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International Journal of Agricultural Sustainability

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tags20

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**To cite this article:** Bezaiet Dessalegn, Eman Abd-Allah, Shaban Salem, Atef Swelam & Yigezu A. Yigezu (2022) Explaining shifts in adaptive water management using a gendered multi-level perspective (MLP): a case study from the Nile Delta of Egypt, International Journal of Agricultural Sustainability, 20:7, 1397-1414, DOI: 10.1080/14735903.2022.2082765

**To link to this article:** https://doi.org/10.1080/14735903.2022.2082765

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
2022, VOL. 20, NO. 7, 1397–1414
https://doi.org/10.1080/14735903.2022.2082765



# Explaining shifts in adaptive water management using a gendered multi-level perspective (MLP): a case study from the Nile Delta of Egypt

Bezaiet Dessalegn [a], Eman Abd-Allah[b], Shaban Salem[b], Atef Swelam[c] and Yigezu A. Yigezu[a]

[a]International Center for Agricultural Research in the Dry Areas, Cairo, Egypt; [b]The Agricultural Research Center of Egypt, Cairo, Egypt; [c]Office of Innovation, Food and Agriculture Organization of the United Nations (UN-FAO), Rome, Italy

**ABSTRACT**

Understanding the logic behind farmers' choice of adaptive water management practice is important to appreciate the opportunities and challenges they face and to scale targeted solutions effectively. This paper aims to understand the main drivers of change that induce adaptation in water management. The Multi-Level Perspective (MLP) framework that juxtaposed the within and across micro-, meso-, and macro-level drivers was applied to a case study of the Nile Delta to identify key drivers of change and farmers' adaptive responses. The framework helped in contextualizing key gender, temporal, and spatial dimensions of the drivers, and to identify their individual and interactive effects on farmers' adaptation decisions. We find that farmers' gender-differential water management choices are influenced not only by the individual changes in the three spheres of influence but also their interactions. The study highlights the benefits of using MLP to identify challenges that should often be tackled simultaneously to improve agricultural water delivery and use. We demonstrated that adaptation choices in water management are more sustainable when farmers' decisions are supported by enabling environments, including local regulations, norms, national institutional frameworks, and policies. They are also informed by and responsive to global trends such as climate change and markets.

**KEYWORDS**

Adaptation; gender; multi-level perspective; irrigation water management; climate change

## 1. Background

The Middle East and North Africa (MENA) are one of the most water-scarce regions in the world, with an average annual per capita water consumption that is about half of the water scarcity threshold (1000 $m^3$/capita/year) and an expectation to reach the absolute water scarcity threshold (500 $m^3$/capita/year) by 2025 (Bird et al., 2016; Qadir et al., 2010). Egypt has one of the world's lowest per capita water shares globally, which is further aggravated by increasing population growth and industrialization (MWRI, 2014). Agriculture is one of the cornerstones of the Egyptian economy, which consumes 86% of Egypt's water share and supports the livelihoods of about 55% of the population (Abu Zeid & Elrawady, 2014). Effective management of water resources is thus a national priority to maximize efficiency per unit of water and rationalize its use to meet the growing demand within the agricultural and non-agricultural sectors.

Egypt's irrigation water in is mainly sourced from the Nile River and freely supplied to farmers through a well-established irrigation network. The main canal water is supplemented with agricultural drains. Recycling of the drainage water is officially managed by the Ministry of Water Resources and Irrigation (MWRI), which either pumps it back into the Nile River and irrigation canals or uses it to recharge shallow groundwater in the Nile Delta (Wolters et al., 2016). Within the delta, farmland location is

**CONTACT** Bezaiet Dessalegn b.dessalegn@cgiar.org International Center for Agricultural Research in the Dry Areas, 2 Port Said, Victoria Square, Ismail El-Shaaer Building, Cairo 11711, Egypt
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

critical in determining farmers' access to and reliance on canal and/or drainage water, which determines a farmer's access to the amount and quality of water. Generally, water availability and quality decline as one goes from the head to the tail end of the canal or drain. The access also varies over time depending on changes in temperature and changes in water demand and consumption by upstream users. In the latter case, the change also includes changes in the quality of effluents that enter the drains, including the quality of the agricultural drainage, treated wastewater that is pumped into the drains, and discharges from neighbouring households (Molle et al., 2013). Therefore, farmers are constantly learning and adapting to make the best use of scarce resources to support their livelihoods.

*Adaptation* refers to a specific reaction to a shock or change and involves some form of learning (Stringer et al., 2020). It includes responses to perceived risks and calculated responses to maximize benefits and become more resilient (Tatlıdil et al., 2009). Adaptive management can be applied at the individual, community, national, and global levels depending on the driver of change and ability to adapt, including the policy and institutional environment, which enables or hinders change (Simane et al., 2016; Tompkins & Adger, 2003). However, the literature indicates that adaptive management is relatively easy when it is done by an individual, as the entire process starting from adaptive experiments to adaptive governance, happens within one person who has the flexibility to learn by doing and continually adapt and change as needed (Stringer et al., 2020).

*Adaptation and adaptive water management* are also influenced by several factors that influence farmers' adaptive capacity and their preferred choices of response. Among these include differences in adequate and timely access to key natural resources, information, technologies, markets, and alternative sources of income; variations in levels of education; incompatibility of technologies with local conditions; and institutional frameworks, which create enabling environments or hinder large-scale adoption of proven technologies and agricultural practices (Emerick et al., 2016; MacAlister & Subramanyam, 2018; Nguimalet, 2018; Nyberg et al., 2021; Rodenburg et al., 2021; Sujakhu et al., 2018; Tessema et al., 2017; Yigezu et al., 2021). The literature is, however, dominated by analysis from biophysical perspectives where the goal is to improve resource management at different levels, or is neoliberal oriented where the goal is to find optimal economic outcomes that provide the best economic scenario from the perspective of the household or national economic interest. The role of gender in technology adoption processes is also well documented by many other studies, which demonstrate the gender-based differences in access to extension services, improved seeds, agricultural technologies, etc. and its subsequent effect on low levels of adoption and agricultural productivity on women-owned farms (Doss, 2015; Gaya et al., 2017; Nyberg et al., 2021; Peterman et al., 2010; Ragasa et al., 2013, 2014). However, there is a gap in the literature that systematically presents a comprehensive view of the combined effect of different factors that influence farmers' choice of adaptation strategy. Against this backdrop, we seek to understand the key factors that influence farmers' choice of an adaptation strategy and the interlinkages between them if any.

