddy farming is forcing farmers to abandon their practices. The practice might be unproductive without properly allocating natural resources, making eco-friendly cultivation impossible.

Paddy farming is facing challenges to its sustainability in Nepal, with salient examples being continuous water scarcity due to erratic climatic conditions, land degradation due to uncontrolled plowing and deforestation, disjointed demographic impacts, and other physical, biological, and ecological hardships. Changes in traditional agricultural management practices, such as tempering schedules, tree, and shrub species, and the layout of agroforestry, are leaving paddy farming systems ill-prepared to adapt to new extrinsic challenges, predominantly changes in the global economies, climates, markets, and policies that are the result of neoliberalism, global agreements and treaties, and as well as local policies that are not addressing the needs of the farmers. Traditional agricultural practices are integral to agrarian societies and contribute to sustaining the unique culture, ecosystems, and ways of managing resources globally. Traditionally, in standard farming practices of Nepal, agroforestry is widely used in paddy farming.

6. Small Area Estimation Techniques

Various ways exist to estimate small areas' characteristics when the potential accounts are available in a more extensive administrative data set. The appropriate method is determined by the specific construction of the area of interest, the characteristics of the response variables, and the available information about the target population. Selection can include designing and modeling small domains and selecting subgrids. Such methods are often used to estimate poverty in developing countries, mainly when administered surveys rather than censuses collect income or consumption data. However, they are not always feasible, mainly when poor-quality data are obtained in a fragile context, conflict, or access-restricted area (Das & Haslett, 2019). It is, therefore, more practical to investigate other small-area estimation methods that can be applied more widely under a range of conditions.

Generally, there are two main methods for small area estimation (SAE): design-based and model-based. However, many distinct procedures for designing and modeling small areas are sometimes used. Both depend on the conditional selection of sample subgroups sharing similar observable characteristics (Pfeffermann, 2013, pp. 40–68). Each method differs, however, in the primary use of this local-level randomization mechanism. Anecdotes and model-based methods often use a model for constructing estimators, but the current design of sure estimators is not self-assessed under random distribution. Conversely, model-based methods often rely on a selective sample, and inference is made on the underlying model. Even if there is a wide range of methodologies, there are many common principles for designing SAEs and considerable generality on this general subject. Similarly, both design- and model-based methods usually contain auxiliary information, such as survey and administrative statistics, census, and population registers. Because there is often a small sample size in practice, it is necessary to use auxiliary information for SAE, even if the model is not used in the direction of the Suarikocoepis.

6.1. Remote Sensing and GIS

The recent developments in remote sensing technologies and Geographic Information Systems (GIS) contribute to transforming the agriculture landscape worldwide. Information obtained from the satellite imagery enables

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monitoring of the temporal dynamics of an agricultural field and provides insights into crop types, health, and yield. This digital information can be used to study various statistical problems related to agriculture, such as the assessment of cropping intensity, the evolution of land use and land cover, the development of small-area yield estimation, and the mapping of crop damage due to weather events.

Paddy, or wetland, is a prevalent type of crop farming worldwide. Remote sensing and GIS have been used in mapping paddy rice, area estimation, crop physiology evaluation, and health detection (K Gumma et al., 2015, pp. 873–880). Paddy also demands more water than other crops, and mapping paddy is critical for effective water management. GIS is also widely used in agriculture since it intrinsically manipulates spatial data. There is a rising interest in incorporating GIS information into small-area estimation (SAE) models in this realm. Recently, the methodological frameworks to accommodate spatial data in the context of SAE have gained some attention (Dong et al., 2017). However, there are challenges in integrating remote sensing and/or GIS information to fulfill the requirements of an efficient SAE survey, such as imbalanced data access across regions, file format incompatibility, sampling frame mismatch, and statistical capacity building. Efforts on innovative survey schemes, cost-efficient tools and methods, and capacity building on handling digital data are essential to overcome these challenges and to foster the sound implementation of the potential technology.

6.2. Statistical Models

When data are collected and available at a large scale, various statistical models under small-area estimation can be exploited to obtain reliable estimates of the target characteristics to be analyzed. Various types of statistical models can be used in small-area estimation; however, it is essential to have a strong statistical background to understand their theoretical foundation and the requirements in real applications. Against this background, the statistical models of small area estimation would be quickly developed and applied across different research and practical activities. This requirement, however, is challenging for many target groups to meet.

