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EDITED BY
Francisco Areal,
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Wataru Kodama,
Asian Development Bank Institute (ADBI), Japan

*CORRESPONDENCE
Krishna D. Joshi
k.d.joshi@irri.org

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# Methods for assessing the adoption of rice varieties and land use changes in Chitwan, Nepal, using global positioning system transects and focus-group discussions

Krishna D. Joshi[1]*, Nabraj Khanal[1], Krishna B. Rawal[2], Santosh Upadhyay[3], Krishna P. Devkota[4], Govind R. Joshi[5] and John R. Witcombe[6]

[1]Rice Breeding Innovation Department, International Rice Research Institute, Los Baños, Philippines, [2]Karnali Integrated Rural Development and Research Centre, Lalitpur, Nepal, Previously SUPPORT Foundation, Mahendranagar, Nepal, [3]Faculty of Agriculture, Sudur Paschim Vishwavidyalaya, Mahendranagar, Nepal, Previously IRRI Nepal Office, [4]International Centre for Agricultural Research in Dry Areas, Rabat, Morocco, Previously Local Initiatives for Biodiversity, Research and Development, Nepal, [5]Department of Agriculture, Prime Minister Agriculture Modernization Project, Dhangadhi, Nepal, [6]College of Natural Sciences, Bangor University, Bangor, United Kingdom

Rice varietal adoption was assessed using randomly selected global positioning system (GPS) coordinates in Chitwan district, Nepal. At pre-determined sampling points along the transects, which researchers located using GPS, data were collected on land use and the name of any rice variety grown. These data were then triangulated through focus group discussions (FGD) for each transect. The first two surveys were done in 2005 and 2006 in 14 transects with 440 GPS coordinates representing the major rice-growing areas of Chitwan. Using the same approach, a third survey was conducted in 2022 in 72 out of the 440 GPS coordinates to document rice varietal adoption dynamics over a 16-year period. Farmers had changed the rice varieties they grew, but they continued to grow two to three old-improved varieties that covered more than 40% of the land. Hence, despite large changes in the rice varieties grown, the weighted average age of the varieties over 16 years was not reduced significantly. Despite their lower yields compared with newly released varieties, the older popular varieties persisted as they were in demand by the rice millers, who have little motive to replace rice varieties for which they have an established market. The adoption of rice varieties released in the previous 15 years was low except for Sawa Masuli sub-1, a stress-tolerant rice variety that was adopted in 16% of the study area more than a decade after its official recommendation. This variety had the advantage of having similar grain characteristics to the established variety Sawa Masuli, so millers could easily replace it with the new variety. The study revealed that premium rice lands in Chitwan were replaced with cattle and poultry farms, fishponds, and vegetables. Rice lands with better drainage and close to the Mahendra *Raj Marg* (highway) had been converted into real estate and settlements. There was a good agreement between the data collected from the sampled GPS coordinates and the FGDs. Random selection of GPS coordinates and sampling points is an unbiased, rapid, and efficient method for assessing the adoption of agricultural technologies, varietal dynamics, and changes in natural resources management and land use.

KEYWORDS

adoption, rice, GPS, age of varieties, land use change

# 1. Introduction

Seeds are the vehicles for transferring new genetic gains to farmers. Adoption of new varieties with better seeds is the most economical way for smallholder farmers to increase yields and profitability, as they do not have to spend more on external inputs. A periodical evaluation of the adoption of new agricultural technologies, such as new varieties, identifies the constraints to their adoption and allows an estimate of the return on investment from agricultural research and development (R&D). Adoption and diffusion of agricultural technologies are expected to help make production systems more productive, profitable, and sustainable (Shang et al., 2021). However, estimating the adoption of technologies, such as the adoption of modern rice varieties, in smallholder-based farming systems is complex and resource-consuming. Consequently, there are few studies on rice varietal adoption, and those that report varietal changes over time are rare. For example, Witcombe et al. (2016a,b) stated that their study was perhaps unique in reporting changes over time.

All estimates of adoption must use some form of survey, either of farmers or of key informants such as seed producers or agricultural extension workers. All are open to bias in the selection of the participants and are then also open to their own biases. Seed production statistics are less open to bias and can be used to easily identify the relative popularity of varieties while demanding fewer resources than household surveys. However, it ignores the considerable areas grown from farm-saved seed (more than 80% in developing countries), all varieties that are not in the official seed production system, and provides little or no information on their distribution in the agricultural landscape.

We are not aware of any prior study that employed GPS to determine a sampling frame to evaluate the adoption and spread of agricultural technologies. We report here on three surveys made over a period of 16 years using GPS-located samples. The rice varieties were grown, and the land use was recorded. The findings from transects were triangulated by means of focus group discussions (FGDs), where groups of local farmers were interviewed.

# 2. Methods

## 2.1. Use of the global positioning system

The study district has three major rice-growing areas, namely, eastern, western, and southern Chitwan (Appendix 1; Figure 1). In 2005 and 2006, rice varietal diversity was sampled from 14 transects covering a total of 440 GPS coordinates and 770 sampling points to best represent geographical areas, land types, and rice production ecologies. Out of 440 GPS coordinates, 220 each were allocated to Eastern and Western Chitwan. Southern Chitwan was excluded due to the adverse security situation in 2005. In 2022, 72 GPS coordinates (16% of the total coordinates) from eight out of 14 transects were sampled (Figure 2A).

A baseline sampling frame was established in 2005. Lists of the central points of the transects were prepared by drawing seven-figure random numbers (two for degrees, two for minutes, and three for seconds to one decimal place) using Excel. Only those that fell within the targeted areas were included. The central points of the transects were marked on a topo-map published by the Department of Survey, HMG/Nepal (map not shown). These points were then verified in the field, and non-rice lands such as settlements, forest areas, rivers, irrigation canals, roads, and uplands grown to maize or other crops were excluded and replaced by the next randomly selected point in the list. The coordinates of each point were noted, given the corresponding GPS identification number (a unique identification number), and loaded into an eTrex GARMIN handheld GPS.

Transect Walks were carried out along a 1-km transect. Sampling was done at 100-m intervals, and, in 2005 and 2006, at each interval there were five sampling points (Figure 2B). While deciding the directions of the transect from the central point, non-agricultural areas in the sample were minimized, but to remove bias, there was a pre-decided priority for the direction of the transect, i.e., north, south, east, and then west. Hence, the direction of the study was not always the same (Appendix 2). At each GPS sampling point, the land type (Appendix 3) and the rice variety grown were recorded. In 2005 and 2006, the name of the rice variety grown was determined with the help of the owners or cultivators of the field. In 2022, in addition, each owner or cultivator was interviewed using a checklist to collect additional information, such as the area under the variety and the estimated grain yield per unit area.