In the next section, we delve into the methodology used to identify the study sites and collect and analyze the data. In Section 3, we present the results of our analysis – which applies the MLP approach to establish a comprehensive and gendered understanding of the factors that influence farmers' decisions, the discussion of which is offered in Section 4. The last section summarizes the key findings and concludes with suggestions for future studies to understand the logic behind farmers' choice of adaptive water management practices.

## 2. Materials and methods

In this study, we seek to answer the following specific questions:

(i) What are some of the key bio-physical and socio-economic factors that influence farmers' choice of adaptive water management practices?
(ii) Are there gender-based differences in the types of adaptive water management practices implemented by male and female farmers?
(iii) Are there inter-linkages between the different factors? And if so, how do they collectively influence farmers' choices of adaptative water management practices?

To this effect, we use data on various variables collected from several sources and specific locations in Egypt, to which we applied the MLP approach, the details of which are presented below.

### 2.1. Study area

Kafr El-Sheikh governorate is located in northern Egypt, bordered by the Mediterranean Sea in the North, by Gharbia governorate in the south, Dakahlia governorate to the east, and by River Nile's branch in Rashid to the west. The governorate's total area is about 3748 $km^2$ and is characterized by traditional agriculture. Dominant crops grown in the area include rice, wheat, corn, and broad beans. The governorate suffers from a chronic water shortage, especially during the summer season, as it is located at the tail-end of irrigation canals. Farmers thus commonly use agricultural drainage water, which is of lower quality, to irrigate their fields. The governorate's proximity to the sea also exposes it to high levels of soil and water salinity due to high groundwater tables and seawater intrusion. While the villages located at the head of the drain sometimes use mixed water (canal and drain water) for irrigation, the quality declines as one moves along the drain, with villages located at the tail-end at times mixing the drain water with water from the Mediterranean Sea. As is the case with many farmers in the delta, most farmers in Kafer Sheikh use surface irrigation. The study was conducted in Hamrawe, Daqalt, and Arimon canal domains, representing different water management practices (Figure 1).

### 2.2. Data

For data collection, the three sites in the governorate were purposely selected to represent areas with different but traditional water management practices such as furrow surface irrigation, elevated concrete mesqas by replacing earthen ones, and subsurface pipelines, respectively. Daqalt also represents an area where improvement in legislation and organizing management practices was undertaken. Additional information on the selected areas, including current water management practices implemented, is summarized in Table 1.

Site selection was further broken down by the location of the farms along the canals to account for differences in quantity and quality of water available to them. As such, selected sites represented the upper, middle, and tail end of each domain (see Figure 2).

Qualitative data were collected to garner the required insight and nuance into the complexities that inform farmers' choice of adaptation strategy. The data were collected using Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) held with relevant stakeholders. FGDs were selected as a preferred method of data collection as they offer greater opportunities and flexibility to seek a deeper understanding of standard views on the topic because they, for further exploration through follow-up questions, capitalize on collective memory to establish the historical chronology through agreed landmark events, and assess the logic behind farmers' choices and decisions (Asmamaw et al., 2011; Nyumba et al., 2018). The discussions were guided by semi-structured objective and subjective questions, which sought to capture the incremental nature of adaptation to challenges in agricultural productivity, including changes in – access to quantity and quality of water, arable land, agricultural information, and inputs; markets; government policies and social norms; the role of a community-based organization (CBOs), and perceptions on climate change (CC). During the FDG, we encouraged discussion and recorded only the results that got consensus. KIIs were needed to solicit expert opinions from selected individuals, who have special knowledge on the subject matter, either based on their specific position or role within the overall irrigation water management in the area (Marshall, 1996). The KIIs were also conducted using semi-structured questions designed to solicit required data from those knowledgeable in terms of experience, expertise, and historical knowledge.

A total of 27 KIIs were conducted with relevant community members, including agricultural and specialized extension agents, governorate level public officials, and heads of agricultural cooperatives (AC) and water user associations (WUAs). A total of 34 FGDs were held with 308 participants representing different community groups to account for variations in capabilities at their starting points and the types of adaptive responses available to them (Table 2). In the mid canals of Deqalt and Arimon, two FGDs each were held among the men, women and youth as there were more people available to participate in the discussions. In so doing, we included vulnerable groups of the community, whose perspectives are often excluded or under-represented (Adger, 2006). This is also based on the understanding that different management practices have different implications on different members of the community (positive and negative externalities) and that vulnerabilities could be compounded by other shocks to the system.

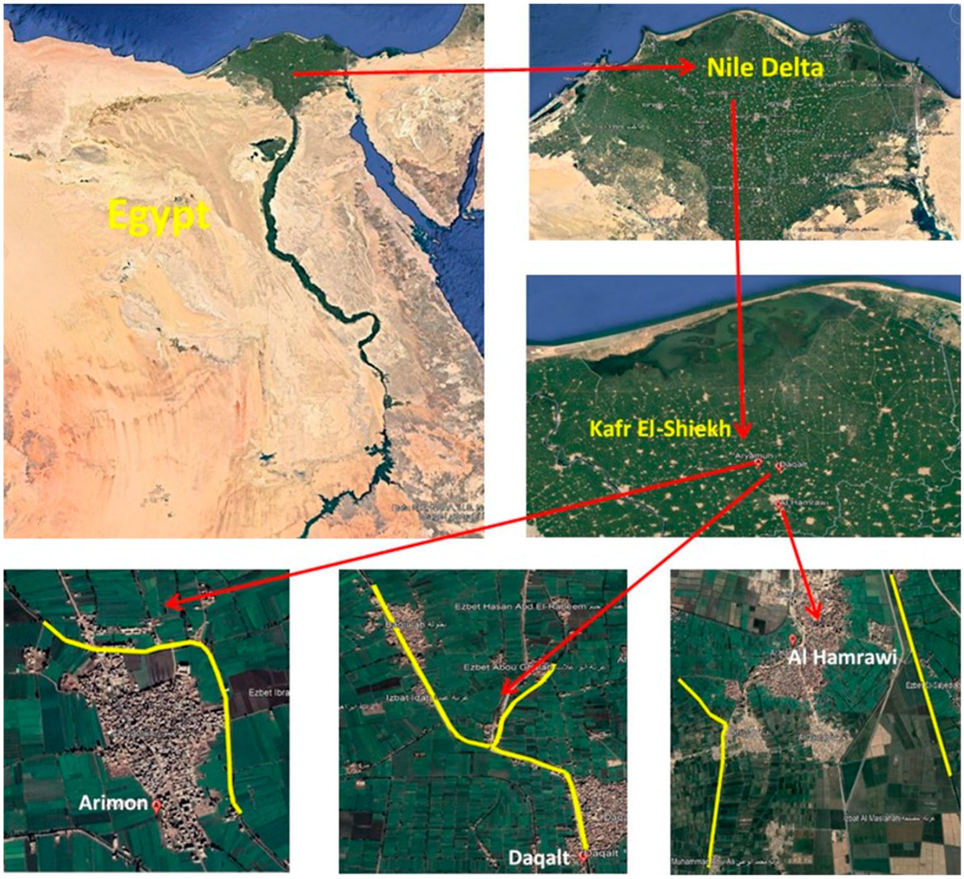


**Figure 1.** Geographic locations of the study area.

FGD discussions were held among farmers with land holdings in the head, middle and tail ends of Hamrawe, Daqalt and Arimon branch canal domains.

