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Typology analysis of Egyptian agricultural households reveals increasing income diversification and abandonment of agricultural activities

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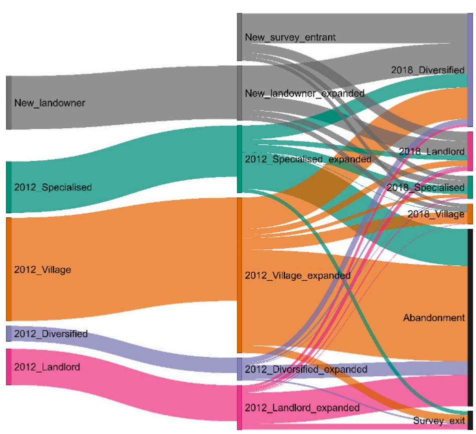
HIGHLIGHTS

- Insights into farming households are needed to improve policy effectiveness to meet increasing demand with limited resources.
- Heterogeneity within farming households in Egypt, and their development between 2012 and 2018 investigated.
- Four farm household clusters identified: specialised farming, village farming, diversified income, and landlord households.
- Trends of high levels of abandonment and increasing income diversification away from agricultural activities found.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Egyptian agriculture is challenged by increasing demands from a rapidly expanding population, and insufficient water and arable land resources, exacerbated by the expected impact of climate change further reducing these resources. Recent government policy has focused on large projects to meet increasing demand, with a reduced focus on the livelihoods and economic sustainability of low-income farmers. Insights into variations and changes within the farming population are needed to improve the effectiveness of policies to meet these challenges.

OBJECTIVE: This research aims to understand the heterogeneity within farming households in Egypt, to determine the characteristics which best describe these variations, and to trace developments within the sector over recent years and their dependencies on contextual factors.

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METHODS: We performed a typology analysis based on the 2012 and 2018 Egyptian labour market panel surveys, identifying and using 12 categorical and 31 continuous variables to describe farming households. Highly skewed continuous variables were transformed, and highly correlated variables were removed. Subsequently, a factor analysis was carried out to determine which variables contribute the most to variation within the dataset. Hierarchical clustering was used to identify the number of clusters and a cluster analysis was carried out to define the clusters. The evolution of the clusters was determined by tracking the households present in both surveys and determining how their type changed between the two surveys.

RESULTS AND CONCLUSIONS: The variables which contributed the most to the variation within the household population were the degree of income diversification, cropping intensity, and water use per unit area. The clustering analysis resulted in four clusters being identified, which were specialised farming, village farming, diversified income, and landlord households. High levels of abandonment of farming were identified, with 45% of households abandoning agricultural activity in 2018 having participated in agriculture in 2012. There was a clear trend towards greater income diversification with 59% of households new to farming in 2018 being part of the diversified income household cluster. The analysis demonstrates a clear trend away from dependence on agricultural income, presenting risks to the sustainability of small-holder farming.

SIGNIFICANCE: Using the characteristics of the household types, this research presents policymakers with the opportunity to simulate responses to policies targeting greater water use efficiency, and increased income for the lowest-income households, and investigate how to meet increasing demand most efficiently. Additionally, it reinforces the global trend towards reduced participation in agricultural activities due to environmental and socioeconomic challenges.

1. Introduction

Agriculture is an important sector within the Egyptian economy, accounting for an average of 13.7% of the gross domestic product (GDP) between 2010 and 2014 (e.g. Bertini and Zouache, 2021). Additionally, it provided employment to >17% of the population in 2018 (Assaad et al., 2020). Meanwhile, Egyptian agriculture faces challenges that have been developing over decades. Rapid population growth coupled with limited water availability has reduced Egypt's renewable water from 1750 $m^3.capita^{-1}.year^{-1}$ in 1970 to 590 $m^3.capita^{-1}.year^{-1}$ in 2019 (Tutwiler, 2021), well below the 1000 $m^3.capita^{-1}.year^{-1}$ threshold of water scarcity (Falkenmark et al., 1989). Additionally, urban encroachment on agricultural land and desertification threaten the limited arable land (Abd-Elmabod et al., 2019). Climate change will exacerbate the already constrained water and land resources in the coastal region through salination of groundwater resources and loss of agricultural land due to sea-level rise, increased crop water demand due to increasing temperatures, and more severe and more frequent extreme weather events, to name but a few (Abutaleb et al., 2018).

Egypt has been increasingly dependent on imports of key staples to meet growing demand and compensate for stagnant domestic production. Egypt imports over half of all of the wheat it consumes, the staple which constitutes a third of total calorific intake and nearly half of all protein (Veninga and Ihle, 2018). This makes Egypt very vulnerable to global food price shocks. The years preceding the significant political instability of 2011 were characterised by low domestic yields due to extreme weather, followed by global food price rises (Soffiantini, 2020).

Most Egyptian farming households are categorised as smallholders, with >80% of households holding <2 ha (Abdalla et al., 2022). Because of a warm winter climate and access to year-round Nile River waters, farmers can grow a variety of field crops, fruit and vegetables over three seasons (Abdalla et al., 2022; Abdelaal and Thilmany, 2019). Although Egyptian farmers enjoy some of the highest yields globally (Nikiel and Eltahir, 2021), the dominance of smallholder farming, downward pressure on prices and upward pressure on costs, has resulted in farming households becoming dependent on mixed livestock-crop farming systems and secondary incomes (Abdelaal and Thilmany, 2019; El Nour, 2015).

Policy has played a major role in farming choices in Egypt. For decades, strong top-down governance has characterised agricultural policy (Bush, 2007). Since the 1980s, market liberalisation attempted to reduce state spending while maintaining cheap inputs for key staple crops, limiting the production of 'thirsty' crops such as rice and cotton, and, at times, restricting exports of key staples in order to increase self-sufficiency and improve water-use efficiency (Fuglie et al., 2020). These governmental policies have been inconsistent, however, with rapidly changing agricultural policy priorities creating instability for farmers and limiting policy impact (Abdalla et al., 2022). One policy priority of the 1990s was the liberalisation of land rental laws, which allowed landlords to set land rents (previously constrained to no >7-times the land tax rate) based on free market prices. Furthermore, liberalisation removed the 'tenancy in perpetuity' provided under previous laws. These changes resulted in >900,000 tenants losing tenancy (El Nour, 2015). Large headline-grabbing projects have dominated agricultural policy at the expense of investment in low-income farming households (Bush, 2022). The 1.5 Million Feddan Project, a project to reclaim 1.5 million feddan[1] of desert land in the Western Desert and bring it under cultivation, is typical in focusing on large private or state investments. Additionally, it is predominantly operated by either large state or commercial enterprises. The main aim of the 1.5 Million Feddan Project is to reduce Egypt's dependence on imports for key grains, with a minor focus on providing land and income to the low-income, landless, and underemployed section of the population (Bush, 2022; Nour, 2020).

The Egyptian context presents a number of complex social, environmental, and policy challenges. Farm and farmer typology analyses are widely used to support policy design for such challenges through the identification of important socio-environmental, farmer, and farm structural characteristics (Huber et al., 2024). Typologies reveal commonalities within farmer populations, summarise large groups into representative types (Hammond et al., 2020; Shukla et al., 2019), and help in the development and ex-ante analysis of policy options (Nyambo et al., 2019; Rega et al., 2022). They can also focus on relatively neglected aspects such as roles, desires, and goals (Blanco et al., 2015) alongside environmental and structural resources (Huber et al., 2024).