In 2022, the sampling along the transect was done at 500-m intervals from the primary point, with three observations taken at each interval (Figure 2B). To compare data from 2006 with 2022, only the 72 GPS coordinates from the same eight transects were considered from both years.

## 2.2. Focus group discussion

FGD is a simple participatory method, and one FGD was conducted at each transect after the transect walk with the owners or cultivators and their neighbors to collect data for triangulating with those from the transects. In each FGD, there were 15–20 male and female participants. A total of 300 farmers participated in both 2005 and 2006, and 145 in 2022. The participants were decided by the community, but they were advised to have

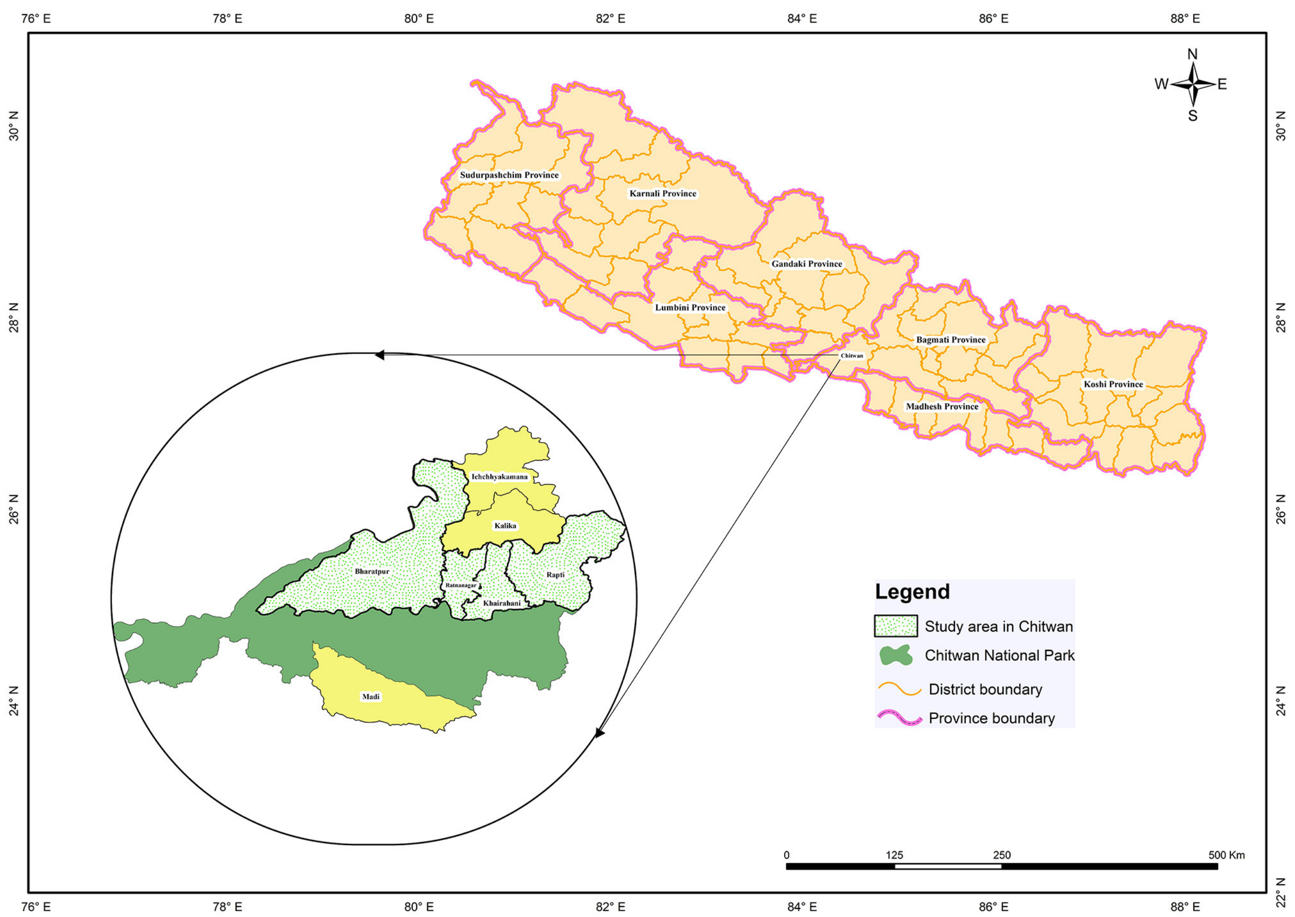


FIGURE 1
Map of Nepal showing the study area in Chitwan district.

knowledgeable farmers of both sexes and that they should try and represent ethnic groups, disadvantaged groups, and youth. In each FGD, 4–5 farmers also participated in the transect walk. The discussions lasted from 1 to 1½ h. The area coverage of each rice variety, their yield, and other benefits were discussed and documented.

## 2.3. Statistical analysis

Simple statistics such as percentage, average, and weighted average, standard error for the yield of rice varieties, and coefficient of correlation were computed using the data collected in the study. Descriptive analysis was the main analysis used in the study. The frequency of counts of any variety in the transect data would be expected to be directly related to the area on which it is grown. Hence, we consider the frequencies and area percentages to be equivalent. To have clarity about varietal dynamics between 2006 and 2022, rice varieties were classified into the following categories: (i) new improved, (ii) old improved, (iii) new climate resilient, (iv) new unregistered, (v) old unregistered, (vi) hybrids, and (vii) landraces.

# 3. Findings

## 3.1. Adoption of rice varieties from 2005 to 2006 in the 14 transects using GPS

The data for 2005 and 2006 indicated distinct year-to-year rice varietal dynamics in the study area. Old-improved varieties dominated the rice production system for both years; interestingly, farmers in 2006 switched to old-improved varieties, which resulted in an area reduction under new-improved varieties (Figure 3). In general, the same rice varieties were identified, but with changes in the frequency of their occurrence. The most striking changes were for rice varieties bred using client-oriented breeding (COB) (from 8 to 3%), Sawa Masuli and hybrids (from 0 to 4%), Masuli (from 24 to 33%), and Radha-4 (from 6 to 3%), while there was no change for Sabitri (Table 1; Figure 3).