**Table 1.** Management practices at the level of the three canal domains.

| | Hamrawe | Daqalt | Arimon |
|---|---|---|---|
| Start Date of Implementing Improved Irrigation | – | –2007 1998 | 2003/2002 |
| Mesqas' Improvement Start Date (Improved Field Irrigation) | – | 2001 to date | 2011, 2016 |
| Fuel/Energy Source | – | Diesel | Electricity and Diesel |
| Total Cultivated Area | – | 5500 acre | acre 3300 |
| Total Improved Area | – | 4440 acre | acre 835 |
| Improvement Rate (Improved/Cultivated) | – | 0.8 | 0.25 |
| No. of Stations | – | 74 | 31 |
| No. of Community-based organizations | – | 4 | 1 |

The farmers were randomly selected from among a pool of farmers identified through a stratified sampling method to ensure equal geographical representation. Recall-based questions were used to establish a historical recount of the drivers and ensuing reactions. Farmers were thus encouraged to compare their current practices with their management practices 5 and 10 years ago and explain the logic behind their decisions to adapt their ways. The questions also sought to capture normative changes to assess broader contexts that facilitate or hinder change.

In the case of CC, we expanded the time to 30 years, as trends in CC take longer to manifest. According to IPCC's MENA report, CC is expected to increase temperature and reduced annual precipitation in the region (IPCC, 2021). However, reduced precipitation is not anticipated to impact Egypt as average rainfall is already low. We thus considered changes in average annual temperature as a proxy indicator for CC to

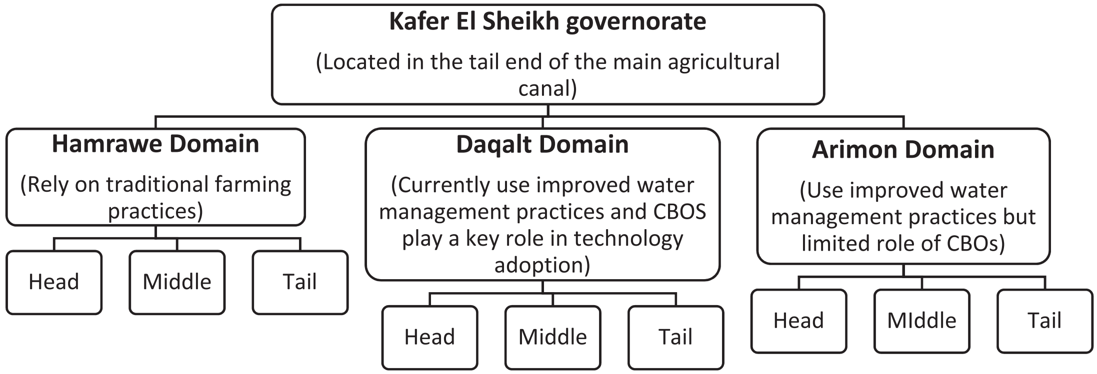


**Figure 2.** Hierarchic description of the specific sites selected for the study.

assess farmers' awareness of climate change and climate variability and its potential effect on agriculture (Tadese et al., 2021).

As changes in temperature are understood by farmers in relative terms, we used coloured and numbered gradients to assess their perceived change on a scale ranging from 0 (coldest summer temperature) to 10 (extremely hot temperature in the summer), and another scale ranging from 0 (Warmest winter temperature) to 10 (extremely cold temperature). Gradient number 5 represented the average temperature in both cases. Colour codes showed participants the incremental differences between the gradients (See Figure 3). Although the initial plan was to use these as Likert scales during the discussion, it proved difficult to secure specific numbers as farmers preferred to speak in relative terms such as 'hotter', 'warmer', and 'colder'. The planned quantitative analysis was thus revised, and the collected data were analyzed along with the rest of the qualitative data collected using thematic coding schemes.

#### 2.2.1. Ethical considerations

Ethical protocols were made throughout the data collection process. All the participants involved in the FGDs and the KIIs were informed that all collected information would be confidential. They were made aware that they should only answer questions that they are comfortable addressing and that they could stop the discussion and/or interview at any time. All the interviewees were voluntary participants. All the individual answers were recorded as confidential information and were analyzed anonymously to be strictly used for the study. All data were collected after verbal consent to these conditions was received from all participating individuals. No specific permissions were required from local authorities though they were informed of the study's objectives and planned to collect qualitative information and were given copies of all proposed questions.

### 2.3. Methods

Collected data were first transcribed and systematically organized into thematic groups and subgroups in line with the research questions. Then, we created a large matrix based on three variables, namely village, location, and farmers' grouping. Each of the first two had a three-tier classification within, while the third had a four-tier classification as follows: The village variable takes one of three values, namely Arimon, Hamrawe, or Daqalt; the location variable is classified into three categories called Upstream, Middle, and Tail; and a farmers' grouping can be either of men, women, youth, or woman household head. Accordingly, we created a $3 \times 3 \times 4$ matrix containing 36 cells indicating that each question was answered by 36 unique respondent types. As the same questions were presented to each of the unique groups, a qualitative analysis method was used to compare the results in each of the 36 cells and identify similarities and differences. The data were further scrutinized to understand the explanations for the findings and assess the validity of the data through triangulation. Responses from the KIIs were very useful to validate some of the responses from the farmers and in offering insight into relevant community and national level influences. Due to the nature of the data (single observation per unique cell), no statistical analysis or parametric and non-parametric tests were carried out in this study.