Typology analysis has been widely used to understand and summarise the diversity within smallholder farmers in various contexts (Guarín et al., 2020; Nin-Pratt et al., 2018; Shukla et al., 2019; Sinha et al., 2022), and is a common tool in the assessment of technology adoption (Nin-Pratt et al., 2018; Rega et al., 2022; Sarker et al., 2021; Shukla et al., 2019). Farm household typology analysis would enable a greater understanding of the key characteristics and needs within Egyptian farming households while developing common archetypes, which can be used to define and assess the impact of policy, maximise the benefit derived from positive characteristics of the system, and respond to

[1] Feddan is the standard unit of agricultural area utilised in Egypt. 1 feddan = 1.038 acres = 4200 m^2 = 0.42 ha.

challenges of climate change.

Several farmer typologies have been developed for the Egyptian context. Most examples in Egypt are limited to small spatial areas (e.g. Aboul-Naga et al., 2022; Alary et al., 2014; Alary et al., 2020) or address a single socioeconomic level (e.g. Martin et al., 2020). These studies usually develop and implement local surveys to delineate typologies, but national-level market panel surveys have been used to produce national typologies (Helmy, 2020; Nin-Pratt et al., 2018). For example, Nin-Pratt et al. (2018) conducted a farming household typology analysis based on 2012 labour market panel survey data. This analysis utilised continuous variables to develop typologies based on resource and environmental characteristics and used these typologies to analyse the impact of different climate change scenarios on agricultural production. Helmy (2020) used the complete labour market panel survey series (1996, 2006, 2012, 2018) to analyse the evolution of livelihood diversification in Egypt. Farming, salaried agricultural labour, and livestock activities were included within diverse livelihood strategies, but the diversity and characteristics of the farmer and farm structures were not specifically investigated. Together, these past studies provide an overview of agriculture's role in Egypt, but do not trace developments within the sector over recent years or their dependencies on contextual factors. In particular, a typology analysis including household economic and social characteristics, for example levels of education, dwelling type and ownership status, is so far lacking.

This study identifies farming household types utilising structural and functional characteristics and determines how these types evolve over time. The study is not intended to find a preferred farmer type that could improve farmer welfare and efficiency, but rather to understand the characteristics of farmer typologies and how they have changed in order to enable the development of targeted interventions with relevant policies. This is achieved by addressing the following research questions: 1. What are the key structural and functional characteristics that explain variability in Egyptian agricultural households? 2. Using a multivariate analysis, how can agricultural households be classified? 3. How have these farming typologies evolved through time? 4. What are the possible causes of such changes?

2. Data

The most recent Egypt Labour Market Panel Surveys (ELMPS), carried out in 2012 and 2018 (Krafft et al., 2021), were used to determine the farming household typology. The ELMPS started in 1998 and was conducted in 2006, 2012, and 2018. It was designed to be representative of the labour market (Assaad and Krafft, 2013; Krafft et al., 2021). The surveys were conducted via individual and household interviews over a number of months, and included details on demography, employment, and income, among others. Sampling was carried out using primary sampling units based on enumeration areas of the government statistical master sample. Each new survey recruited the original households, new households that emerged due to splits in the original households, as well as refresher samples. At each round of the panel survey, the number of primary sampling units was increased. Results were compared to labour force surveys and censuses to ensure the representativeness of the ELMPS to the labour market (Assaad and Krafft, 2013; Krafft et al., 2021).

The 2012 survey was the first year in which detailed enquiries into the specifics of farming households were included. The ELMPS data were reinforced with data from annual governmental statistical reports (CAPMAS - Central Agency for Public Mobilization and Statistics, 2021). These reports included annual, governorate-level agricultural area and production bulletins and water use reports per crop type, and national crop and livestock incomes. These reports were used to calculate values for regional water use per unit area for each crop, crop-specific yields for each governorate, and national income per tonne of crop produced.

The 2012 and 2018 ELMPS included both individual and household questions relating to the socioeconomic conditions of the survey participants. The individual questionnaire included questions on demographic details, such as employment and education. Additionally, a household questionnaire included details of household income and capital, such as off-farm and farm enterprises, remittance, and other household income (Economic Research Forum and Central Agency For Public Mobilization and Statistics (CAPMAS), 2013, 2019).

A summary of the total and farming individuals and households of ELMPS 2012 and 2018 surveys are included in Table 1.

3. Methodology

The first stage of the analysis was data preparation. This included utilising 2012 and 2018 ELMPS and complementary data from various national statistical reports to estimate missing responses and standardise units where necessary, summarising individual responses across each household, and rebasing 2018 monetary values to 2012. Data preparation details are provided in Appendix 1. Variables were chosen from those available to capture functional and structural characteristics of the households, and for consistency with similar typology analyses (e.g. Huber et al., 2024; Nin-Pratt et al., 2018; Sarker et al., 2021; Shukla et al., 2019). Analyses of key variables of farming households demonstrate that important descriptors of variability include characteristics of the head of household – such as age and level of education - and characteristics of the household - including size, education levels of members, and dwelling type. Additionally, farming household income, capital, and off-farm income have been widely used to produce typologies for the development of policies to improve farm income and increase production (Huber et al., 2024). These variables are then used to complete an initial exploratory analysis followed by statistical and clustering analyses. Although some statistical and clustering analyses transform mixed data either into categorical or continuous forms, statistical methods using survey data in their original forms retain all information in the original data within the analysis and do not diminish its variability (Shukla et al., 2019).

Subsequently, outliers were identified by defining rational limits on certain variables, to account for missing and incorrect data – see Appendix 1 for more details – reducing the original 3593 cases to 3526. Histograms, given in Appendix 1, were used to visualise the distributions of the continuous variables. The skewness of all continuous variables was calculated, with skewness >1 and <-1 considered highly skewed and transformed to satisfy normality assumptions in subsequent methods. Box-Cox transformations were carried out using the *'MASS'* R package (Venables and Ripley, 2002). Due to the nature of the agricultural system in Egypt, many variables are highly positively skewed, representing the dominance of subsistence farming.

Correlated variables were identified using the '*hetcor*' function of the *'polycor'* R package (Fox, 2022), which provides Pearson product-moment correlation coefficients between continuous variables, polyserial correlations between continuous and categorical variables, and polychoric correlations between categorical variables. Correlations greater than an absolute value of 0.7 were deemed high and the variables were removed. Variable reduction was then carried out using the Factor Analysis on Mixed Data (FAMD) technique using the *'FAMD'* function of the *'clustMixType'* R package (Szepannek, 2018). FAMD is a combination of Principal Component Analysis and Multi Correspondence Analysis that reduces the number of variables in a mixed dataset whilst maintaining key variability (Nyambo et al., 2019).

Table 1
Summary of 2012 and 2018 Egypt Labour Market Panel Survey details.

Property	ELMPS 2012 (% of total)	ELMPS 2018 (% of total)
Total number of individuals	49,186	61,231
Total households	12,060	15,746
Farming individuals	9210 (18.72%)	8197 (13.39%)
Farming households	1821 (15.10%)	1772 (11.25%)

To determine the number of clusters, hierarchical clustering on principal components was used. The defined number of clusters was used in the 'kproto' function of the 'clustMixType' R package (Shukla et al., 2019). K-Protoypes is an unsupervised clustering on mixed data that partitions the data into k clusters, where each data point belongs to the cluster with the nearest centroid (van de Velden et al., 2018). K-prototypes uses a combination of the Euclidean distance for numerical features and the dissimilarity measure for categorical features (Foss et al., 2018).