## 3.2. Adoption of rice varieties from 2006 to 2022 in the eight transects from the GPS

The adoption of rice varieties for 72 sampling points from eight transects in 2022 was compared with the same sampling

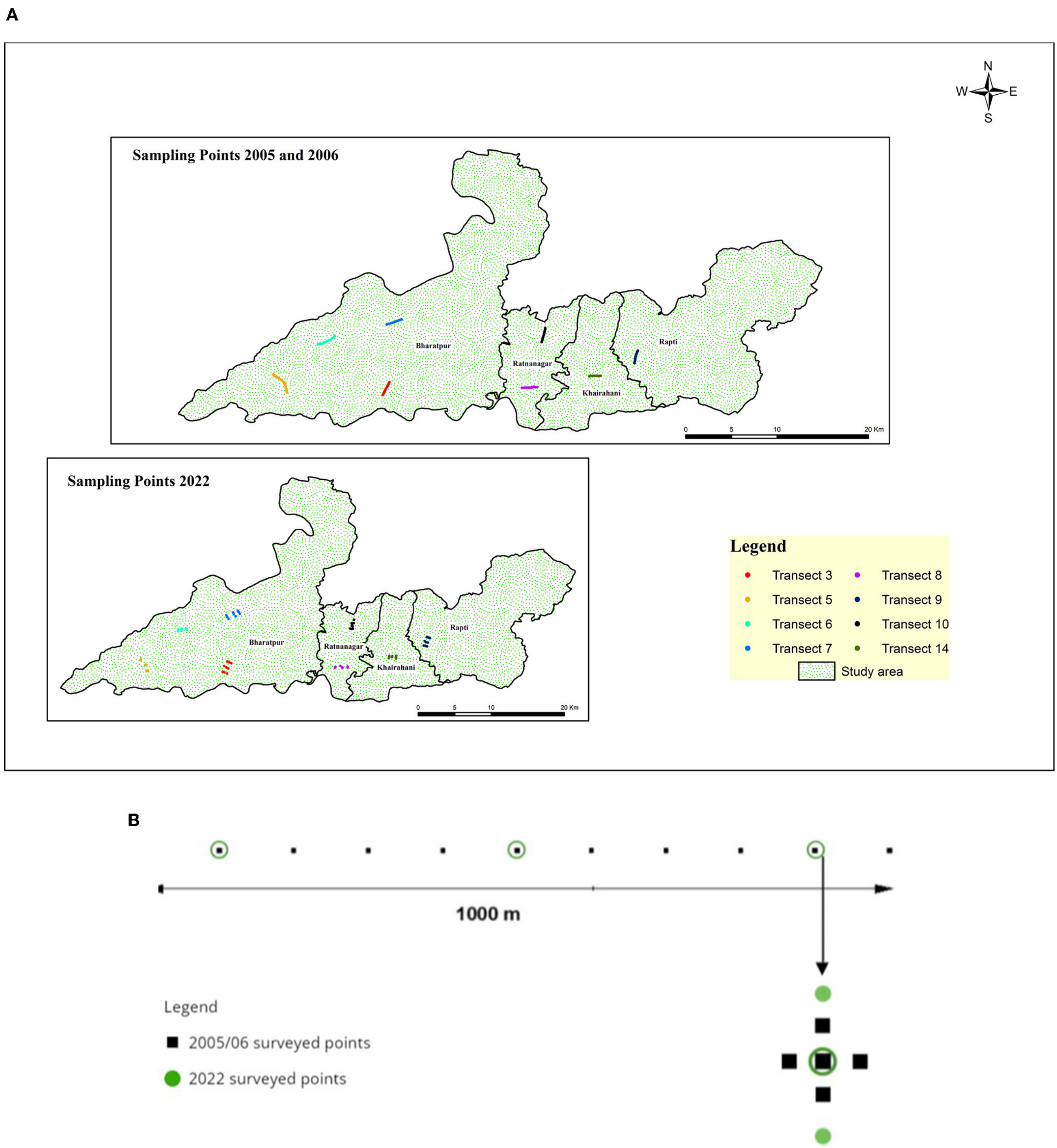


FIGURE 2
**(A)** Map of the study area in Chitwan, Nepal, showing GPS coordinates for 2005, 2006, and 2022. Four hundred and forty GPS coordinates and 770 sampling points were randomly sampled in 2005 and 2006, while 72 of those were randomly selected and resurveyed in 2022. **(B)** A schematic diagram showing how the survey was done at each sampling point in 2005, 2006, and 2022.

frame for 2005 and 2006. A total of 29 rice varieties were found across the three surveys. Overall, the rice varietal richness had increased, as 19 varieties were recorded in 2022 in the transects compared with 11 in 2005 and 12 in 2006 (Table 1; Appendices 4, 5 in Supplementary material). The area under old-improved varieties decreased to 40% in 2022 from nearly 66% in 2006. Interestingly, old-improved varieties were replaced in large part by unregistered varieties, and a few of those were also quite old rice varieties from India. Interestingly, area under the new improved varieties decreased slightly.

In 2022, three hybrid varieties were identified, whereas, in 2006, hybrid rice varieties were only reported as a category. In 2006,

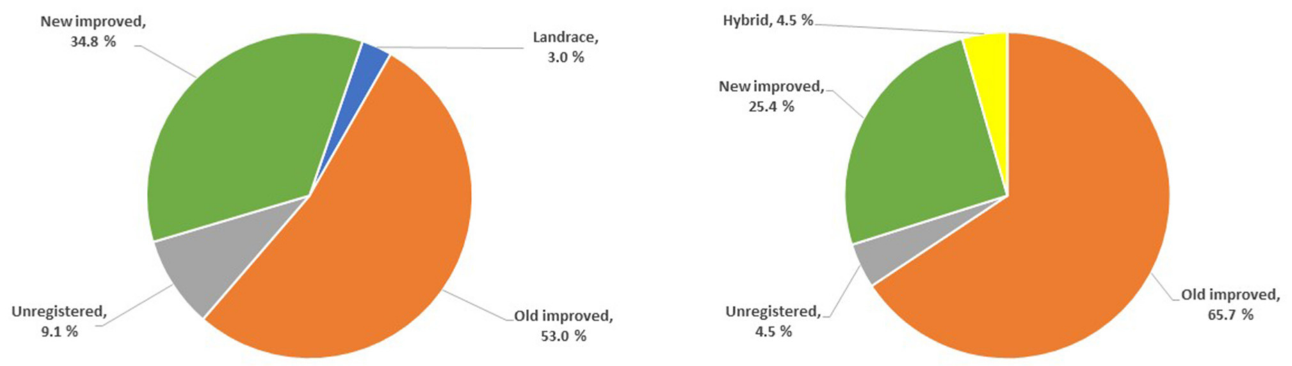


FIGURE 3
Overall rice varietal frequencies (%) across the fourteen transects in 2005 **(left)** and 2006 **(right)** in Chitwan district, Nepal.

hybrids occupied only 4% of the area, and this increased to 7% by 2022 (Table 1; Figure 4; Appendix 1).

A total of 12 inbred varieties grown in the 2022 survey were new as they were not found in 2006, and their ages ranged from 11 to 48 years. The two oldest varieties, namely, Hema (48 years) and Moti (34 years), were recently introduced old varieties from India that are not released in Nepal. In total, 11 varieties grown in 2006 were not found in 2022 (Table 1; Figure 4). Hence, three varieties, namely, Hardinath 1 (3% of area in 2006 to 2% of area in 2022), Ram (12–19%), and Sabitri (28–19%) were cultivated in both years.