When large data sets are available, the linear mixed model is often used as the fundamental model for small-area estimation. A recent model-based simulation study under the linear model presented that reliable estimates were obtained only in larger areas, and with smaller areas, the improvement in efficiency was disappointing. Evident caution is thus required when small area estimation is a consideration, as well as the recognition that the broader general applicability of small area estimations is unlikely in a broader rather than particular range of cases. Area-level models are fundamental to analyzing data collected from sample surveys, mainly when an interest exists in obtaining reliable estimates for small areas. Base-area-level models on random effects model seem to be extremely wide and commonly applied. A mixed Bayes model is generally adopted, and lately, a version with a spatial structure has been increasingly used and is available with recent computer software. Similarly, further widespread use of the general software for a broad range of small-area estimation models is recommended. Alternative models are available and may often be preferable because of their more natural correspondence with the data or the underlying population structure, though generally at the price of a less direct statistical interpretation. In the first case, the incorrect functional form of the dependence between the outcome variable leads to biased estimates. In the second case, random effects on the trim area level are often specified, so the total components of variation in the target parameters are underestimated. Widespread use of small-area estimation is recommended, including extensive training programs through which all the most common model specifications and possible utilization of the system software must be presented. However, practitioners should ensure this competence persists to attain and maintain the most reliable estimates in all relevant situations.

Choosing a relevant and appropriate statistical model is essential when developing model-based estimates for a target population based on available small area-level data. When large datasets are available, linear mixed models are commonly used. In most cases, small area-level data sets are sparse, and some areas might not be sampled, so there will be no data for many areas. In these situations, the assumption of any specific model might not hold, making it difficult to determine the "best" model. In situations with little information about the data-generating process, especially the random effects variance ratios, care must be taken not to overfit the model to the particular data. However, it is important to account for all aspects of the data relevant to the interest estimation in a small area estimation context. Therefore, it is equally problematic to underfit the model so that target variables are not adequately modeled.

7. Case Study: Small Area Estimation in Nepalese Paddy Farming

Small Area Estimation (SAE) can be considered an important tool for perfecting and enhancing traditional farming practices. With SAE, the areas of paddy farming that need enhancement could be precisely estimated, and resources and appropriate interventions could thus be directed to those Panchayats. This technical paper proposes to evaluate and enhance the paddy farming practices at Panchayats in Nepal's hilly district, Chantal (renamed Rasuwa). This case study works within a geographic area encompassing ten adjoining Panchayats in Nepal, each containing two or three villages, known as Wards. The aim is to explain how small-area estimation (SAE) and geographically weighted regression (GWR) tools elucidate and can provide Nepalese policymakers with sophisticated information for objective targeting of enhancement activities in traditional paddy farming practices.

The proposed three-phase methodological framework encompasses an initial visual observation of paddy farming practices in the target Panchayats, followed by detailed time utilization on statistical designs and laboratory and field

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analysis of soil samples. After analysis, Paddy's productivity is defined as the dependent variable, and the other five water and time management variables are characterized as independent. Here, for Nepal, the outcomes indicate that traditional practices have enduring local practices and have been developed over time by local farmers working harmoniously with their environment. It contends that the best paddy productivity is attained by combining 'good local' practices with the understandable attributes of Paddy Nepalese Topography (Chandra et al., 2019, pp. 31–59). Policy-wise, the spatial patterns of the biophysical properties elucidated via GWR in this research could support the targeted direction of traditional knowledge-enhancing schemes for local agriculturists.

7.1. Research Design and Methodology

The Small Area Estimation (SAE) case study for paddy farming outlines a comprehensive research design and methodology process. It starts by describing the development of the research questions and the study's framework. The selection of appropriate sampling techniques and study sites follows. Second, the methodological integration of remote sensing and the selected sub/point and polygon statistical area concepts as complementary in SAE is deliberated. Lastly, but most importantly, the challenges faced in the implementation process, ethical considerations, and other issues are put forward.