4. Results

A total of 43 variables were included in the analysis: 10 nominal variables, 2 ordinal variables, and 31 continuous variables. Table 2 gives the mean and standard deviation of the continuous variables and the frequency and percentage of each response for the categorical variables. Fig. 1 in Appendix 1 shows the distribution of each continuous variable and the count of each response for categorical variables. Skewness is detailed in Table 5 in Appendix 1. Most continuous variables were highly skewed (−1 > skewness >1), indicating unequal distribution of resources between households. The most highly skewed variables were the total agricultural area, with a skewness of 59, and total off-farm capital, with a skewness of 50. This high positive skewness is an indication of many very low values for both variables and a small number of very high values. There were two negatively skewed variables – cropping intensity and ratio of owned to rented land – which had a skewness of −0.27 and − 0.79, respectively. These results indicate a prevalence of multiple harvests per year and a high degree of land ownership, respectively. Categorical variables are in line with expectations for farming households in Egypt, with 87% being male-headed households, higher rates of illiteracy among the heads of households than in the household, and 88% of households being rural.

4.1. Multivariate analysis

After the transformation of the highly skewed continuous variables, a correlation analysis was carried out on the transformed variables. Fig. 3 in Appendix 1 shows the correlation plot for all variables. Eight variables had a correlation >0.9, a further eleven variables had a correlation between 0.7 and 0.9. Four variables had large negative correlations. For each highly correlated pair of variables, a single variable was removed. Table 6 in Appendix 1 includes details of the highly correlated variables, the details of the degree of correlation, and the 10 variables which were removed from further stages of the analysis.

The factor analysis was carried out on the reduced set of transformed variables, and returned eigenvalues detailed in Table 7 of Appendix 2. As per the Kaiser criterion, dimensions with eigenvalues above 1 were retained. Therefore, 22 dimensions were retained, explaining a cumulative variance of 59%. Table 8, in Appendix 2, gives the contribution that each variable makes to the dimension of the FAMD. Fig. 1 shows the eigenvectors for dimension 1 and 2, and 1 and 3 of the factor analysis, indicating the relative contributions of each variable to each of the dimensions. The total variance explained by dimensions 1 and 2 is 13.6%. Cropping intensity, water use per unit area, and the ratio of agricultural to total income have the highest loading for dimension 1, whilst year of survey, the highest level of education in the household, and total household income per capita were the largest contributors to dimension 2.

Based on the factor analysis, variables contributing <10% to the first 22 dimensions of the factor analysis were removed. A total of 13 variables were removed, leaving 20 variables for the cluster analysis. The remaining variables are those highlighted in yellow in Table 8 of Appendix 2.

The subsequent stage of the analysis entailed the completion of hierarchical clustering on principal components (HCPC) to determine the appropriate number of clusters for the cluster analysis. To make this

Table 2
Data summary of typology analysis dataset. This includes the description, variable code, and data type for each variable. Additionally, the means and standard deviation for continuous variables, and count and percentage of each response for categorical variables, are included. Details of advanced, intermediate, and basic agricultural equipment are included in Appendix 1.

Variable (unit)	Data Type	Response+	Mean (Standard Deviation)* / Count (%)+
Characteristics of head of household			
Age of head of HH (yr)	**Continuous**		51.07 (13.85)
Sex of head of HH	**Categorical (nominal)**	**1 (male)**	3073 (87.15)
		2 (female)	453 (12.85)
Level of education of head of HH	**Categorical (ordinal)**	**0 (none)**	1957 (55.50)
		1 (primary)	542 (15.37)
		2 (preparatory)	175 (4.96)
		3 (general secondary)	45 (1.28)
		4 (technical secondary − 3 years)	531 (15.06)
		5 (technical secondary - 5 years)	23 (0.65)
		6 (middle institute)	36 (1.02)
		7 (higher institute)	18 (0.51)
		8 (university)	184 (5.22)
		9 (postgraduate)	15 (0.43)
HH characteristics			
Size of HH	**Continuous**		4.84 (2.30)
HH region	**Categorical (nominal)**	**Lower Egypt**	1669 (47.33)
		Middle Egypt	863 (24.48)
		Upper Egypt	994 (28.19)
Urban/rural	**Categorical (nominal)**	**1 (urban)**	413 (11.71)
		2 (rural)	3113 (88.29)
Housing type	**Categorical (nominal)**	**1 (apartment)**	1682 (47.70)
		2 (more than one apartment)	46 (1.30)
		3 (villa/house)	542 (15.37)
		4 (village house)	1063 (30.15)
		5 (one room or more in same unit)	140 (3.97)
		6 (one independent room or more)	49 (1.39)
		7 (cottage/tent)	2 (0.06)
		8 (cemetery)	1 (0.03)
		9 (other/ basement)	1 (0.03)
Housing ownership or rental type	**Categorical (nominal)**	**1 (owned)**	2868 (81.34)
		2 (condominium)	148 (4.20)
		3 (rent, unfurnished)	33 (0.94)
		4 (rent, furnished)	6 (0.17)
		5 (rent, new law)	20 (0.57)
		6 (fringe benefit/ grant)	451 (12.79)
Highest level of education within HH	**Categorical (ordinal)**	**0 (none)**	1369 (38.83)
		1 (primary)	455 (12.90)
		2 (preparatory)	256 (7.26)
		3 (general secondary)	71 (2.01)
		4 (technical secondary − 3 years)	820 (23.26)
		5 (technical secondary - 5 years)	30 (0.85)
		6 (middle institute)	64 (1.82)

(continued on next page)

Table 2 (*continued*)

Variable (unit)	Data Type	Response+	Mean (Standard Deviation)* / Count (%)+
		7 (higher institute)	32 (0.91)
		8 (university)	399 (11.32)
		9 (postgraduate)	30 (0.85)
Type of internet access	Categorical (nominal)	1 (dsl)	177 (5.02)
		2 (usb modem)	30 (0.85)
		3 (dial-up)	107 (3.03)
		4 (through neighbours)	59 (1.67)
		5 (none)	3147 (89.25)
		6 (other)	6 (0.17)
Total HH income per capita (2012 EGP**)	Continuous		11,695 (29964)
Agricultural details			
Agricultural capital			
Area of agricultural land (feddan)	Continuous		3.15 (106.11)
Advanced agricultural equipment	Categorical (nominal)	1 (yes)	642 (18.21)
		2 (no)	2884 (81.79)
Intermediate agricultural equipment	Categorical (nominal)	1 (yes)	876 (24.84)
		2 (no)	2650 (75.16)
Basic agricultural equipment	Categorical (nominal)	1 (yes)	562 (15.94)
		2 (no)	2964 (84.06)
Number of cattle	Continuous		0.91 (1.29)
Number of sheep and goat	Continuous		0.77 (3.47)
Total livestock capital (2012 EGP**)	Continuous		16,430 (20583)
Agricultural income and expenses			
Total income from crops (2012 EGP**)	Continuous		17,138 (41848)
Income from animal products e.g. poultry, honey, dairy (2012 EGP**)	Continuous		130.75 (1347)
Income from rent of land (2012 EGP**)	Continuous		734.02 (3784)
Cost of land rental (2012 EGP**)	Continuous		1101 (5995)
Total agricultural income (2012 EGP**)	Continuous		18,032 (41870)
Agricultural resource use			
Cropped area (feddan)	Continuous		1.53 (2.75)
Total agricultural water use (m^3)	Continuous		5189 (10147)
Number of HH agricultural workers	Continuous		1.76 (1.27)
Number of hired agricultural workers	Continuous		0.59 (3.21)
Agricultural efficiency			
Cropping intensity (copped area/land area)	Continuous		1.31 (0.82)
Ratio of crop earnings to crop income	Continuous		0.32 (0.34)
Cropping income per unit area (2012 EGP/feddan)	Continuous		9743 (11115)
Ratio of high-value to field crop	Continuous		0.06 (0.20)
Ratio of crop production sold at market	Continuous		0.30 (0.32)
Ratio of owned to rented land	Continuous		0.68 (0.45)
Water use per unit area (m^3/feddan)	Continuous		2666 (1974)
Livestock capital per unit area (2012 EGP/feddan**)	Continuous		26,951 (51420)
Ratio of hired agricultural workers to household workers	Continuous		0.09 (0.24)
Ratio of agricultural to total income	Continuous		0.49 (0.37)
Non-agricultural income and capital			
Total HH income from off-farm employment (2012 EGP**)	Continuous		7000 (22004)
Income from remittance (2012 EGP**)	Continuous		936.41 (6527)
Other income (2012 EGP**)	Continuous		12,339 (56589)
Total non-agricultural income (2012 EGP)	Continuous		18,032 (41870)
Total non-agricultural capital (2012 EGP)	Continuous		2362 (41180)
Survey year	Categorical (nominal)	12	1806 (51.22)
		18	1720 (48.78)