## 3.3. Agreement between the GPS transects and the FGDs

Overall, there was good agreement between the data from the GPS coordinates and sampling points and the FGDs in both the 2006 and 2022 surveys. This was also the case in 2005 (data not shown). The correlations between the areas from the FGDs and the frequencies from the transects were high ($r^2 = 0.89$). The FGDs always gave a higher estimate of the total number of rice varieties grown than were found in the transects (Figure 5).

## 3.4. Age of rice varieties, grain yield, and adoption lag

The uptake and adoption of more recently released rice varieties was slow, as only two out of 36 rice varieties released between 2006 and 2022 for cultivation in the Nepal Terai (SQCC, 2022) were adopted by farmers (Table 1; Figure 3). These were Sawa Masuli sub-1 and Swarna sub-1, and both were stress-tolerant rice varieties (STRVs) developed by the International Rice Research Institute (IRRI) in the project "Stress-Tolerant Rice Varieties for Africa and South Asia." Sawa Masuli Sub-1 covered 16% of the area, while Swarna Sub-1 covered 4% (Figure 4; Table 1). Several rice varieties grown by farmers were not actually recommended by the seed regulatory system of Nepal, including Malaysia, Katarni, Godawari, Chandan, Gangottari, Hema, Moti, and Panganga (Table 1).

Several of the old-improved varieties that were popular in 2006, such as Masuli (the most popular rice variety in Nepal until early 2000), Sawa Masuli, Makwanpur-1, Kanchhi Masuli, Radha-4, and Radha-11, were not found in the 2022 FGD (Figure 4). The areas under popular varieties Sabitri and Hardinath-1 also decreased.

The average age of cultivars is measured by their age (the number of years since they were released) weighted by the area they cover. Only improved varieties can be included in the calculation because the ages of landraces and traditional cultivars are unknown. The average weighted age of the 19 rice varieties found in the 2022 study was 19.5, which was slightly lower than the 20.6 years found in 2006 (Table 1). The average age is underestimated because of lengthy testing and delays in official release; several of the rice varieties, such as Hardinath 1 and Ram, were released years after their introduction. For example, Hardinath-1 was introduced in Nepal in 1988 and was adopted by farmers, but it was not officially released in Nepal until 2004 (Joshi et al., 2012).

In 2022, nine out of 19 varieties were 7–14 years of age, but the average weighted age was nearly 20 years. High yielding and newly released rice varieties had low adoption; hence, the weighted average age was higher than the average age. The top five varieties occupied most of the land in both years, i.e., 81% in 2006 and 70% in 2022. In 2022, two of these were Ram and Sabitri, which had the lowest yield but covered 19% of the area each (Table 1).

In the FGDs, the participants told the researchers that Sabitri was preferred for its wide adaptation, stable rice yield in varied conditions, and ability to do well even under partially irrigated conditions with moderate application of nutrients. A higher straw yield is another reason for its preference by farmers. Ram is preferred for its good grain quality, softness of cooked rice, adaptability to low input conditions, and fetches good market price. Sawa Masuli, a short-duration variety, is popular for its fine grains, tasty, and softness of rice, and it does well in irrigated conditions. Sawa Masuli sub-1 is preferred over Sabitri because of its higher yield, better taste, and higher market price. Being a late-maturing variety, it is preferred for lowland irrigated conditions. FGD participants also said that hybrid rice varieties are not adopted in larger areas because of high input costs (83% of participants), being highly prone to insect pests and diseases (25%), and a lack of knowledge to confidently invest in hybrid technology (100%).

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TABLE 1 Adoption of rice varieties in eight transects over 72 GPS coordinate in 2005, 2006, and 2022, the age of varieties (*), weighted age, crop duration (*), and yield (**).

| Variety | Type of variety | Information on release or registration | | Frequency of occurrence | | | Percentage of occurrence | | | Age of variety | | Weighted age of varieties | | Duration (days)* | Yield t/ha** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Year | Country | 2005 | 2006 | 2022 | 2005 | 2006 | 2022 | 2006 | 2022 | 2006 | 2022 | | |
| Anadi | Landrace | § | § | 2 | 0 | 0 | 3.0 | 0.0 | 0.0 | | | | | | |
| Ankur Jyotika | Pure line | 2019 | Nepal | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 3 | | 0.05 | | |
| Arize-6444[1] | Hybrid | 2011 | Nepal | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 7 | | 0.12 | 122 | 5.8 |
| Chandan (CR898-2)[2] | Pure line | 2009 | India | 0 | 0 | 5 | 0.0 | 0.0 | 8.8 | | 13 | | 1.14 | 125–130 | 4.3 |
| COB | Pure line | 2006 | Nepal | 5 | 2 | 0 | 7.6 | 3.0 | 0.0 | 1 | | 0.03 | | | |
| Gangotri[2] | Pure line | 2011 | India | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 11 | 0 | 0.19 | | 4.3 |
| Godabari[2] | Pure line | 2011 | FSS | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 11 | 0 | 0.19 | | 4.1 |
| Gorakhnath 509[1§] | Hybrid | 2011 | Nepal | 0 | 0 | 2 | 0.0 | 0.0 | 3.5 | | 11 | 0 | 0.39 | 123 | 4.5 |
| Hardinath-1 | Pure line | 2004 | Nepal | 1 | 2 | 1 | 1.5 | 3.0 | 1.8 | 2 | 24 | 0.06 | 0.42 | 120 | 4 |
| Hema[2] | Pure line | 1974 | India | 0 | 0 | 2 | 0.0 | 0.0 | 3.5 | | 48 | 0 | 1.68 | | 4.6 |
| Hybrid | Hybrid | | | 0 | 3 | 0 | 0.0 | 4.5 | 0.0 | | | 0 | 0 | | |
| Jira masino | Landrace | § | § | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | | 0 | 0 | | |
| Kaberi sona[2] | Unknown | § | India | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | | 0 | 0 | | |
| Kanchhi Masuli[3] | Pure line | 1992 | Nepal | 1 | 1 | 0 | 1.5 | 1.5 | 0.0 | 14 | | 0.21 | 0.00 | | |
| Katarni[2,4] | Pure line | 2008 | FSS | 0 | 0 | 4 | 0.0 | 0.0 | 7.0 | | 14 | 0 | 0.98 | | 4.1 |
| Makawanpur 1 | Pure line | 1987 | Nepal | 3 | 0 | 0 | 4.5 | | 0.0 | | | 0 | 0 | | |
| Malaysia[2,5] | Pure line | 2001 | FSS | 1 | 0 | 0 | 1.5 | | 0.0 | | | 0 | 0 | | |
| Masuli | Pure line | 1973 | Nepal | 16 | 22 | 0 | 24.2 | 32.8 | 0.0 | 33 | | 10.84 | 0.00 | 145–150 | |
| Moti (CR 260−136 - 321 IET 9170)[2] | Pure line | 1988 | India | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 34 | 0 | 0.60 | | 4.8 |
| Mukawala 23 | Pure line | 2019 | Nepal | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 3 | 0 | 0.05 | | |
| Panganga[2] | Unknown | | | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | | 0 | 0 | | |
| Radha 4 | Pure line | 1994 | Nepal | 4 | 2 | 0 | 6.1 | 3.0 | 0.0 | 12 | | 0.36 | 0 | | |
| Radha-11 | Pure line | 1996 | Nepal | 3 | 2 | 0 | 4.5 | 3.0 | 0.0 | 10 | | 0.30 | 0 | | |