**Table 2.** The number of individuals consulted through FGD and KIIs.

| Canal | Irrigation method and location | | No. of participants in FGDs (one FDG/location) | | | | KKIs with key stakeholders | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Women (younger) | Men (older) | The Youth | Women HHs (older) | Chairman of Coop | Agric Extension Agent | Water and Climate Ext. Agent | Gov. level Ag. Official | WUAs |
| Hamrawe 1 | Traditional irrigation 0 | | 16 | 20 | 16 | 9 | 2 | 2 | 0 | | |
| Daqalt* | Improved Irrigation | Head of canal | 10 | 13 | 10 | 1 | 1 | 1 | 2 | | 1 |
| | | Mid of Canal | 19 | 18 | 16 | 8 | 2 | 2 | | | 2 |
| | | Tail of Canal | 10 | 12 | 10 | 1 | 1 | 1 | | | 1 |
| Arimon** | More Improved Irrigation | Head of Canal | 11 | 10 | 10 | 1 | 2 | 2 | | | 1 |
| | | Mid of Canal | 16 | 18 | 17 | 7 | | | | | 2 |
| | | Tail of Canal | 10 | 10 | 8 | 1 | | | | 1 | |
| Total number of individuals consulted | | | 92 | 101 | 87 | 28 | 8 | 8 | 2 | 1 | 8 |

*Serves more than one village and **serves only one village

### 2.3.1. The multi-level perspective (MLP) framework

MLP involves classifying themes into different levels of influence. We use an adapted version of the MLP approach, generally used in innovation studies to understand the initiation, evolution, and adoption of innovations. Under the MLP approach, change from one technology to another is an outcome of multiple inter-related factors that occur at the micro, meso, and macro levels, as opposed to single causation (Geels, 2002, 2004, 2005, 2010; Geels & Schot 2007; Markard & Truffer, 2008; Smith, 2007; Smith et al., 2010). The micro-level captures the niches that facilitate the generation of radical innovations; the meso-level represents the landscape where innovations become stable and even go through trajectories supported by enabling environments; and the macro-level represents the scenario where changes take place in gradual steps (Geels, 2002).

Adapted versions of the approach have been applied in other studies. For instance, MLP was used to explore reasons for abandonment of maize landraces in Mexico (McLean-Rodriguez et al., 2019). In this case, MLP was used to study varietal loss as a process while accounting for multiple causes and the interactions among them. We adopt the transparency of the MLP framework, particularly its ability to consider different factors across various levels and spheres of influence to understand farmers' adaptation choices. We use the MLP approach to explore the role of multiple drivers of change across the micro-, meso- and macro- levels of influence and across different community groups and their subsequent implication on farmers' choice of adaptation strategies.

In this study, the *micro-level* refers to drivers of change over which the farmer has control or the ability to respond to and influence outcomes; the *meso-level* represents community-level factors, including norms and institutions that reinforce or create an enabling environment for change that farmers can organize themselves to respond to; and the *macro-level* represents slow-changing factors including policy changes, population growth, global economic trends, and climate changes that are beyond the control of the individual farmers or communities. We used these descriptions to classify and categorize collected data on various drivers of change that induce farmers' individual and/or collective adaptation measures. We explored their interactions for a

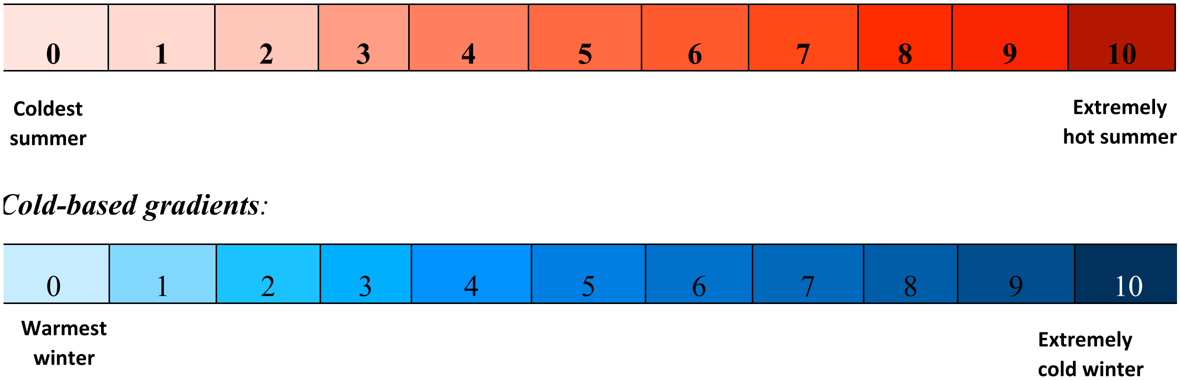


**Figure 3.** Colour-coded scales to assess perceptions of temperature changes.

comprehensive understanding of the system. In this context, adaptation is understood as incremental changes induced by changes in one or more levels of influence. We used the MLP to examine how farmers adapted their water and land management practices in response to emerging challenges across the three levels of influence by comparing current practices with strategies used 5 and 10 years ago.

## 3. Results

The results show key adaptation strategies widely used by farmers, including changes in the source and/or methods of irrigation, crop and/or varietal choices, agronomic practices, energy sources used to power irrigation pumps, the contribution of agriculture to household income, reliance on the private sector, gender norms and perceptions of a 'good farmer', contribution of agriculture to household income, and shifts in roles of civil society concerning agricultural water management. Collected data on key parameters were analyzed by age with special consideration of the youth, sex (male/female), and geographic location – to capture the contextual variations in endowments at the respective starting points, differences in access to essential resources, and ability to adapt and respond to prevalent challenges. Findings on each adaptation strategy, including the timing and reasons for adaptation, are presented below.

### *3.1. Change in the source of irrigation water*

Under this category, the results show key bio-physical conditions that influence farmers' (men, women and youth) choices of adaptive water management practices. Farmers' access to water is primarily influenced by the amount of water the Ministry of Water Resources and Irrigation (MWRI) releases into the canal. Before 1990, the amount was based on established cropping patterns (Kassim et al., 2018). Currently, farmers in the *old* (the Delta) and the *new* land (reclaimed agricultural land) can grow what they want. However, this compromises MWRI's water rationing decisions and availability for downstream users.

The geographic farm's location also determines the type, amount, and quality of irrigation water farmers can readily access. Depending on the farm's location, farmers can tap into cleaner canal water or be forced to rely on agricultural drains of varying quality to irrigate their farms. Those located at the head of the canal or agricultural drain tend to receive better quality and a more stable flow of water than those that own land at the middle or tail end. The latter face relatively greater water shortages, especially during the summer and times of drought. The water quality also tends to be at its worst, which aggravates challenges with soil salinity, increases the demand for fertilizers and pesticides, and limits crop choices that can be grown under such limited bio-physical conditions. , The location of the land also determines soil salinity (proximity to the water table) and availability and access to groundwater. Therefore, farm location can create or hinder opportunities for different adaptation strategies.

We find that 10 years ago, all the three domains solely depended on canal water. However, in the last five years, farmers began to rely on alternative sources due primarily to the growing population and increasing demand for water – within and outside the agricultural sector. The results show that even though total water available in the branch canals was declining for all three sites, farmers with land holdings in the head and middle part of Daqalt and Arimon domains continued to alternate between using canal water and mixing canal water with marginal water, while those at the tail-ends mainly relied on marginal water. The two domains benefited from large-scale projects invested in concrete lining the masqas or field level irrigation canals from where the water is lifted.