* Mean and standard deviation for continuous variables.
+ Response, count and percentage for categorical variable.
** All monetary values are presented in 2012 Egyptian pounds (EGP). This exchange rate in 2012 was 6.06 EGP to 1 USD (https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=EG).

possible, categorical variables were converted to binary coding, with each response becoming a new variable and zero or one used to identify which observation is included in this response. A principal component analysis (PCA) was carried out on the converted data. Fig. 2 shows the cluster dendrogram and inter-cluster inertia gain plot for the HCPC. A review of both diagrams in Fig. 2 shows that there are between 2 and 5 appropriate clusters. Only utilising two clusters was deemed too coarse to allow for the sufficient description of the variability within the sample population. The relative difference in inter-cluster inertia for 3, 4 and 5 clusters is similar, with 4 being slightly >5 and 3. The "NbClust" R package was used to assess the appropriate number of clusters using 23 different indices (Charrad et al., 2014). Most indices returned 4 as the most appropriate number of clusters. Appendix 5 includes details of results for 3 and 5 clusters as a comparison to the results presented below.

The final stage of the analysis entailed the use of k-prototype clustering on the dataset post-FAMD to determine the final clusters. There is a need to stipulate the number of clusters for this methodology. As per the result of the HCPC, 4 clusters were used. Table 3 includes the number and percentage of households in each cluster. Fig. 3 includes the percentage of each response for each cluster for categorical variables. Additionally, Fig. 4 includes the constituent components and total value of agricultural and off-farm income for each cluster. Finally, Fig. 5 is a radar chart of key efficiency indicators for each cluster. The efficiency indicators were scaled based on the range of each variable and the mean was calculated for all cases. The results are summarised in detail in the

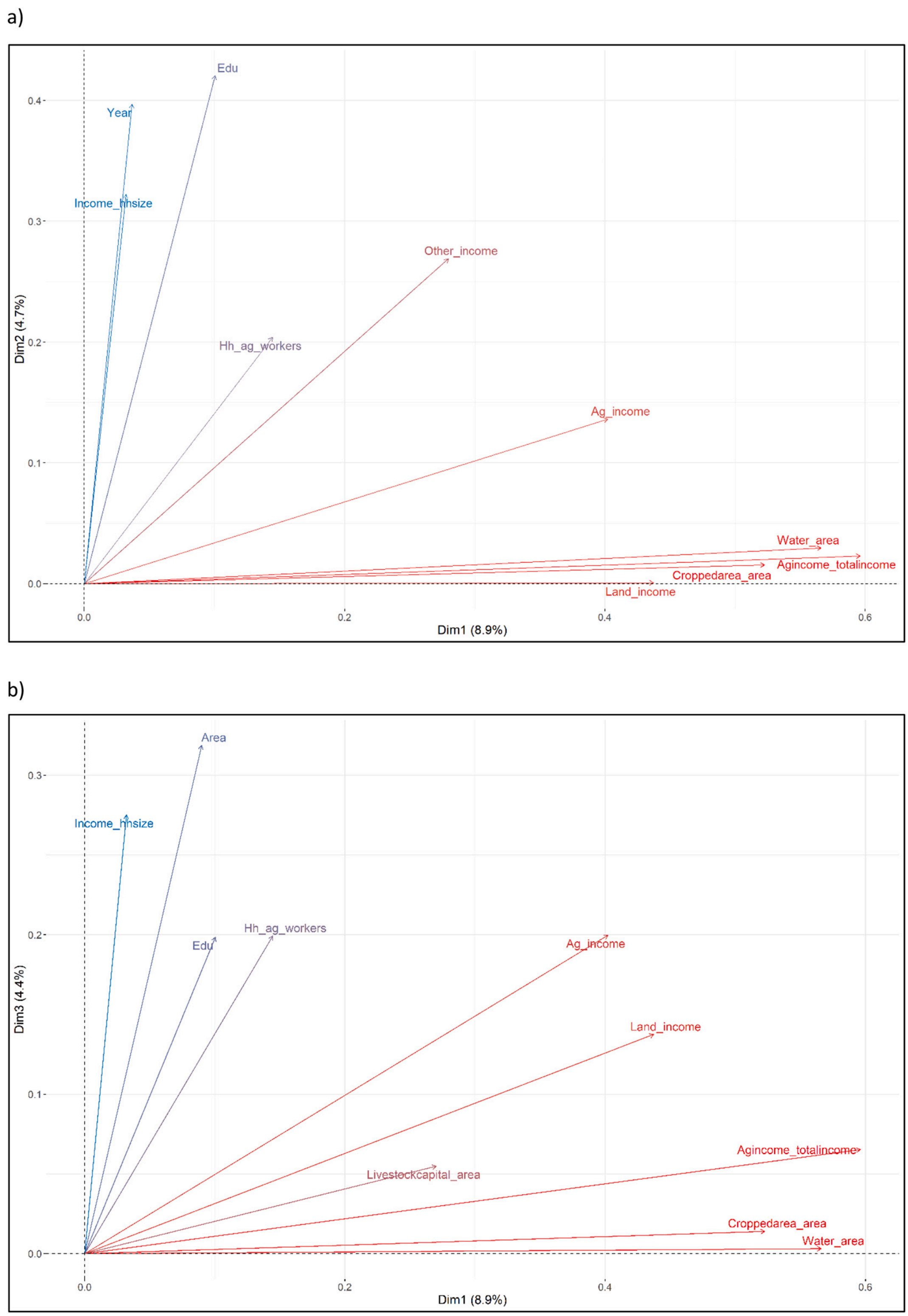

Fig. 1. Results from the Factor Analysis on Mixed Data: The ten variables which contribute the most to a) dimensions 1 and 2, b) dimensions 1 and 3. The length of the arrow shows the eigenvector, a degree of contribution. The colour of the arrow demonstrates the extent to which it contributes more to the dimension 1 (red) or the y-axis dimension (dimension 2 or 3) (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

emergent clusters section below. The emergent cluster names were assigned based on their key differentiating attributes.