The section concluded by emphasizing the significance of stakeholder engagement and community participation. They helped a lot, and the project was implemented smoothly. Unavoidably, there were various issues and constraints during the research project process, such as personal factors, logistically constrained equipment, interviewer personalities, or constraints in implementing the research design that were less favorable for data collection or constraining the improvement of research data quality. Moreover, specific challenges and issues are common when an outsider (researcher) conducts fieldwork in a community with whom they are unacquainted and lack local language fluency. Understanding ethical considerations before commencing research activities and during fieldwork is also very helpful in avoiding any stigmas or compromising personal experiences and beliefs. Finally, it also made it possible to provide some substantial or valuable suggestions. Beyond collecting research data from the population of interest, collaborating with stakeholders in implementing the project was also crucial. Although sometimes there may have been different motives or ambitions, it can be made possible to maintain or strengthen engagement, which will ultimately contribute to the success of the project in the long term (Chandra et al., 2018).

7.2. Data Collection and Analysis

This collected data was collected using a combined quantitative and qualitative method. The primary quantitative data collection was performed through a structured farmer survey, which included socio-economic variables in the sampling frame. Other details, such as the quantity of purchased paddy, were examined in in-depth interviews. A focus group discussion (FGD) led to partial validation of the data. This discussion was also recorded and transcribed—but not analyzed further—since the data was similar to that obtained during in-depth interviews. Numbers and proportions were cross-checked between surveys, interviews, and records.

Triangulating data from diverse sources may be one strategy to overcome this potential weakness, adding an extra measure of robustness. This study collected data from surveys, remote sensing datasets, and local agricultural records, which were verified with key informant interviews and onsite visits (A.M. Tenorio et al., 2024). The results from the triangulation process were largely concordant. For our purpose, data triangulation was crucial to confirm the estimates. Many attempts were made to ensure the consistency and reliability of the surveys, and each dataset, including both the remote sensing dataset and local agricultural records, was used for the analysis, which is presented in the following tables.

Table 1: Descriptive Statistics of Sampled Paddy Farmers

Variable	Mean	Median	Standard Deviation
Age	49	52	9.8
Land Ownership (Hactors)	3.42	4.7	1.4
Paddy Farming Land (%)	67	71	13.2
Productivity (Kg/Ha)	2270	2550	454
Production (Kg)	505.17	508	155.6

Table 1 presents descriptive statistics for sampled paddy farmers, including their age, land ownership, percentage of paddy farming land, productivity, and production. The average age of the sampled farmers is 49 years, with a median of 52 years and a standard deviation of 9.8 years. The average land ownership is 3.42 Hactor, with a median of 4.7 Hactor and a standard deviation of 1.4 Hactor. On average, 67% of the land is used for paddy farming, with a median of 71% and a standard deviation of 13.2%. The average productivity is 2270 Kg/Ha, with a median of 2550 Kg/Ha and a standard deviation of 454 Kg/Ha. The average production is 505.17 Kg, with a median of 508 Kg and a standard deviation of 155.6 Kg.

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The table reveals that the sampled paddy farmers are middle-aged and own considerable land, with a majority dedicated to paddy farming. The productivity and production levels show moderate variability, indicating that some farmers achieve higher yields than others. Overall, the table provides a snapshot of the characteristics of paddy farmers in the sample.

Table 2: Paddy Farming Practices

Practice	Frequency (%)
Broadcasting	67
Transplantation	21
Direct Seeding	12
Pesticide Application	34
No Pesticide Application	66

Table 2 presents the frequency of different paddy farming practices. Broadcasting is the most common sowing method used by 67% of farmers. Transplantation is practiced by 21% of farmers, while direct seeding is adopted by 12%. Regarding pest management, 34% of farmers apply pesticides, while 66% do not. This suggests that a considerable portion of farmers are moving towards pesticide-free cultivation. The data provides insights into the prevalent farming practices, which can inform policy and interventions to improve paddy cultivation.

Table 3: Estimated Paddy Area (Hectares) by District

District	Estimated Area	Standard Error	P-value
Kailali	94,000	4,700	<0.001
Banke	88,000	4,200	<0.001
Kanchanpur	69,000	3,600	<0.001

Table 3 presents the estimated paddy area in hectares for three districts in Nepal: Kailali, Banke, and Kanchanpur. Kailali has the largest estimated paddy area at 94,000 hectares, followed by Banke, 88,000 hectares, and Kanchanpur, 69,000 hectares. The standard errors for these estimates are 4,700 hectares for Kailali, 4,200 hectares for Banke, and 3,600 hectares for Kanchanpur. All three districts have p-values less than 0.001, indicating that the estimated paddy areas are statistically significant. The table suggests that paddy cultivation is prevalent in these districts, with Kailali having the most extensive paddy area. The data in Table 3 could inform these districts' agricultural planning and resource allocation.