On the other hand, farmers with holdings in the Hamrawe domain who did not benefit from such large projects increasingly relied on marginal water and groundwater. Continued use of groundwater, solely or mixed with drainage water of compromised quality, also increased soil salinity – limiting their crop choices and costs of production and reducing their profit margin. The challenge was even more pronounced for female-headed households who did not own land, relied on marginal lands, and had no or limited access to groundwater and extension services to learn plausible coping strategies. In all three study sites, we found that farmers at the tail ends of the respective canals had limited access to irrigation water, especially during the summer seasons, and received poorer quality water, which limited their crop choices.

### 3.2. Changes in irrigation methods

The results show that surface irrigation is the dominant method in the study areas. However, large-scale investment in concrete lining irrigation canals in Daqalt has led to the use of sub-surface irrigation to increase water use efficiency and reduce waterlogging and soil salinity. However, such systems require substantial investment by the farmer and commitment by the community to maintain the infrastructure and ensure its efficient use. This option was primarily adopted by farmers who owned their farmland, could afford such an investment, and were supported by Water User Associations (WUAs) that coordinated the overall water management system. When considering differences among the sexes, we find that women heads of households and the youth were at a disadvantage in terms of land ownership, size of land owned and having the required financial resources to invest in such an undertaking.

### 3.3. Changes in land size

The results show that per capita ownership of agricultural land is declining due to increases in family size resulting in land fragmentation, land loss to salinity and peri-urbanization with increasing encroachment on agricultural land due to the construction of residences and infrastructure (Abdelmageed et al., 2019; Alfiky et al., 2012). For instance, urban areas in the Nile Delta significantly increased from 755 $km^2$ to 1890 $km^2$ during 1992–2015, an average of 47 $km^2$ per year (Radwan et al., 2019). The size of agricultural land owned or rented limits farmers' crop choices and discourages crop rotation and adoption of technologies. Land ownership and inheritance are also influenced by cultural norms wherein the ownership rate for women in the area is very low (Najar & Baruah, 2020). Farmers in all groups agreed that small land size is one of the driving forces for owning or renting multiple pieces of land.

### 3.4. Change in crop and/or varietal choices

The results identified change in crop and/or varietal choices as a common adaptation strategy. The parameter was thus analyzed in greater detail to understand the various drivers of change that influence farmers' (men, women and youth) adaptation choices. We find that depending on the specific location – farmers either increased, decreased, and in some cases stopped the production of selected crops; and/or shifted planting seasons in response to changes in policies, water, and land scarcity, soil salinity, input and output markets, and their perception of climate change in terms of increase or decrease in temperature, and trends in water availability.

The FGD indicated that farmers changed their planting and harvesting time of summer crops, including rice and maize, in response to their perception of temperature increases. Farmers recalled that before 2014, they used to plant rice in June and harvest it in October. By 2017 the planting and harvesting season changed to May and August, and they currently plant it in April and harvest it in August. An increase in temperature also affects available water for irrigation, as irrigation interval increases during the summer season. In response, farmers replaced rice with maize because it requires less water. The increase in temperature also affected salinity levels in their fields due to higher usage of marginal water sources with high salinity levels. Farmers responded by applying agricultural gypsum to their soil.

Similar changes were made for planting and harvesting schedules for winter season crops such as wheat. Before 2014 farmers planted wheat in late November and harvested it in May. Now they plant in early November and harvest in May. The change was not as dramatic because wheat is a national strategic crop with extensive research and extension service committed to developing and delivering varieties tolerant to biotic and abiotic stress.

Access to agricultural inputs also influenced farmers' decisions on crop choices. We find gender-based variations in access to inputs, as men could access subsidized fertilizers from ACs, where land ownership is a criterion for membership. Women thus had to purchase more expensive and uncertified fertilizers, which increased their overall cost of production. However, access to improved seed varieties was somewhat similar between men and women, as both mainly sourced their seeds from the national agricultural research center or the market. Those with such access grew crop varieties that are high-yielding and tolerant to many biotic and abiotic stresses. For instance, farmers in all three sites and despite their location along the canal sustained production of wheat, rice, corn, clover, and sugar beet over the past five years.

Socio-economic status also influenced farmers' ability to pump groundwater and hire labourers during peak seasons. Men in all three sites had relatively better access to information through frequent contact with extensionists and membership in AC. Women's reliance on labourers for planting and harvesting caused financial stress. We learned that labour (availability and cost) was the main factor influencing farmers' decision to stop growing cotton over the past five years.

Adaptation strategies pursued concerning each crop are discussed below.

(i) *Cotton*: used to be cultivated 10 years ago in all three locations with average productivity of 8–9 quintals/acre. However, planted areas started to diminish five years ago due to water scarcity, increasing cost of production, including the cost of labour, fertilizers and pesticides; and shifts in policy and market trends, including contract farming where farmers enjoyed guaranteed markets before production. The reduction of subsidies for cotton since 2015 also resulted in its reduced production and its substitution with rice – a more lucrative summer crop (Kassim et al., 2018). Increasing import of cotton at competitive prices also resulted in a declining demand from local factories. Currently, all three sites do not produce cotton.
(ii) *Rice*: is grown by farmers in all three sites, but productivity is low in Hamrawe due to water shortage and quality and soil salinity. The problem is worse among those without alternative water sources and with limited access to timely information on plausible solutions. In both cases, female-headed households fared poorly, followed by young farmers who did not own land and could not benefit from subsidized inputs through membership in ACs.

On the contrary, farmers with land holdings in the head and middle of the Daqalt and Arimon canal domains benefited from increased productivity due to water availability and active roles of extension services in raising awareness and promotion of new drought-tolerant and high yielding rice varieties. However, those in the tail-ends of both domains faced challenges with water shortages and high soil salinity levels.

(iii) *Corn*: productivity in Hamrawe fluctuated due to water shortage and increasing soil salinity due to frequent use of groundwater in irrigation. On the other hand, productivity increased in Daqalt and Arimon domains due to water availability and access to new high-yielding varieties. Farmers in Daqalt and Arimon also began using the crop as silage over the past five years, increasing the value of the crop. We found that though men, women and youth faced similar biophysical limitations in increasing productivity, the cost of production for those who did not own land was slightly higher due to their lack of access to subsidized inputs. Women-headed households also faced added labour costs and had limited access to advisory services and improved seed varieties.
(iv) *Sugar Beet*: production and productivity increased over the years in Hamrawe and farmers located at the tail-end of the Arimon canal because the crop tolerates salinity. Farmers in these areas use manure to improve soil fertility which had deteriorated due to increased use of marginal water

sources for irrigation. Men, women and youth with land holdings in these areas used this as an adaptation strategy to compensate for the loss of productivity in other crops.