4.2. Emergent clusters

4.2.1. Cluster 1: Specialised farming household

The specialised farming household type is highly specialised,

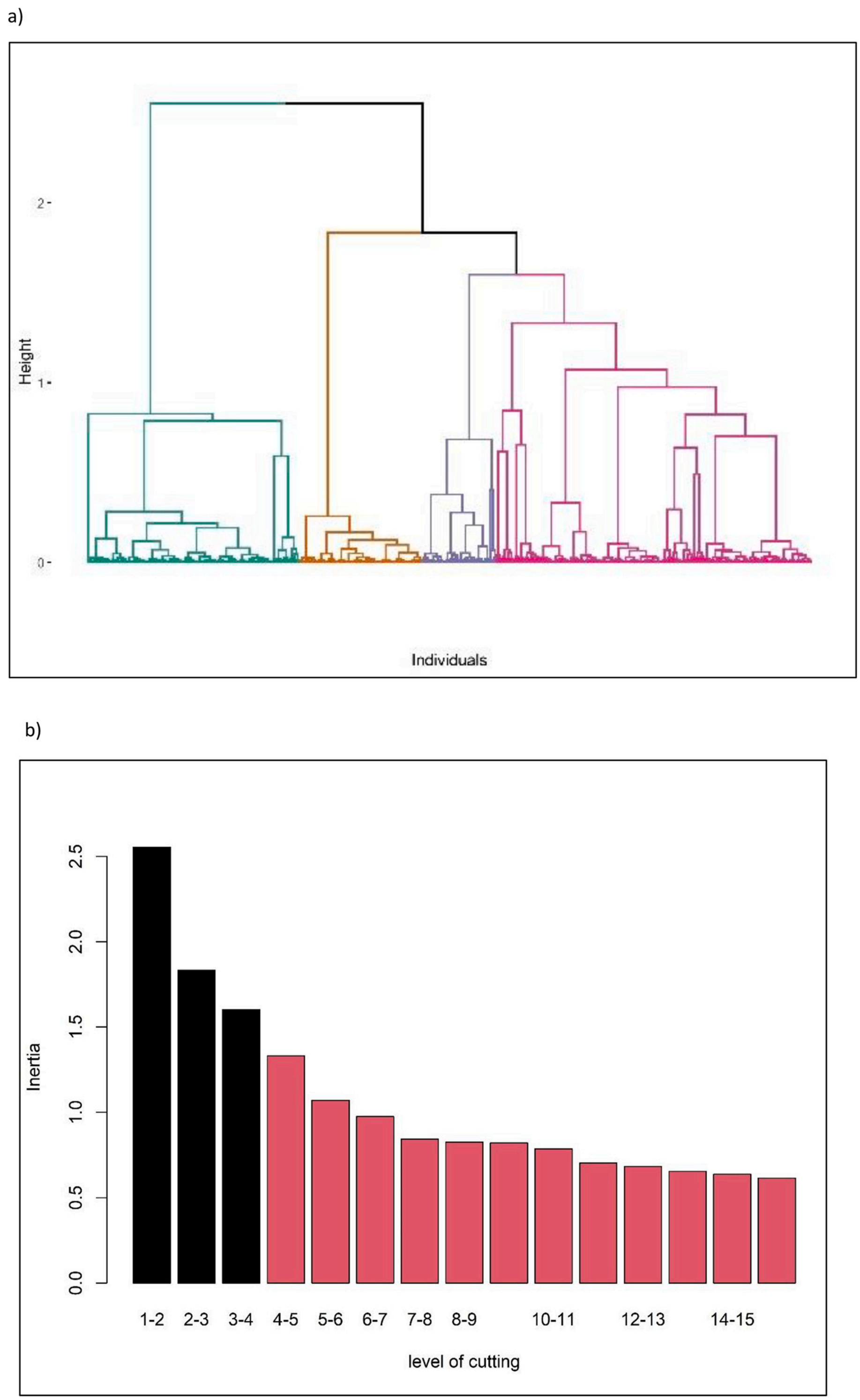

Fig. 2. Hierarchical Clustering on Principal Components results: a) Cluster dendrogram derived from the Hierarchical Clustering on Principal Components (HCPC) of survey individuals. This is derived by conducting a Principal Component Analysis of continuous variables and binary coded categorical variables, identified in the FAMD, using Ward's criterion. Four different clusters are highlighted in different colours. b) The inter-cluster inertia gain, showing the drop in inertia between each pair of cluster number. For example, the first bar shows the difference in inertia between having a single cluster and having two clusters. The difference in colour highlights the relative drop in inertia of 4 clusters.

generating 62% of their income from agricultural activity, compared to an overall mean of 49%. It exhibits the greatest profitability – 51% earnings to income - and has the highest average cropped area (2.37 feddan). This household type also has the highest ratio of high-value to field crops, with 15% of crops produced being high-value, (the mean across all households is 6%). Additionally, specialised farming households sell 49% of produced crops and use the remainder for household consumption. This household type also uses the most water per unit area at 5406 m^3/feddan. Specialisation is focused on crop production, with livestock capital per feddan being the lowest of the three household types focused on agricultural activity (17,888 EGP). However, this household type generates the most income from the sale

Table 3
Number of households in each cluster and percentage each cluster represents from the whole sample.

Cluster	Number of households	Percentage of households
1 - Specialised	650	18
2 - Village	1085	31
3 - Diversified	1130	32
4 - Landlord	661	19

of animal products, with a mean annual income of 187 EGP.

The off-farm income of this household type is dominated by off-farm employment (6335 EGP) and governmental support (5874 EGP). The specialised farming household receives the second highest income from remittances (1182 EGP), 26% higher than the overall mean of 936 EGP. However, the specialised farming household has lower levels of education, with 71% having no one with a secondary education, second only to the village farming household. Additionally, the household type has high rates of living in apartments (64%; compared to an average of 48%). This household type is also less likely to live in a village house (21% compared to the 30% average). The dwelling type may be due to a high geographical skew; 74% of specialised farming households reside in Lower Egypt which is more densely populated. Finally, the specialised farming household type is highly skewed to 2012, with 69% of this type being from 2012 households.

4.2.2. *Cluster 2: Village farming household*

This cluster is characterised by a very high rate of village-dwelling, with 60% living in village houses, compared to a mean of 30%. Agricultural income contributes 70% to the total household income, well above the survey average of 49%. However, the mean total agricultural income is 18,115 EGP, the second lowest of the four household types. The village farming household has the highest level of livestock capital (21,437 EGP). Although this household type has the highest cropping intensity (1.64), it has the lowest income per unit area (10,999 EGP per feddan). This can be explained, in part, due to the village farming household being less likely to grow high-value crops – 6% of crops grown are high-value on average – and the lowest water use per unit area between farming types that grow crops (2454 m^3/feddan). This household type employs the most external workers compared to the number of household members who work on the household's farm (0.16).

The village farming household type has the lowest level of education, with 78% of heads of households not having completed primary education and 93% not having completed secondary education. For the household, levels of education are also the lowest among the household types, with 90% of households having no one who has completed a secondary education. The village farming household type has the lowest access to internet – 96% of households are without any internet access. This household type, with an average of 5.54 people, also has the largest average household size. In terms of off-farm income, off-farm

Fig. 3. A summary of categorical variables for each cluster: The charts show the percentage of each response. Key: HH = household, agri = agricultural, equip = equipment.