*(Continued)*

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TABLE 1 (Continued)

| Variety | Type of variety | Information on release or registration | | Frequency of occurrence | | | Percentage of occurrence | | | Age of variety | | Weighted age of varieties | | Duration (days)* | Yield t/ha** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Year | Country | 2005 | 2006 | 2022 | 2005 | 2006 | 2022 | 2006 | 2022 | 2006 | 2022 | | |
| Ram | Pure line | 2006 | Nepal | 9 | 8 | 11 | 13.6 | 11.9 | 19.3 | 1 | 16 | 0.12 | 3.09 | 130–137 | 4 |
| Sabitri | Pure line | 1979 | Nepal | 19 | 19 | 11 | 28.8 | 28.4 | 19.3 | 27 | 43 | 7.66 | 8.30 | 145 | 3.6 |
| Sawa Masuli sub-1[6] | Pure line | 2011 | Nepal | 0 | 0 | 9 | 0.0 | 0.0 | 15.8 | | 11 | 0 | 1.74 | 145–150 | 4.9 |
| Sawa Masuli[7] | Pure line | 2019 | Nepal | 0 | 3 | 0 | 0.0 | 4.5 | 0.0 | | | 0 | 0 | | |
| Swarna sub-1[6] | Pure line | 2011 | Nepal | 0 | 0 | 2 | 0.0 | 0.0 | 3.5 | | 11 | 0 | 0.39 | 155–160 | 5.1 |
| Swarna[2] | Pure line | 1982 | India | 2 | 3 | 0 | 3.0 | 4.5 | 0.0 | 24 | | 1.07 | 0 | | |
| US-305[1] | Hybrid | 2019 | Nepal | 0 | 0 | 1 | 0.0 | 0.0 | 1.8 | | 12 | 0 | 0.21 | 132 | 5.6 |
| Total[€] | | | | 66 | 67 | 57 | 100 | 100 | 100 | | | | | | |
| Weighted age* | | | | | | | | | | | | 20.6 | 19.5 | | |
| Average grain yield | | | | | | | | | | | | | | | 4.6 |
| Sem | | | | | | | | | | | | | | | 0.17 |

[€]The total frequency in the table for any year does not add up to 72. This is because the study recorded 6, 5, and 15 survey points without a rice crop, respectively, in 2005, 2006, and 2022. Such farms either got replaced for agricultural activities other than rice or got converted into real estate and settlements.
[1]Hybrid rice varieties are registered in Nepal. [§]Gorakhnath 509 was de-notified in Nepal but is still grown by farmers.
[2]Rice varieties from India are neither registered nor released in Nepal.
[3]A rice variety was evaluated in multi-environment trials and on farm trials during the 1990s and proposed for release in 1992, but was declined by the variety releasing committee of Nepal. Spread from farmers' seed systems.
[4]Katarni was first reported in Nepal by Witcombe et al. (2009), and it spread through farmers' seed systems.
[5]Malasia was first documented in Chitwan and Nawalparasi by Devkota et al. (2005), and it spread through farmers' seed systems.
[6]Stress-tolerant rice varieties (STRVs).
[7]Registered in Nepal 30 years after its release in India.
[§]Means not applicable, FSS, spread through farmers' seed systems.
*The age of rice varieties and crop duration were obtained from the SQCC (2022).
**The grain yield of rice varieties was collected from the 2022 GPS transect study.

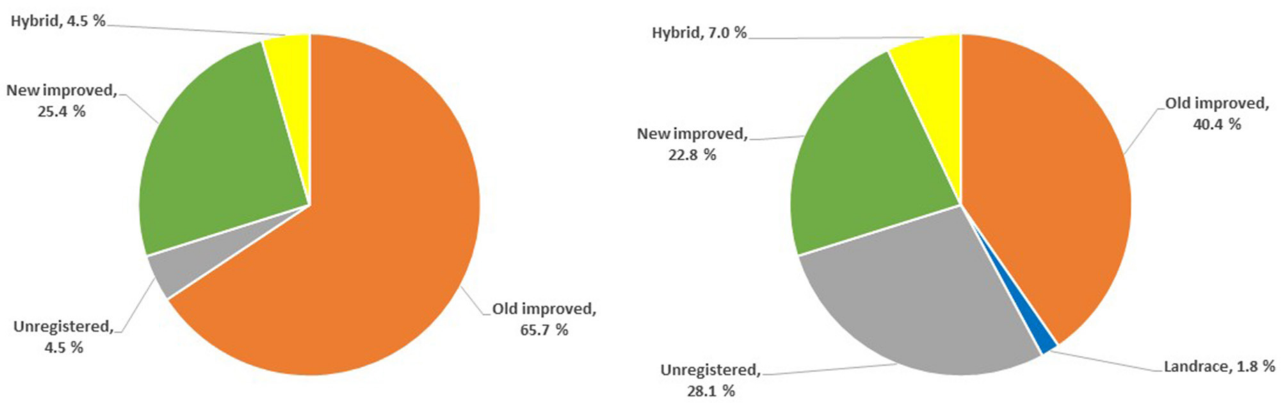


FIGURE 4
Change in rice varietal frequency (%) from 2006 **(left)** to 2022 **(right)** in eight transects with a total of 72 sampling points in Chitwan district.

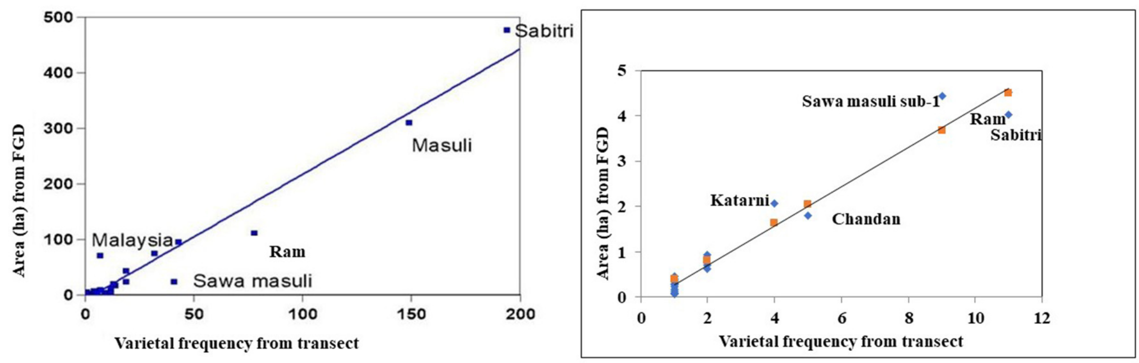


FIGURE 5
Comparison of the varietal frequency count in the transect and the estimates of the area from focus group discussion (FGD) from 14 transects in 2006 **(left)** and from eight transect in 2022 **(right)** that were common both in FGD and transect in Chitwan district, Nepal. The best fit between the two variables using linear regression is shown.