(v) *Wheat*: is a strategic crop that is nationally promoted and supported through various policies and large projects. Farmers thus have better access to seed varieties that are drought-resistant and high-yielding; and enjoy a guaranteed market where they directly sell their wheat to the government at a higher price (Abdelmageed et al., 2019; Kassam & Dhehibi, 2016). Wheat producers also benefit from access to subsidized nitrogen fertilizers provided through ACs. Therefore, farmers generally grow wheat, which offers a more secure livelihood. However, we find that the benefit is relatively higher for farmers in Arimon and Daqalt with land holdings in the head and middle parts of the canal and those with access to subsidized fertilizers, improved seeds and extension services. We find that in all counts, women-headed households and youth relatively benefit less.

### 3.5. Increased reliance on the private sector

Among the key drivers of change commonly identified by consulted farmers are shifts in the role of the private sector. The parameter was thus separately analyzed to understand its role in influencing farmers' decisions. Changes in input and output markets directly affect the cost of production, overall profitability, and farmers' income. Farmers indicated that 10 years ago, the selling prices of dominant crops were determined by the government and announced before the planting season, contract farming was common, and ACs facilitated collective marketing. However, with market lateralization, including the reduced role of the Egyptian Agricultural Bank in providing subsidy and credit and diminished roles of contract and collective marketing – farmers now rely on the private sector to secure essential agricultural inputs and sell their produce.

Although changes in the marketing system apply to both sexes, we found that male farmers have the added advantage of travelling outside their villages to market their produce and have better information on input markets and the quality of products offered – giving them better negotiation power on product prices. The latter is essential as gaps in enforcing quality control on chemical inputs have led to the marketing and use of ineffective inputs. Ensuring access to timely information on market forecasts and outlets the ability to explore markets outside their villages and negotiate prices have thus become essential adaptation skills for the average farmer.

### 3.6. Change in agronomic practice

We find that a common adaptation strategy changes in agronomic practices in response to shifts in weather patterns, water and land availability, soil fertility, etc. We find that 10 years ago farmers commonly practiced mixed cropping and crop rotation due to relatively better access to water, agricultural land, stable market systems, and the 1960 government policies that required farmers to practice crop rotation (Gouda 2016). However, farmers explained that with the abolishment of the policy, drastic changes in water availability, increase in the cost of production, land fragmentation, climate variability, and market fluctuations – they stopped practicing crop rotation five years ago. This was the same in the case of male and female farmers in all study areas, though the challenge was slightly pronounced among the youth and female farmers who tend to have smaller plots of land. However, we learned that some farmers with land holdings in the head of the Daqalt and Arimon branch canals still practice mixed cropping as they have relatively better and stable access to water.

### 3.7. Change in roles of community-based organizations (CBOs)

Local institutions are integral rural partners for sustainable and inclusive natural resource management (Pretty et al., 2020). ACs and Water User Associations (WUAs) have a similar role in the Egyptian Agricultural System. ACs are organized under the auspices of the Ministry of Agriculture to facilitate farmers' access to agricultural inputs and advisory services (Abdelhakim, 2017). WUAs operate at the mesqa and branch levels and focus on improving irrigation systems, devising irrigation schedules, and resolving conflicts (Amer et al., 2017; El-Haddad et al., 2020).

Understanding the specific roles of the ACs and WUAs in promoting water management practices is thus essential. We find that WUAs in Daqalt and Arimon were better organized through support from large-scale infrastructural projects that built technical and organizational capacities of the associations, thereby equipping them to play an active role in monitoring the water management system (Table 3).

Installed gates and water flow control locks allowed WUAs to ration available water better. Farmers adapted by changing their energy source from diesel – which is very expensive, to electricity – which is partially subsidized to save on time and cost of irrigation. Farmers also changed lower capacity irrigation pumps (20–40 L/second) to larger capacity ones (60–120 L/second) to efficiently use available water. However, the role of WUAs was relatively diminished in the Hamrawe command area, where traditional irrigation practices prevailed, and no-large projects were implemented. As is the case with ACs, we find women's representation and face-to-face engagement with leaders of WUAs to be nominal.

### 3.8. Change in norms

Cultural norms are the unwritten self-enforcing rules comprising collective beliefs, practices, perceptions, and guiding principles that govern societies (Young, 2015). Therefore, changes in social norms are slow processes requiring deep and widely experienced triggers that initiate change and acceptance among the majority. The results indicated shifts in gender norms. We thus created a separate category to assess changes in norms and their role in influencing farmers' decisions to adapt their ways. We find change in norms as an outcome and initiator of commonly applied adaptation strategies to key drivers of change summarized in Table 3 below. Two specific changes in social norms were identified through the study, namely changes in gender norms that dictate the roles of men and women within the public domain, including on- and off-farm activities, and changes in one's perception of a 'good farmer'.

**Table 3.** Key roles of WUAs in Daqalt and Arimon.

| | | |
|---|---|---|
| Daqalt | Head of Canal | Raising farmers' awareness on reducing the length of irrigation time to avoid over-irrigation, wastage, and conflict among farmers |
| | Mid of Canal | Applying irrigation shifts to organize the irrigation process, community mobilization to reapply concrete lining on selected mesqas, and monitoring changes in energy sources for pumping irrigation water |
| | Tail of Canal | Applying irrigation shifts to organize the irrigation process, ensuring the appropriateness of improved irrigation stations to available water in the canal |
| Arimon | Head of Canal | Raising farmers' awareness on reducing the length of irrigation time to avoid over-irrigation, wastage, and conflict among farmers; monitoring the use of sub-surface irrigation |
| | Mid of Canal | Raising farmers' awareness on reducing the length of irrigation time to avoid over-irrigation, wastage, and conflict among farmers |
| | Tail of Canal | Regulation of irrigation schedules to manage a large reduction in the amount of irrigation water |

We find that the roles of young male farmers in agriculture mainly dwindled because of increases in costs of living, land fragmentation, high cost of production but low revenue from agriculture, elimination of subsidies and credit services, and increased mechanization, which reduced demand for labor, improved education levels, and prospects to earn better income outside of the agriculture sector, and opportunities for temporary migration to neighboring countries. This was also partially true for older male farmers with small landholdings and located at the tail-ends of the three branch canals under study.