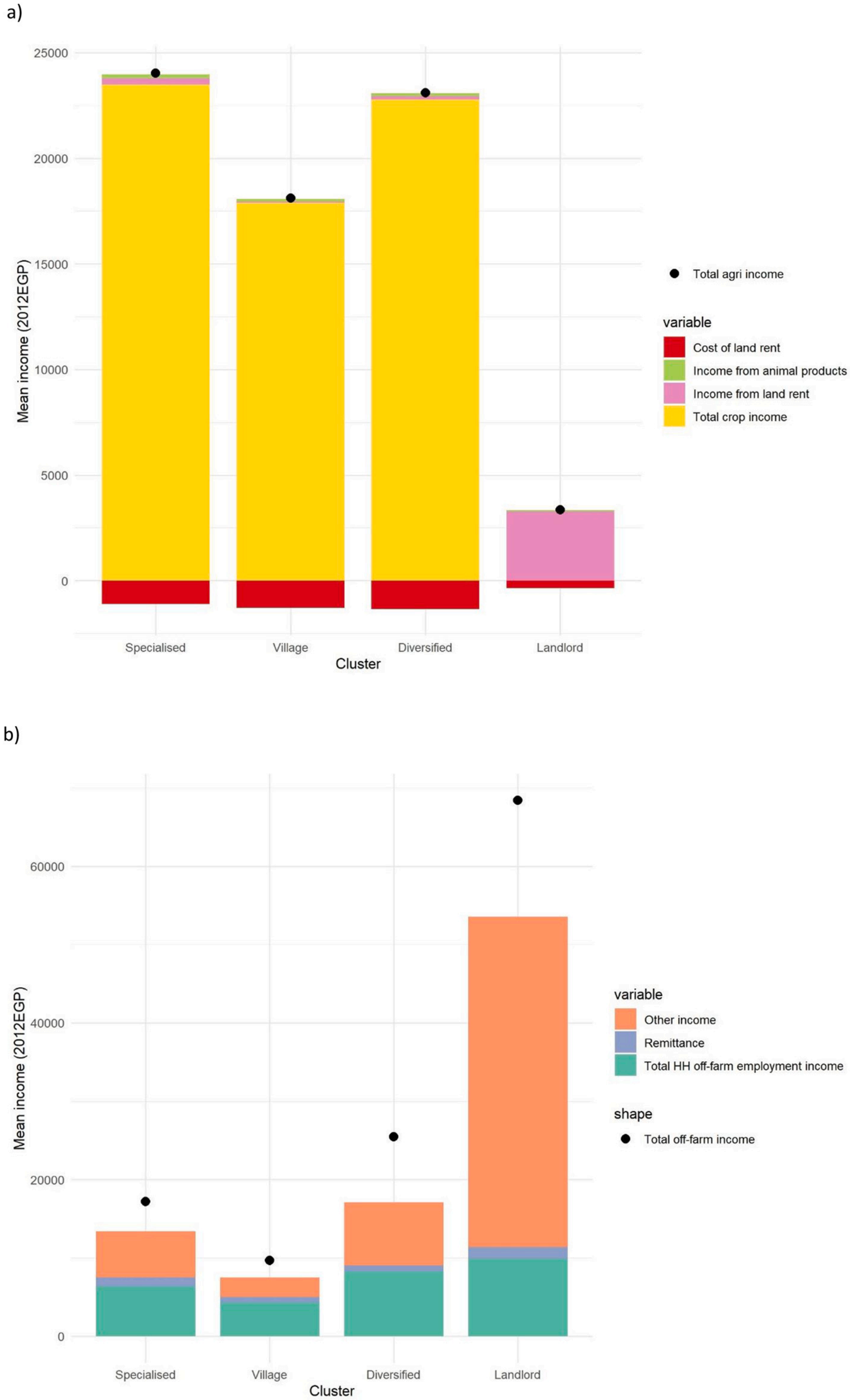

Fig. 4. Breakdown of agricultural and off-farm income for each cluster: a) The mean income per household type for agricultural income, including constituent parts and the overall mean. b) The mean income per household type for off-farm income, including constituent parts and the overall mean. Key: agri = agricultural, HH = household.

employment, and support and benefits from the government and other organisations contribute 4291 EGP and 2490 EGP annually to the total off-farm household income of 9643 EGP. The lower income and high dependence on agricultural income contribute to this household type having the lowest household income per capita (5987 EGP). The village farming household type was far more common in 2012 than 2018, with 84% of households in this household type coming from 2012. Geographically, the village farming household cluster is skewed towards Middle Egypt – 63% compared to an overall percentage of 24%.

4.2.3. *Cluster 3: Diversified income household*

This household type has the most diversified income, with 46% of income from agricultural activities and the remainder from off-farm income. The 23,098 EGP annual agricultural income is mostly

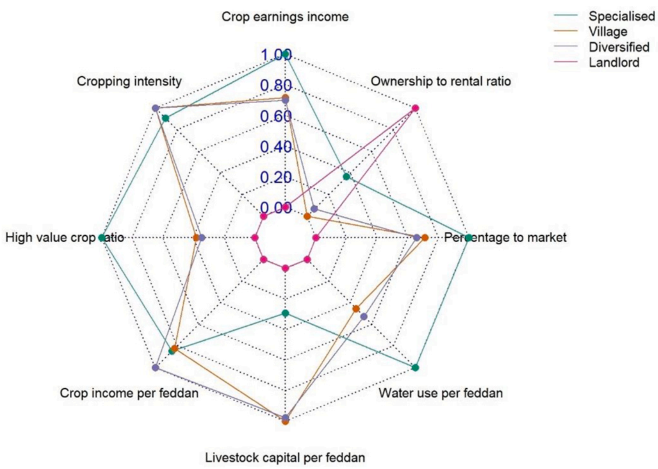

Fig. 5. Radar chart of agricultural efficiency: The ratio of crop earnings to crop income, the cropping intensity, ratio of high value to field crops, the crop income per unit area, livestock capital per unit area, water use per unit area, percentage of crop sold at market, ratio of ownership to rental of land. All variables have been standardised by range and the cluster mean for each variable is included in the chart.

generated from crop production (22,778 EGP). The diversified income household type spends the most on land rental (1341 EGP). Of the 3 household types which participate in crop production, this household type sells the least at market; only 32% of produced crops. However, the crop income per feddan is the highest of any household (13,343 EGP/feddan). The diversified income household type is most dependent on household labour and least on hired labour for farming activities, with 2.47 household farm workers and 0.26 hired workers per household. Additionally, this household type has more sheep and goats than cattle, with a mean of 0.78 head of cattle per household and 0.96 head of sheep or goats per household; a pattern that is unique among crop-producing household types.

The diversified income household type has the highest level of education, with 50% of households having at least one person who has completed a 3-year technical secondary education and 13% with university undergraduate or postgraduate education. Additionally, this household type has the lowest level of illiteracy among heads of household as only 37% have not completed primary education. Regarding off-farm income, the diversified income household type generates a total of 25,439 EGP per year. This is made up primarily from off-farm employment (8280 EGP) and governmental support (8062 EGP). This household type is much more common in 2018, with 88% coming from the 2018 survey.

The results, in Fig. 4 and Fig. 5, show that the diversified income household type is similar to the village farming household type in terms of income, and agricultural efficiency. However, the difference in degree of dependence on agricultural income, dwelling type, location, education level, and year of survey, are important differences which warrant maintaining two household types for these households.

4.2.4. Cluster 4: Landlord household

This household type has a mean income per member of household of 21,118 EGP, the highest of any household. Additionally, the typical household generates 3273 EGP per year from land rental, ten times that of any other household type. This is further highlighted by the absence of any cropped area and, therefore, no income from crop production and no crop water use. The 7% of income derived from agricultural activities comes from land rental and the sale of animal products. Additionally, this household type has low agricultural capital, with the lowest mean livestock capital of (5266 EGP) and the lowest access to basic, intermediate, and advanced agricultural equipment – with 3.5%, 5.8%, and 2.9% having access to each of those levels of equipment, respectively. The landlord household is mostly dependent on government support, deriving 42,174 EGP of a total of 68,399 EGP of off-farm income from pensions and other governmental support. Additionally, this household type earns the most from household off-farm employment, with a mean income of 9914 EGP.

The landlord household type is more likely than others to have a female head – 24% are female-headed compared to an overall survey percentage of 13%. Although this household type has the highest level of higher education – 14% of household heads have a university or postgraduate education and 22% of households have at least one person who has a university or postgraduate education – 50% of households have no one who has completed a secondary education. This appears high, but is the second-lowest among the household types. Furthermore, 61% of this household type live in apartments, compared to 48% of the overall surveyed households. The landlord household type has the highest access to the internet (23%). Additionally, this household type is the most likely to be from an urban area, with 18% coming from urban areas compared to an overall percentage of 11%. The geographic distribution of the households in this household type is similar to the overall sample, and the temporal distribution is almost equal with 48% of households from 2012.