## 3.5. Changing land use patterns

Studies conducted in 2005 and 2006 (considering 72 GPS coordinates and sampling points) recorded rice cultivation in 86% of them, but 16 years later, it had decreased to 79%. The further shrinkage of 7% premium rice land was the conversion of 4.2% of the land to non-rice agricultural commodities, while 2.7% was converted into non-agricultural uses, such as real estate and settlements. The largest change in growing other agricultural commodities was because rice was replaced with vegetables, forage crops such as maize during the rainy season, poultry farms, cattle farms, and fishponds. Planting bananas on rice lands was also a new practice (data for individual commodities are not shown). This change depended on factors such as land type, proximity to the road head, and markets (Figure 6).

The conversion of rice fields was higher in the villages close to the *Mahendra Rajmarg* highway (largely well-drained fields). Up to 20% of rice lands in some villages were converted into non-agricultural use; the lowest conversion (5%) was reported in Phulbari, which is nearly 10 km away from the road head at Bharatpur, while in Birendranagar, Rapti Municipality, which adjoins the highway, 20% of the rice lands were converted (Figures 1, 6).

# 4. Discussion

## 4.1. Methods of evaluating varietal adoption, varietal dynamics, and change in land use patterns

The main objective of evaluating the adoption and impact of agricultural technologies is to measure their degree of success and provide information about the effectiveness of the research investment. Data from impact studies can be used to help design subsequent research better targeted to deliver multidimensional impacts, e.g., on productivity, on-farm income, poverty, and inequality. More accurate surveying enables researchers to carry out analyses that provide better evidence-based advice to policymakers (Gibson and McKenzie, 2007). Using a GPS-facilitated survey with randomly selected locations had the great advantage of providing an unbiased sampling frame based on

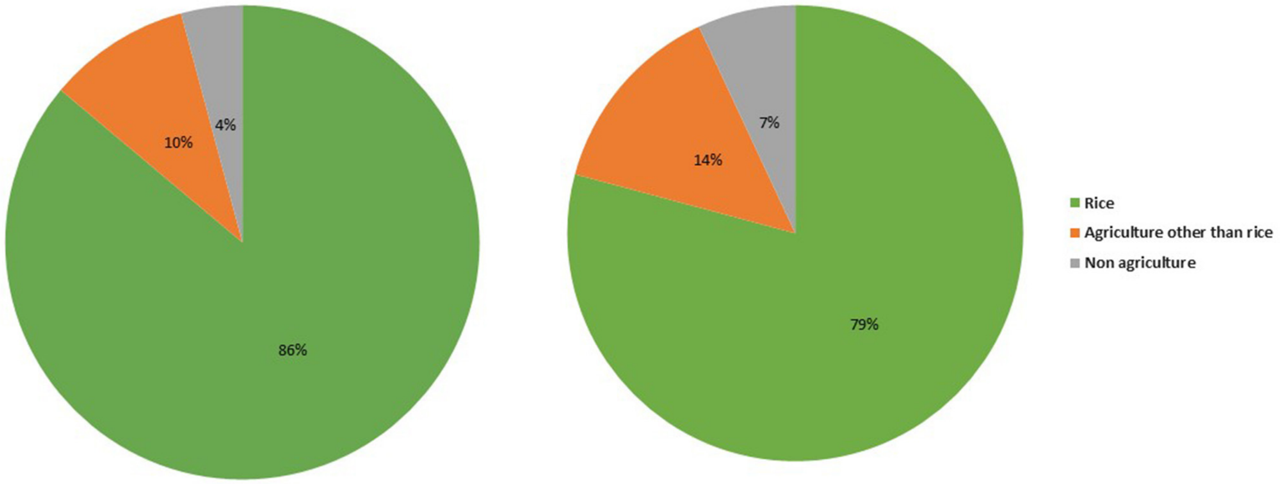


FIGURE 6
Land use change in Chitwan from 2005 to 2006 **(left)** and 2022 **(right)** across the eight transects and 72 sampling points in the Chitwan study area.

the agricultural landscape rather than on households. There is no equivalent and cost-effective way of reducing bias in samples that involve interviews with households and stakeholders. Another important advantage is that the sampling frame can be used for subsequent unbiased monitoring of changes over time, which is impracticable using households because their compositions and even their positions vary over time.

The unbiased sample was made using random numbers to identify the latitude and longitude of the sampling points. When the original study was made, there was no GPS system on mobile phones. This would now be the method of choice, and it is convenient to use the application "What3words" to handle the coordinates. This application identifies every three by three-meter square (9 $m^2$ area) on the surface of the earth by a unique combination of three words. The application can be used to navigate to a sampling point, and the three-letter word can then be used to identify the location of the data collected (varietal name, land type, etc.). For example, a sampling point on the Ratna Nagar transect is at 27°34′50′′N 84°15′54′′E, and this is a nine-meter square "bias.upwardly.crouched" in what3words (note that it is easier to enter the decimal equivalent of latitude and longitude into the application, in this case 27.58055N and 84.26500E). The position indicated on a mobile phone may wander slightly between adjacent named squares, but not to an extent that will change observations made at field level.

In this study, we sampled rice varieties at two different intensities; in 2006, each 1,000-m transect was sampled at 100-m intervals and at five points (the center, and 30 m east, and west, north, and south of it). In 2022, the sampling was done at 500-m intervals, and the individual points were further apart (100 m from the center instead of 30 m). The original methodology captured more rice varietal richness, particularly the rice varieties grown by farmers in small areas. Depending on the purpose of the study, the sampling intensity can vary. If the objective is to map the varietal richness and genetic diversity, more intensive sampling is appropriate, but less intensive sampling is required to evaluate the adoption of the most economically important rice varieties that are grown in the larger areas.