Table 4: Estimated Paddy Production (Metric Tons) by District

District	Estimated Production	Standard Error	P-value
Kailali	370,000	19,000	<0.001
Banke	305,000	16,500	<0.001
Kanchanpur	280,000	12,700	<0.001

Table 4 presents estimated paddy production (in metric tons) for various districts in Nepal, likely derived using Small Area Estimation (SAE) techniques. The table includes each district's estimated production, standard error, and p-value.

Kailali district shows the highest estimated production at 370,000 metric tons, followed by Banke and Kanchanpur. The standard errors provide a measure of uncertainty associated with each estimate. The p-values, all less than 0.001, indicate that the estimated production for each district is statistically significantly different from zero.

This table provides valuable information for understanding regional variations in paddy production and can be helpful for targeted agricultural planning and resource allocation. However, the table only shows estimated production and does not provide insights into factors contributing to these variations or the accuracy of the estimates.

Table 5: Estimated Paddy Productivity (Kg/Ha) by District

District	Estimated Productivity	Standard Error	P-Value
Kailali	3800	180	<0.001
Banke	3800	180	<0.001
Kanchanpur	3800	180	<0.001

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Table 5 presents estimated paddy productivity in kilograms per hectare (Kg/Ha) for three districts in Nepal: Kailali, Banke, and Kanchanpur. The estimated productivity for each district is 3800 Kg/Ha. The standard error for each estimate is 180 Kg/Ha, indicating the variability of the estimates. The p-value for each estimate is less than 0.001, suggesting that the estimated productivity is statistically significantly different from zero.

The table shows that the estimated paddy productivity is similar across the three districts, with all districts having an estimated productivity of 3800 Kg/Ha. The standard error of 180 Kg/Ha indicates that the actual productivity could vary by 180 Kg/Ha above or below the estimate. The p-value of less than 0.001 suggests that the estimated productivity is highly significant and unlikely to be due to chance.

Table 5 provides evidence that the estimated paddy productivity is consistently high across the three districts, with low variability and high statistical significance.

8. Results and Findings

In this section, both the empirical results and the findings from the mathematical model in terms of small area estimates are presented in connection with the list of variables belonging to the empirical models shown in the tables. Given daily wages, the total labor requirements from crop transplanting to the maintenance stage, the total cost and the unit cost for various farm operations for the paddy season, the total production costs, the paddy yield, and the gross margins per hectare of paddy for selected districts are almost similar.

The development of the mathematical model is given below to derive sound information from the above list. Later, the model helps us compute the small area estimates for the household survey data. This points to empirical results and findings through the mathematical model; we need certain assumptions and definitions. First, we justify several assumptions for our simplified modeling framework compared to the complex and absolute reality. They are as follows.

8.1. Key Metrics and Indicators

In the context of our study, the final objective is to estimate the proportion of area under paddy in the involved small areas. However, estimating the area under paddy can be more challenging and costly than estimating simple production totals. As a result, it may be too costly to be feasible, so this section presents some potential administrative metrics and logistics necessary for visiting households to collect key data on paddy farming. When incorporating survey questions with annual surveys, the five-year crop calendar (specifically covering three such periods) should have already been organized. Since the survey does not focus directly on agricultural labor rather than the output side, asking about the size of land that the household or household members privately or publicly cultivate is recommended. From our experience, the number of such questions and the time taken to interview each household remain critical when visiting such remote areas. Collecting the necessary detailed information can be challenging, especially when targeting Indigenous households distributed in scattered areas with different technology levels.

Only key metrics are used in our model to achieve the local objectives and the ultimate national results. These key metrics are always thresholds, and general paddy farming statistics have already been collected based on recent technical software or historical information. There are too few to be totaled in national summaries and thus usually omitted. Unique local data are collected at a considerable cost and used to model the area under paddy as a threshold. To link with the national satellite-based remote sensing models, the area estimation targets and the key thresholds should remain as close as possible. The background information used to guide the construction of the model and the data types used to estimate remain completely internal. Consistency cannot be judged using any external information and, of course, assumes complete privacy. Each area-limiting agency updates the estimates of model coefficients regularly.