The role of female farmers in agriculture also diminished because of increased mechanization, which reduced demand for their labor, abandonment of cotton production, and increasing use of the broadcasting method for planting rice and shifting to other activities like poultry and livestock production. The increasing cost of living and the inability of households to sustain their livelihoods solely based on the agriculture sector, coupled with increasing enrollment of women in education, also created unique prospects for women to pursue non-agricultural employment opportunities. The shift from traditional norms that limited their productive role to work on neighborhood farms thus gradually changed as an adaptation strategy to respond to challenges within the agricultural sector.

Progressive changes in *perception of a 'good farmer'* were noted across the sexes and study locations. All respondents alleged that 10 years ago, a 'good farmer' was perceived to be the one 'who devotes full attention to farming and conserving his farmland, cares to clean irrigation and drainage canals on regular basis and earns enough money to cover the costs of living for himself and his family'. The perception slightly changed five years ago with additions of other attributes including 'the desire to learn and use new crop varieties and technologies that help minimize losses and achieve high productivity'. Current perceptions emphasize that the 'farmer realizes high productivity and net revenue, is financially capable and uses modern technology' representing a shift from a previous focus on conserving or maintaining environmental sustainability of farmlands and communal engagements.

### 3.9. Shifts in the contribution of agriculture to household income

According to farmers' responses, the sector's contribution to household income is gradually declining due to water scarcity, land fragmentation, increases in the cost of production, market fluctuations, increased education levels, and increased urbanization which created alternative job opportunities, pull factors in regional labor markets, as well changes in gender norms that increasingly allow women's participation in productive services outside of the sector.

Furthermore, data collected on the various adaptation strategies were categorized into three levels following the MLP framework (Table 4).

## 4. Discussion

Collected data on farmers' adaptive response to key drivers of change were further analyzed to gain insight into the intricate and complex interlinkages

**Table 4.** Summary of intra-level adaptation strategies used to respond to changes in key drivers.

| Key drivers of change | | | Adaptation strategy |
|---|---|---|---|
| Macro-level | Meso-level | Micro-level | |
| - Population growth | - Water available at the branch and mesqa level -the impact of large-scale projects on water conveyance efficiency | - Access to advisory services, their financial ability to invest in alternative water sources, and manage soil salinity at the farm level | Change in the source of irrigation water |
| | -Location along the branch canal - The impact of large projects, the role of WUAs (G) | - Farmers' capabilities to invest in alternative energy sources and pumping engines | Changes in irrigation method |
| - Increase in temperature requiring shifts to short-maturing crops; increased water scarcity; policy changes on subsidies, credit and input-output market regulations, advanced research and dissemination of improved crop varieties | - Changes in irrigation water available at the mesqa level, land fragmentation, labour markets (G), extension services (G), and availability of alternative water sources, farm-level soil and water salinity (G) | - Farmers' socio-economic status in terms of land ownership and financial ability to tap into groundwater resources; their access to information, agricultural inputs, credit, and market outlets; sex and age; and ability to manage farm-level soil salinity | Change in crop and/or varietal choices |
| - Policy changes on input subsidies and contract farming, energy pricing, and changes in international demand and supply of key commodities such as wheat and cotton | - Changes in labour markets (G), water availability, and the role of ACs in facilitating collective marketing (G) | - Farmers' socio-economic and educational status, personal connections and networks, prevalent gender norms that conditioned women's role in the public domain, and personal dispositions to negotiate prices (labour, machinery, inputs, and output) | Increased reliance on the private sector |
| - A policy that deregulated the practices, water scarcity, and climate variability | - Geographic-based water allocation and market fluctuations, equitable access to extension services (G) | - Limitations in land size and access to alternative irrigation water sources | Change in agronomic practice |
| The increased cost of living and cost of production, better opportunities for off-farm income-generating opportunities | Change in gender norms | Increased levels of education, better opportunities for off-farm income-generating opportunities | Shifts in the contribution of agriculture to household income |
| Policy changes that reduced the roles and responsibilities of CBOs | - A large project implemented in the two domains | - The financial capability to change energy sources and/or capacity of irrigation pumps | Change in roles of CBOs |
| - Population growth, changes in standards and costs of living, increase in education coverage, increase in peri-urbanization, and globalization | - Growing challenges in the agriculture system and its declining ability to sustain livelihoods (G) | - Willingness to adapt and continually seek ways to sustain their livelihoods | Change in norms |

Note: Due to the challenge in presenting them in this table, the interaction effects of inter-level drivers of change are elaborated in the discussions section. 'G' denotes the presence of gender-based constraints at meso-level; all micro-level influences are gender-sensitive.

between different levels of influence and how these define farmers' capabilities and options to adapt. The MLP framework is adapted to categorize and understand the drivers from the perspective of their individual and combined spheres of influence. We begin by contextualizing and categorizing the different triggers of change into specific levels of influence and present their combined role in necessitating the specific adaptation strategy.

We find that changes in the *source and amount of water* available for agricultural use were influenced by a combination of factors that span across the three levels of influence. At the macro-level, population growth increased overall water demand, while at the meso-level, adaptation strategies were influenced by the impact of large-scale projects on water availability at head, middle and end-tails of branch canals. Farmers' decisions also depended on micro-level influences, including access to advisory services, their financial ability to invest in alternative water sources, and manage soil salinity at the farm level.

The results demonstrated that *changes in irrigation methods* – from traditional furrows to sub-surface irrigation were a direct effect of meso-level influences, such as location along the branch canal, large-scale investments facilitated through megaprojects, and the role of WUAs that maintained and ensured its sustainable use. Alternatively, farmers' choice of energy source and type of irrigation pump was influenced by personal financial capability – a micro-level influence.

Farmers' explanation for *shifts in crop and/or varietal choices* also cut across the three levels of influence. Macro-level triggers include changes in import-export markets, climate variability that required shifts to short-maturing and drought-tolerant crops, increased national water scarcity; and policy changes on subsidies, cropping patterns, input-output market regulations including preferential gains for wheat producers, and agricultural credits; as well as advances in agricultural research and dissemination of improved crop varieties. Meso level drivers such as changes in irrigation water availability at the mesqa level, land fragmentation due to population density and encroachment on agricultural lands, labor markets, extension delivery, and availability of alternative water sources played a critical role in influencing farmers' adaptation strategies. At the micro-level, farmers' socio-economic status in terms of land ownership and financial ability to tap into groundwater resources, their access to information, credit and agricultural inputs, market outlets, sex and age, as well as ability to manage farm-level soil and water salinity influenced their options and preferred choices of adaptation. Although productivity levels varied depending on access to water, and despite their location along the canal, farmers in all locations continued growing wheat, rice, corn, clover and sugar beet over the past five years.