Focus group discussions are a more flexible and interactive tool compared with a randomly selected sampling framework, and they generate more comprehensive information. We found a high degree of agreement between the transects and the FGDs for the rice varieties grown, so the transects can be used on their own as they also provide an unbiased quantitative assessment. The FGDs do, however, capture the presence of varieties that are grown in smaller areas (Figure 5). An FGD involves the combined knowledge of participating farmers that come from different parts of a village and so effectively samples a larger area than the set points of a transect, so it was unsurprising that FGDs identified more varieties in all the three surveys. Additional data can also be collected using FGDs, such as which varieties give a higher yield or harvest value. Combining the data from transects and FGDs maximizes the benefits of both approaches.

## 4.2. Persistence of old rice varieties in the context of weak varietal popularization and weak seed regulatory frameworks

Rice adoption is dynamic in Nepal, as can be seen from the change in the portfolio of varieties grown over time. In the surveys done over an interval of 16 years, a total of 29 rice varieties were found in the study area, and only three were grown by farmers in both years (Sabitri, Ram, and Hardinath-1), which collectively occupied 42% of the area in 2006 and 41% in 2022. The average weighted age of the rice varieties slightly decreased from 2006 to 2022 (Table 1). The reason there was little change in the weighted average age, despite the high varietal turnover, was the persistence of these three varieties, now 16 years older.

These findings on the age of varieties agree with earlier studies. Gauchan and Pandey (2012) and Wang et al. (2012) reported that the average age of rice varieties was 24 years based on household surveys in Bangladesh, Eastern India, and Nepal and 20 years based on the expert elicitation (EE) method. Rice varietal age has been consistently above 20 years for the last decade in these countries. In Nepal, the average age of rice varieties in 2011 in 16 Terai districts was around 23 years (Witcombe et al., 2016a).

The five most widely grown varieties in the western, central, and eastern districts occupied about 70% of the area (Witcombe et al., 2016a) somewhat lower than the 82% in the 2006 survey and 78% in the 2022 survey. As in the surveys reported here, they also found that the weighted average was always higher than the average age no matter what region or year is considered.

Old and obsolete varieties, some released in the 1970s, are still grown by farmers in Nepal. This is a common phenomenon in developing countries, particularly in subsistence economies where a few old and popular varieties cover most of the rice areas (Gauchan and Pandey, 2012; Joshi et al., 2012; Witcombe et al., 2016a,b). Moreover, several of the rice varieties documented in the study were not recommended by the Seed Quality Control Center, the Seed Regulatory body of Nepal, but their seeds were sold by Agrovets (private companies trading agricultural inputs and veterinary medicines). Rice seeds of nearly 50-year-old obsolete varieties such as Hema and Moti were sold by Agrovet labeled as "new" varieties (Table 1).

Slow turnover of crop varieties is a real obstacle to delivering new genetic gains to farmers' fields and slows potential increases in rice production that will enhance food security. Since 2006, nearly three dozen rice varieties have been released in Nepal, but their uptake and adoption have been slow. Although simple and cost-effective methods for varietal evaluation and scaling up have been developed (Joshi and Witcombe, 2002; Joshi et al., 2012) such approaches have not been institutionalized. The Department of Agriculture (DoA) and the Nepal Agriculture Research Council (NARC) used to conduct country-wide Farmers' Field Trials (FFTs) and Minikits (seed kits) of pipeline or recently released crop varieties, but these activities are no longer prioritized by these organizations. However, the slow uptake of new varieties is not only determined by the promotion and availability of seed for new varieties. There is also the extent of demand for the grain of a variety to consider. In the FGDs, farmers reported that one reason they continued to grow Sabitri and Ram was the existence of an established market for their grain. Rice millers, major purchasers of grain, have an incentive to continue with older varieties as an established market reduces the risk of having unsold grain. Replacing them with newer varieties increases risk, e.g., they may be less accepted by consumers. Moreover, economies of scale are reduced because it is almost inevitable that the grain of newer varieties will be in shorter supply.

## 4.3. Changing land use patterns

Migration and urbanization have complex implications for land use change in Nepal. Many researchers acknowledge that conversion of fertile lands into real estate will result in the loss of arable lands with reduced food production, leaving communities vulnerable to food shortages and price fluctuations and disrupting food security. Rimal et al. (2018), in a study covering 27 years, reported significant loss of cultivated land due to urbanization in the Nepal Terai. The urban cover of 221 km$^2$ in 1989 increased to 930 km$^2$ by 2016 (a 320% increase), and of the new urban cover added since 1989, 93% was formerly cultivated land. Paudel et al. (2014) reported that the migration resulted in the abandonment of productive agricultural lands in the mid-hills of Nepal.

Rampant urbanization and land fragmentation triggered by real estate developers between 1989 and 2016 are two of the major constraints to attaining food security in the country (Shrestha, 2017; Timsina et al., 2019; Dahal, 2023). According to Shrestha (2017), more than 70% of the rice lands in Lekhnath region of Pokhara Metropolitan have already been converted into settlements, and the remaining 30% are also being bought up by real estate developers, says Kamal Bahadur Thapa, the Ward Committee chairman of the metropolitan, who blames the local government for an unplanned growth of urbanization. The study also reported that high-quality heritage varieties such as Jethobudho, Pokhreli Masino, Jhinuwa, Ramani, and such other heritage rice are on the verge of extinction due to the conversion of irrigated lands in Pokhara and Lekhnath, which are the habitats for these rice landraces. In the last decade, 99% of those who migrated to the Middle East or Malaysia shifted to towns, and families of migrant workers invested in real estate. It is reported from eastern Terai that in the last 15 years, one out of every three Nepalese has left their villages to settle in urban and peri-urban areas, resulting in a heightened demand for housing and land in urban areas, subsequently leading to an increase in prices. The price of urban land in Kathmandu city was US$ 22,000 m$^2$, ranking among the top 10 most expensive real estates in the world (Ghimire, 2022; Dahal, 2023). But this price trend for real estate extends throughout the country, and the article also reported that the growth rate of property value in Nepal is 27.7%, which means that real estate values are doubling every 3.5 years. Loss of farmlands over the years has been reflected in the sharp hike in food imports that increased from US$157 million in 1995/96 to over USD$1.378 billion in 205/16 and over USD$3 billion during 2022 (Bhavana and Race, 2019; DoC, 2022). A lack of decentralized development in the country has forced families to settle in lands known for their high agricultural productivity, in the valleys or in the plain areas of the Terai, where better school and health facilities are located. Rimal et al. (2018) revealed that land use change in the Terai is caused by significant inter-regional migration coupled with poor urban planning and lax policies for controlling the fragmentation of peri-urban cultivated lands. They suggested that urban-growth management may reduce agricultural land losses in Nepal.

# 5. Conclusion and recommendation

Varietal adoption and dynamics can be evaluated using GPS-determined transects that provide an accurate and unbiased sampling frame. It can be used to evaluate, over time, the uptake and adoption of agricultural technologies as well as changes in natural resources. It is now very easy for anyone to use this technique by using a mobile phone to geolocate the points.