4.3. Cluster evolution

Utilising the 2018 ELMPS, it was possible to identify the previous household IDs and determine how households transitioned between types. Fig. 6 shows the Sankey diagram from this analysis. A total of 163 (4.7%) farming households exited the panel survey after the 2012 survey, while 417 (12%) were new survey entrants to the survey series in 2018. A further 481 were new to agricultural activities in 2018. Abandonment of agricultural activities was high, with 45% (1554) of households from 2018 abandoning agricultural activity having come from households that participated in them in 2012.

In terms of household type evolution, 59% (530) of all new landowners (both new entrants to the survey and those households which are new farming households) were part of the diversified income household type in 2018. Additionally, there was a marked reduction in the number of households in the village farming household type as this household type reduced from 50% of 2012 households to 10% of 2018 households. There was also a reduction in the specialised farming household type. This household type reduced from 25% of 2012 farming households to 12% of 2018 farming households.

Fig. 6 details the expansion of households. It shows the number of households in each household type in 2012 and 2018. For example, the 906 households in the village farming household type in 2012 became 1363 households in 2018 due to household splitting as members of the household began independent households – shown here as the central, "expanded" section of Fig. 6. The village farming household and the diversified income household types exhibited the greatest rate of household expansion at 50% and 47%, respectively. The original and secondary households either continued as the same household type, transitioned to another household type, or abandoned agriculture altogether. The splitting of households explains, to some extent, the high level of household abandonment of agricultural activity. The total number of unique 2012 households which had a subsidiary household in 2018 which abandoned agricultural activity is 1098. Of these 1098 unique households, 858 had no secondary households in 2018 which carry out agricultural activities.

An analysis of the 2012 households which abandoned agricultural activities and those that continued is summarised in Table 11 of Appendix 4. These results show that households with higher livestock capital, income from crop production, and cropped area remained within agricultural activities. There were also differences between the types most dependent on farming for their income (specialised farming and village farming households) and those with greater off-farm income

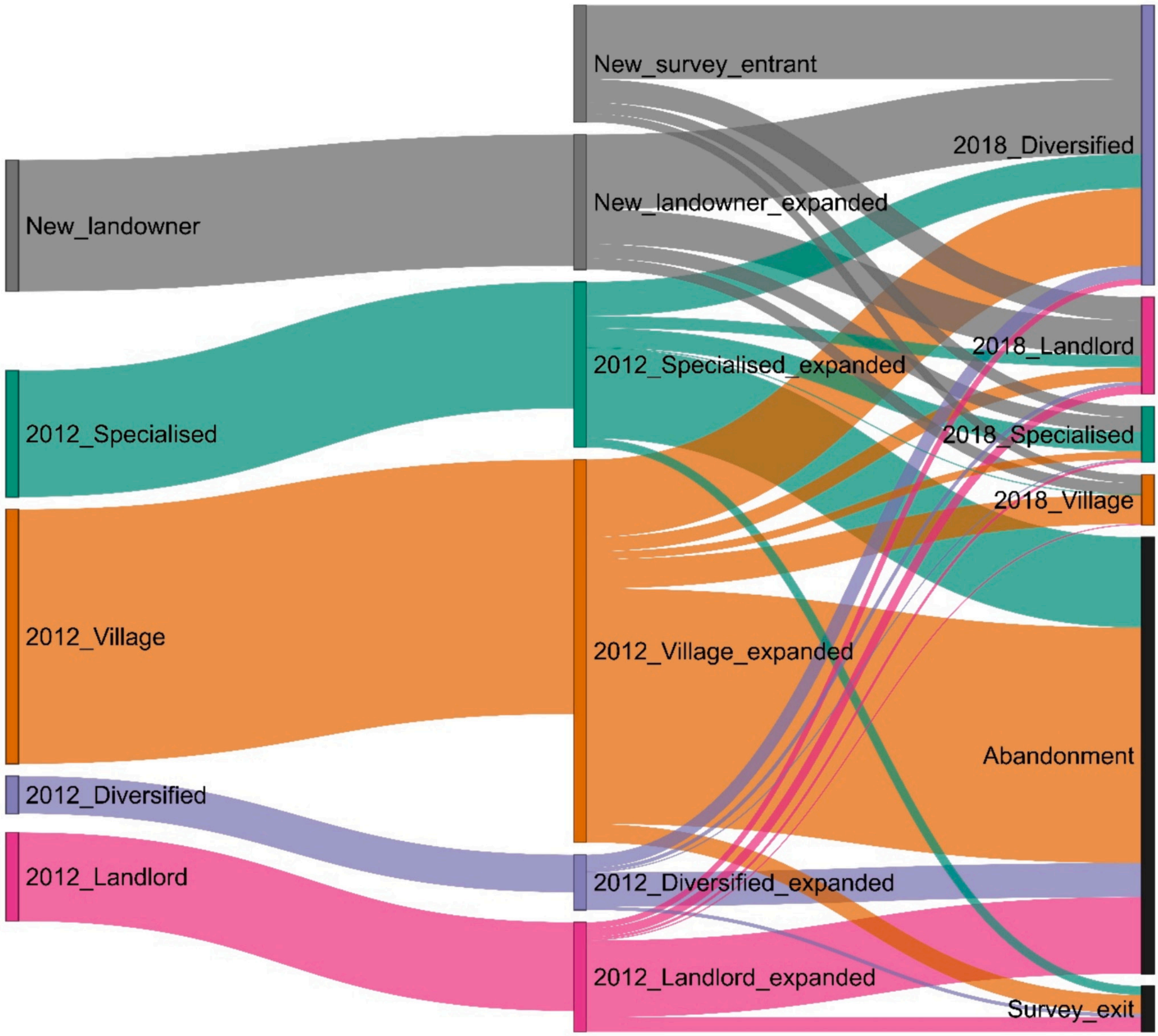

Fig. 6. Sankey plot of the transition between household types: The transition of household clusters from 2012 (left) through the expansion of the 2012 households due to household members establishing secondary households between 2012 and 2018 (middle) and the 2018 household types (right). "New_landowner" are participants in the 2012 ELMPS that only became farming households in the 2018 ELMPS. "Survey_exit" refers to households which exited the survey after 2012. "Abandonment" are households which were farming households in 2012, remain in the ELMPS but are no longer farming. "Specialised" refers to Specialised farming household, "Village" refers to Village farming household, "Diversified" refers to Diversified income household, and "Landlord" refers to Landlord household.

(diversified income and landlord households). Those most dependent on agricultural income abandoned agriculture if their off-farm income or income from governmental support was higher, whilst those who were less dependent on agricultural income remained if their off-farm income was higher.

5. Discussion

This analysis has identified four farming household types with distinct properties. Two household types are more dependent on agricultural income (specialised and village households) whilst two household types derive most of their income from other sources (diversified income and landlord households). The analysis of the evolution of agricultural households demonstrates a large transition of households away from agricultural activities. Although this is in part due to the expansion of households, there are 45% of households which no longer participate in agricultural activities in 2018 having been part of agricultural households in 2012.

5.1. Abandonment of agricultural activities

The abandonment of farming as a means of livelihood has been widely studied in developed countries but is relatively unstudied in developing country contexts (Ahmad et al., 2020). Examples where it has been studied for low-income, smallholder contexts (e.g. Helmy, 2020; Shukla et al., 2019; Valbuena et al., 2014) highlight lower resources and income as being a key driver for exiting farming. In Egypt, Helmy (2020) demonstrated that farming households were abandoning farming activity at a high rate: 40% of households included some farming activity in 2006 but only 14% in 2019. Although Helmy (2020) includes all farming activities and employment within the agricultural sector, and this analysis only includes households which own or rent land, the trend is generally reflected in the work presented here, with a rate of abandonment of agricultural activities of 45% in the observations overall. An analysis of farming household typologies in the Himalayas identified different climate change adaptation strategies (Shukla et al., 2019) and a clear trend that the least diversified and lowest-resourced household types were the most likely to abandon agricultural activities. This is represented in this analysis by households which abandoned agricultural activities, in all household types, having a lower mean livestock capital and cropped area.