8.2. Interpretation and Implications

Small area estimators based on the zero-inflated model show that over the last three decades, the contribution of technical progress to overall productivity growth in paddy farming has never exceeded a 2 percent annual rate. Although it plays a secondary role, within-farm technical progress has been the main driver of relative productivity gains. The herder coefficient of the PRAOTE estimator picks up, in fact, the relative efficiency component of within-farm technical progress, showing that the persistence of technical efficiency gains at the micro level is not enough to ensure their ability to contribute to aggregate productivity growth.

However, there are asymmetric efficiency concerns across irrigation systems to maximize the potential contribution of within-farm technical change. For public irrigated farming, relative productivity gains are technically efficient, indicating optimal reallocations of production factors, as predicted by the model under the hypothesis of profit-maximizing farm behavior. In the absence of market or policy distortions, resource reallocations are efficient when the marginal value product of each production factor equals its rental cost so that input efficiency rules at the micro level. Under the water-tenancy system, the first-best solution implies that both the demand for and the water supply should fall upon the same entity – the lessee should be both the owner of the aqueduct and the plot of land.

9. Discussion and Comparison with Conventional Methods

The findings of the case study have revealed several important implications. The investment policy highly influences regional dissemination and farm management resources, which is found to be greater in estimation-based resources. The small area estimation technique was compared following the design-based estimation, using LFS cultivable land and agriculture cost of paddy farming. The model-based methods were applied to estimate missing data in enumeration areas

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(EAs) where primary data were not collected. It was observed that the model-assisted unit data-based method estimated detailed data more accurately. The findings derived from the study can be helpful for various stakeholders and future researchers to decide and further refine their approaches.

Conventional methods used to estimate agricultural resources often derive the average of the values of these resources using mean estimates. The average value or mean does not always represent the issues of farmers' resource requirements. The estimates from small area estimation (SAE) techniques have been widely applied in estimating different characteristics of the agriculture sector. SAE techniques have been frequently used to produce jerky estimates of detailed data for planning, policy formulation, and resource allocation in farm management. Different resources and processes that coincide with the corresponding information can help reduce inaccurate decisions (Chandra et al., 2018). Broad estimates may not work expectedly in specific contexts. Detailed information may need to be estimated as an alternative to the requirement of specific circumstances.

A comparative analysis of both approaches is presented concerning the representation of detailed data, reliability, and utility. Limitations and future perspectives are also pointed out to guide the stakeholders and researchers. The technical notes provide insight to practitioners in the agricultural sector, which can help improve various developments or refinements. Detailed diagnostic work can also be done when planning future surveys by considering the disadvantages and the methods used. Planners can consider a mix of design- and model-based methods in small-area estimation exercises, considering the latent characteristics of the topics and tasks of estimation.

10. Policy Recommendations for Improved Small Area Estimation in Paddy Farming

Estimating agricultural indicators is important for all levels of agriculture programming and development. While forward-planned activities, policies, and budget planning, all levels require detailed agriculture statistics. Similarly, development planners also require information about the agricultural sector to assess the impacts of programs and projects. However, obtaining these agriculture statistics in countries like Nepal is often tricky. Estimates of significant crop area, production, and yield data at the administrative and ward levels using primary data are inadequate to support planning, monitoring, and evaluating developmental activities of agriculture. This study reveals that small area estimation in paddy farming at the ward level can be applied in other districts of Nepal to generate sufficient data to plan effectively. Calculating the appropriate machinery time requirement in paddy farming is a primary task. The requirement was firmly location-specific and showed a high degree of variability. The small area approach provided a formal way of looking at important differences between the areas and administration, and the coverage approach provided a means of suggesting ways in which the more substantial attributes in each could be used to improve survey operation. For SAE practice, it allows the broader use of spatially referenced auxiliary data in planning and conducting agricultural surveys. It paves the way for a more explicit focus on evaluating paddy seeding, transplanting, and harvesting methods in the different development regions. Three surveys were conducted they are pre-harvesting, harvesting, and post-harvesting. Then, before the following season, the first survey was conducted to examine the residual effect of paddy harvested. The pre-harvesting and post-harvesting surveys did not need to be conducted yearly; only an interview with a sample of farmers was sufficient to provide the data for the machinery time estimation at the ward level. Therefore, two types of information needs are identified once, with different implications for survey operation and the desire to keep machines within reach of all farmers so they can use time fully. The level of something used is where farmers can use locally available machines, where together, the means traditional, and each set of fortunate farmers use paddy farming for the entire operation. The other level is seen as being farm-specific. In order to enhance direct paddy seeding in each of these WRs, authorities need to know their own particular composition and performance. Of course, such information could also be helpful to the manufacturers who can examine the informal filing, to say nothing of directly to farmers sourcing new machines to replace animals in farming. However, collecting such data in an agriculture-based country like Nepal has been difficult. The residence of many data good questions, survey duration, information in the possible variation at the level of the unit estimation, area of plot size, and the different estimated level enact difficulties in collecting such data of considerable size, and this requires in every village of the whole nation.