GPS-based studies can have strategic importance by creating a long-term data base that reliably documents changes in the patterns of adoption of agricultural technologies and natural resources. One can exactly repeat the survey at any time by using the geographic coordinates of the initial study.

The study reaffirmed the dominance of old-improved rice varieties, and this has serious implications for delivering new genetic gains to farmers' fields and for achieving food and nutrition security in Nepal. Of late, varietal deployment and popularization by public sector agriculture research and extension are not very effective, as seen by the slow and limited adoption of newly released rice varieties in a highly accessible area such as Chitwan. An additional factor is the time needed to establish a market for the grain of new varieties because grain purchasers are motivated to buy varieties that have an already-established demand from consumers.

Due to a lack of planned urbanization and appropriate policies in place, widespread conversion of fertile lands into real estate in the Terai and valleys and underutilization and abandonment of agricultural lands in the hilly areas pose the biggest threat to food and nutrition security in Nepal, which is likely to be exacerbated if the current trends related to land use and land cover changes are not addressed with the right policies and other appropriate instruments.

We recognize two limitations to the study. (i) The GPS devices used during 2005, 2006, and 2022 were not the same, and this may have affected the precision of the study to some extent. (ii) The population in any spatial area is likely to be unevenly distributed; therefore, it may not fully represent the entire population.

Future research on the topic can be conducted with a multi-stage sampling approach where the number of samples and GPS coordinates are predetermined based on the population size in each location and spatial points are randomly selected.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

JW designed the research, quality control, and write up and analysis. KJ led the analysis and write up of the article and overseeing field surveys as well as checking data quality. KR and GJ conducted field research during 2005 and 2006 and data compilation as well as contributing to write up. NK and SU conducted field research in 2022, data compilation, analysis, and contributed to write up. KD contributed in field research, data analysis, and write up. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Author disclaimer

The views expressed are not necessarily those of DFID or BMGF.

## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1180520/full#supplementary-material

## References

Bhavana, K. C., and Race, D. (2019). Outmigration and land use change: a case study from the middle hills of Nepal. *Land* 9, 2. doi: 10.3390/land9010002

Dahal, A. (2023). *Rapid Increase in Land and House Price in Nepal*. Nepal Database. Available online at: nepaldatabase.com/rapid-increase-in-land-and-house-price-in-nepal (accessed June 10, 2023).

Devkota, K. P., Gyawali, S., Subedi, A., Witcombe, J. A. D., and Joshi, K. D. (2005). *Adoption of Main Season Rice in Chitwan and Nawalparasi Districts of Nepal from 2001 to 2002. CAZS-NR Discussion Paper Bangor*. CAZS-NR University of Wales. Available online at: http://www.cazs.bangor.ac.uk (accessed July 7, 2023).

DoC. (2022). *Summary of Import/Export During 2022 (Unpublished data)*. Kathmandu: Department of Customs, Ministry of Finance, Government of Nepal. Available online at: https://www.customs.gov.np/

Gauchan, D., and Pandey, S. (2012). Synthesis of key results and implications. In: Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B, editors. *Patterns of Adoption of Improved Rice Varieties and Farm-level Impacts in Stress-Prone Rainfed Areas in South Asia*. Los Baños: International Rice Research Institute.

Ghimire, A. (2022). *How Remittance Is Fueling Agricultural Risks and unplanNed Sprawl*. The Kathmandu Post. Available online at: https://kathmandupost.com/national/2022/04/14/how-remittance-is-fuelling-agricultural-risks-and-unplanned-sprawl#google_vignette (accessed April 14, 2022).

Gibson, J., and McKenzie, D. (2007). *Using the Global Positioning System in Household Surveys for Better Economics and Better Policy. World Bank Policy Research Working Paper 4195* (Washington, DC: World Bank), 29.

Joshi, K. D., Devkota, K. P., Harris, D., Khanal, N. P., Paudyal, B., Sapkota, A., et al. (2012). Participatory research approaches rapidly improve household food security in Nepal and identify policy changes required for institutionalization. *Field Crops Res*. 131, 40–48. doi: 10.1016/j.fcr,.2012.03.001

Joshi, K. D., and Witcombe, J. R. (2002). Participatory varietal selection in rice in Nepal in favourable agricultural environments – A comparison of two methods assessed by varietal adoption. *Euphytica* 127, 445–458. doi: 10.1023/A:1020348620286

Paudel, K. P., Tamang, S., and Shrestha, K. K. (2014). Transforming land and livelihood: analysis of agricultural land abandonment in the mid hills of Nepal. *J. For. Livelihood* 12, 11–19.

Rimal, B., Zhang, L., Stork, N., Sloan, S., and Rijal, S. (2018). Urban expansion occurred at the expense of agricultural lands in the tarai Region of Nepal from 1989 to 2016. *Sustainability* 10, 1341. doi: 10.3390/su10051341

Shang, L., Thomas Heckelei, T., Maria, K., Gerullis, M. K., Börner, J., and Rasch, S. (2021). Adoption and diffusion of digital farming technologies - integrating farm-level evidence and system interaction. *Agric. Syst.* 190, 103074. doi: 10.1016/j.agsy.2021.103074

Shrestha, Y. (2017). *Remittance, Rice, and Real Estate*. Nepali Times. Available online at: https://archive.nepalitimes.com/article/nation/paddy-planting-replaced-by-real-estate3833 (accessed July 7, 2023).

SQCC (2022). *Notified and De-notified Varieties Till 2079-5-30*. Kathmandu: Seed Quality Control Centre, Ministry of Agriculture and Livestock Development, 60. Available online at: https://www.sqcc.gov.np/pages/publications (accessed July 7, 2023).

Timsina, R. H., Ojha, G. P., Nepali, P. B., and Tiwari, U. (2019). Agriculture land use in Nepal: prospects in food security. *J. Agric. Food Sec. Forest. Univ.* 3, 1–9.

Wang, H., Pandey, S., Velarde, O., Hardy, B. (eds.). (2012). *Patterns of Varietal Adoption and Economics of Rice Production in Asia*. Los Banos: IRRI.

Witcombe, J., Lal, K. K., and Joshi, K. D. (2009). *Scoping Study on Adoption of Rice Varieties from Client Oriented Breeding in the Nepal Rice Innovation System*. CAZS natural resources, Bangor University, United Kingdom.

Witcombe, J. R., Khadka, K., Puri, R. R., Khanal, N. P., Sapkota, A., and Joshi, K. D. (2016a). Adoption of rice varieties. I. Age of varieties and patterns of variability. *Exp. Agric.* 53, 512–527. doi: 10.1017/S0014479716000545

Witcombe, J. R., Khadka, K., Puri, R. R., Khanal, N. P., Sapkota, A., and Joshi, K. D. (2016b). Adoption of rice varieties. II. Accelerating uptake. *Exp. Agric.* 53, 1–17. doi: 10.1017/S0014479716000624