Subedi et al. (2022) conducted a systematic literature review of global land abandonment and identified biophysical, economic, regulatory, and socio-political characteristics to be key causes of abandonment. The most common causes discussed in the literature were accessibility of farm, migration and depopulation, farm income, and off-farm employment. A review of land abandonment in the Mediterranean region identified similar causes for abandonment (Quintas-Soriano et al., 2022). The lowest income household type – village household – exhibited the highest rate of household abandonment of agricultural activities, suggesting that low farm income is a contributor to the abandonment of agricultural activities. However, it is not clear from this analysis what was the extent of land abandonment, but it is clear that a large proportion of households no longer depended on agricultural activities for their livelihoods.

The two surveys used here were conducted in the context of the post-Arab Spring era. There is evidence that this period of instability saw a rapid rise in urbanisation, potentially explaining the extent of the household abandonment of agricultural activities in the results. An analysis of the satellite data for Lower Egypt showed an average rate of urban expansion between 2012 and 2017 of 60 km^2/year, with a loss of cropland between 2010 and 2011 – the period of the Arab Spring – of 1.63% (502.21 km^2) (Badreldin et al., 2019). This is mirrored in the review of land abandonment, which highlights political instability and collapse of political systems as a cause of abandonment of agricultural activities (Subedi et al., 2022).

5.2. Explanatory variables

Resource use efficiency, such as water use per unit area, cropping intensity, and the percentage of total income derived from agricultural activity, were the main variables contributing to the principal dimension of the FAMD. Additionally, household properties such as household education level, dwelling type, and total household income per capita are key to explaining the variability within the farming households. Resource endowment is commonly a key dimension in farming household typologies (Falconnier et al., 2015; Sarker et al., 2021; Shukla et al., 2019), with higher resource endowment resulting in greater efficiency and productivity. However, in this analysis, the village farming household, which has the greatest livestock capital, land area, and cropping intensity, has the lowest income per unit area.

Characteristics of the head of household, most notably their level of education, are key descriptors of variation between household types in this analysis. The education level of the head of household varies between the different household types in this analysis – household types which are less dependent on agricultural income have heads of households with higher levels of education. This is similar to the results of the typology analysis in Beni Suef (a governorate in Middle Egypt) by Martin et al. (2020), which identified heads of households with a higher level of education as a key indicator of increased income diversification. However, unlike Shukla et al. (2019), for example, who demonstrate that household types with high resource endowment have older heads of household, this analysis does not identify age as a key descriptor of the differences between household types. Although this relationship is not common in all analyses; for example, a farming typology analysis in Bangladesh showed that age did not improve the adoption of technology (Sarker et al., 2021).

The degree of livelihood diversification is a key differentiator between the different household types. Martin et al. (2020), who undertook a typology analysis of smallholder dairy farmers in Beni Suef, identified the greatest income diversification among poor farming households, with the very poor and the rich diversifying less. This is similar to the results here, where the village farming household and landlord household – the lowest and highest income household types, respectively – were highly dependent on farm and off-farm income, respectively. Martin et al. (2020) propose that low educational or material resources limit the ability for income diversification. This is similar to the results of the clusters identified in this analysis, where the village farming household type has the lowest level of education and is the most dependent on agricultural income. However, the household type with the lowest land resource – diversified income household – has the lowest dependence on agricultural income of the three household types which produce crops. The increase in the diversified income household in 2018 compared to 2012 would suggest that fewer households depend on agricultural income, with more utilising off-farm income, such as income from off-farm employment, to meet household needs.

5.3. Gender

This research considered gender by including the sex of the head of the household among the analysis variables. Female-headed households are not common in Egypt, as shown in the results. The landlord household type, which has 24% female-headed households, compared to around 10% in other household types, was less likely to participate in crop production and was more dependent on income from land rental. This may be in part due to social norms about physical labour and single women participating in male-only spaces. An investigation of female participation in irrigation activities in Egypt showed that women from lower-income female-headed households were likely to participate in irrigation activities out of necessity due to lack of alternative income and the absence of means or the support for someone else to do it (El Garhi et al., 2019). The higher representation of female-headed households in the landlord household type is notable because these households have a greater average income per capita. Most studies of female-headed households in Egypt suggest that the majority of female-headed households are less well-off than male-headed households, often with higher rates and deeper levels of poverty (AbdelLatif et al., 2019). This analysis suggests that this is not the case, at least among farming households.

5.4. Limitations

This analysis utilised a large, national labour market panel survey dataset. However, several typology analyses include more detailed questions on attitudes, views, and perceptions (Hien et al., 2014; Sarker et al., 2021). This can be particularly useful when trying to understand technology adoption or climate change adaptation strategies. Additionally, a long-term longitudinal survey enables the identification of clear trends in the evolution of household types (Falconnier et al., 2015). This analysis would benefit from being repeated using a longer time series and more survey responses relating to attitudes to and perceptions of technology adoption and climate change adaptation. Another limitation of this study is that the survey is designed to be nationally representative of the labour market and demographic characteristics (Krafft et al., 2021; Nin-Pratt et al., 2018) and not necessarily of farming characteristics, such as the crops grown, and access to agricultural equipment. Due to the dataset size, it may be representative of the agricultural sector in Egypt, however, a dedicated survey that specifically attempts to represent the agricultural sector may provide more representative results. What is not specifically clear from these results is to what extent the abandonment of agricultural activities directly relates to abandonment of land. A survey designed to be representative of the agricultural sector could include questions to determine the degree of land abandonment and compare this to household abandonment of agricultural activities.

6. Conclusion

Egyptian agriculture faces several resource constraints which are exacerbated by climate change and continued population growth. Farm and farmer typology analyses are useful tools to identify key characteristics and describe the heterogeneity within a diverse population whilst maintaining a manageable number of archetypes. This work utilises labour market panel survey data for 2012 and 2018 to carry out a typology analysis. Measures of agricultural efficiency - such as the cropping intensity and water use per unit area, household characteristics, and the survey year were important for describing the variability within the survey population. The analysis identifies four household types: specialised farming households, village farming households, diverse income households, and landlord households. The analysis demonstrates a trend towards greater income diversification and reduced dependence on agricultural income. This is mirrored by high rates of abandonment of agricultural activities, and a strong move away from the agriculture-dependent village farming household type, in 2012, to more diverse incomes, in 2018. This analysis provides the basis for targeted policy strategies and development interventions by identifying farm typologies, the key variables which describe the variation between them, and the evolution of the typologies. Targeted interventions could improve the profitability of households dependent on diverse incomes, enabling them to achieve higher incomes for the limited time available to conduct farming activities. Additionally, less profitable farming households that are more dependent on agricultural income, could be targeted to either improve livelihoods through diversification of income or finding alternative incomes in rural settings. Further analysis of the relationship between households who abandon agricultural activities, identified here, and land abandonment is needed to ensure that productive land is not left unused, especially in the context of the large shortfall in domestic production. Additionally, policies are needed to empower smallholder farmers to become profitable enough to continue agricultural activities, whilst increasing resource use efficiency.

CRediT authorship contribution statement

Aimen Sattar: Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Calum Brown:** Writing – review & editing, Supervision. **Mark Rounsevell:** Writing – review & editing, Supervision. **Peter Alexander:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.104000.

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