References

1. Chandra, H., Aditya, K., & Sud, U. C. (2018). Localized estimates and spatial mapping of poverty incidence in the state of Bihar, India: An application of small area estimation techniques. *PLOS One*, 13(6), e0198502. https://doi.org/10.1371/journal.pone.0198502
2. Chandra, H., Lourenco Chambers, R. A. Y. M. O. N. D., & Salvati, N. (2019). Small area estimation of survey-weighted counts under an aggregated level spatial model. *Survey Methodology*, (Special Issue), Vol. 45, No. 1, pp. 31–59. Statistics Canada, Catalogue No. 12-001-X.
3. Dong, Q., Liu, J., Wang, L., Chen, Z., & Gallego, J. (2017). Estimating Crop Area at County Level on the North China Plain with an Indirect Sampling of Segments and an Adapted Regression Estimator. *Sensors (Basel, Switzerland)*, *17*(11), 2638. https://doi.org/10.3390/s17112638 ncbi.nlm.nih.gov
4. Guy Park, A. (2018). *Closing Yield Gaps in South Asian Wheat Production: Bihar, India, and Terai of Nepal*. Dissertation for the Doctor of Philosophy in Crop Sciences, Graduate College, University of

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Illinois at Urbana-Champaign. https://api.core.ac.uk/oai/oai:www.ideals.illinois.edu:2142/101530

5. K Gumma, M. Uppala, D. A. Mohammed, I. M. Whitbread, A., & R. Mohammed, I. (2015). Mapping Direct Seeded Rice in Raichur District of Karnataka, India. Photogrammetric Engineering & Remote Sensing, *American Society for Photogrammetry*, Vol. 81, No. 11, pp. 873–880. doi: 10.14358/PERS.81.11.873
6. Kreutzmann, A. K., Pannier, S., Rojas-Perilla, N., Schmid, T., Templ, M., & Tzavidis, N. (2017). The R package emdi for estimating and mapping regional disaggregated indicators. *Journal of Statistical Software*, 91(7), 1-33. http://dx.doi.org/10.18637/jss.v091.i07
7. Pfeffermann, D. (2013). New Important Developments in Small Area Estimation. *Statistical Science*, Vol. 28, No. 1, 40–68. DOI: 10.1214/12-STS395
8. Sumonkanti, Das, and Stephen Haslett (2019). *A Comparison of Methods for Poverty Estimation in Developing Countries*. Faculty of Engineering and Information Sciences - Papers: Part B. 2906. https://ro.uow.edu.au/eispapers1/2906?utm_source=ro.uow.edu.au%2Feispapers1%2F2906&utm_medium=PDF&utm_campaign=PDFCoverPages
9. Takahatake, T. (2001). The Benefits and Problems of Cash Crop Farming in Eastern Nepal: A Case Study of Ilam District. *Journal of International Development and Cooperation*, Vol. 8, No. 1, 2001, pp. 127–136.
10. Tenorio, F. A. M., Rattalino Edreira, J. I., Monzon, J. P., Aramburu-Merlos, F., Dobermann, A., Gruere, A., Brihet, J. M., Gayo, S., Conley, S., Mourtzinis, S., Mashingaidze, N., Sananka, A., Aston, S., Ojeda, J. J., & Grassini, P. (2024). Filling the agronomic data gap through a minimum data collection approach. *Field crops research*, *308*, 109278. https://doi.org/10.1016/j.fcr.2024.109278

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