Similarly, farmers' *increased reliance on the private sector* was induced by changes across the three levels of influence individually and the interactions among them. At the macro-level, policy changes on input subsidies and contract farming, energy pricing, and changes in international demand and supply of key commodities such as wheat and cotton influenced local commodity pricing, forcing farmers to adapt their ways. At the meso-level, prices were influenced by changes in labor markets, water availability, and the role of ACs in facilitating collective marketing. Specific choices of adaptation strategy at the micro-level were influenced by farmers' socio-economic and educational status, personal connections and networks, prevalent gender norms that conditioned women's role in the public domain, and personal dispositions to negotiate prices (labor, machinery, inputs, and output).

The results indicate that farmers' choices to abandon or continue practicing selected *agronomic practices* were influenced by macro-level triggers such as changes in policy that regulated the practices, water scarcity and climate variability; as well as meso-level deviations including geographic-based water allocation, market fluctuations, equitable access to extension services; and micro-level influences related to limitations in land size and access to information, alternative irrigation water sources.

Changes in *social norms* involve slow processes and often require multiple triggers of change across the three levels of influence before wide acceptance of a 'new' norm is ensured. In this case, we find the changes in gender roles in agriculture and perceptions of a 'good farmer' were induced by growing challenges in the agriculture system and its declining ability to sustain livelihoods. The change also simultaneously adopted several adaptation strategies, including the increased ability of women to earn income outside of the home and the sector in general, as well as perceptions that push farmers to focus on increasing productivity by adopting new and improved agricultural practices. Socio-economic status also influenced farmers' ability to pump groundwater and hire laborers during peak seasons. These factors were similar across the three sites, though differences between men and women.

The above analysis shows the complexities of the triggers and levels of influence that guide farmers' choice of an adaptation strategy and are summarized below (Table 3).

As presented in Table 4, certain drivers of change generate domino effects where macro-level triggers induce meso-level and micro-level triggers of change. For instance, change in the quantity and quality of available irrigation water initiated: (i) macro-level influences, including policies on cropping patterns and agronomic practices, export and import markets on selected crops; (ii) meso-level influences, including water allocation in-branch canals, implementation of large-scale projects to improve water conveyance, changes in social norms and perceptions, and the role of CBOs in facilitating water management; and (iii) micro-level influences such as irrigation water availability at the mesqa level and levels of salinity.

Similarly, population growth, which is a macro-level change, influenced other changes within the same level of influence, including reduced availability of water for agricultural use, the reduced ability of government to subsidize agricultural inputs, and equitably and adequately provide credit and extension services; meso-level influences, such as the reduced role of ACs, demand for labor and agricultural inputs and outputs, and changes in perceptions and social norms. At the micro-level, population growth resulted in reducing per-capita water and land allocations, the contribution of agriculture to household income, and increased peri-urbanization and labor migration.

In other cases, some drivers of change simultaneously trigger different responses. For example, policy change in subsidized agricultural inputs compelled farmers to increasingly rely on the private sector, adjust crop and/or varietal choices, abandon certain agronomic practices, and seek alternative non-agriculture-based income sources. Likewise, the introduction of large water management projects led to the increased role of WUAs in managing water allocation, changes in crop choices and agronomic practices corresponding to water availability, and shifts in energy sources and pump sizes.

## 5. Conclusion

Water scarcity coupled with population growth and anticipated increases in temperature threaten agricultural productivity in the MENA region. For countries like Egypt with limited water resources and dependence on irrigated agriculture, maximizing water use efficiency is a national priority. In the context of these broad challenges, we assessed the evolution of Egyptian farmers' adaptive water management and tried to gain insight into the drivers behind their decisions. We used the MLP approach to contextualize the drivers of change within different spheres of influence, examine the interlinkages among them, and appreciate the complexity of the system and its influence on farmers' choices. We also considered several other factors, including location and gender, that create differential access and capabilities among farmers. In doing so, we established that the drivers of change under the different spheres of influence are often inter-related where a change in one leads to a ripple effect on another in terms of creating an enabling environment to sustain or reverse changes that are initiated.

The study highlighted that changes within the micro-sphere of influence (location of farmland and demographic and socio-economic characteristics) have differential outcomes on men, women, and the youth relative to changes in the meso- and macro-spheres of influence. We also observed that while farmers' micro-environment considerably influences the menu of adaptation options available to them, several meso- and macro-level factors directly and/or indirectly limit their choices. Changes in norms and perceptions also frame the opportunities available for men and women and influence their choices of adaptative management.

The study demonstrates the complexity and interlinkages among the various triggers of change. Hence, the need to consider systemic and integrated approaches beyond the micro-level to create enabling environments that will support and sustain the changes. Hence, the chances of future strategies in achieving more inclusive, equitable, and efficient use of water resources may depend on whether they consider: (1) policy changes that encourage sustainable and efficient use of scarce natural resources and recommend adaptation practices that enhance productivity; (2) building institutional capacity at different levels of management to ensure equitable and adequate provision of essential agricultural inputs and information; (3) facilitating strategic engagement of the private sector with corresponding policies on monitoring the quality of services provided; and (4) investing in market forecasts to support farmers in aligning and strategizing their adaptation strategies to minimize the impact on their livelihoods as opposed to being reactive. Reliable and timely market information will aid farmers in selecting the right type and amount of crop to produce. Moreover, we recommend the collection and analysis of a combination of qualitative and quantitative data to shed more light on the issue. We encourage future research on adaptive water management to consider integrated approaches that cut across all three spheres of influence. Climate change adaptation strategies should thus ensure that men, women, and youth farmers are well-informed, equipped, and supported so that adoption of recommended water management practices will be equitable and sustainable.

## Acknowledgements

The authors would like appreciate for the financial support provided by the Water Land and Ecosystem CRP and the many individuals who coordinated and facilitated data collection. Our special thanks go to the male and female farmers who were willing to sit with us and patiently respond to our questions and provide the required data, without which this research would not have been possible.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was financially supported by the Water Land and Ecosystem CRP, under Grant [200095].

## Data availability statement

Considering the sensitivity of the personal data collected, the complete data supporting this study are housed with the Agricultural Research Center of the Ministry of Agriculture.

## Notes on contributors

*Ms. Bezaiet Dessalegn* is a social scientist with the International Center for Agricultural Research in the Dry Areas (ICARDA). She has over 20 years of experience in development spanning over with a focus on food security, agriculture and rural development, adaptation and adoption of agricultural technologies, and action research and mainstreaming gender in research. Her work experience spans over 12 countries. She holds a master's degree in International Development and Social Change from Clark University in Massachusetts, and a second Master's in International Relations and Public Policy from Purdue University in Indiana, USA.

*Dr. Eman Abd-Allah* studied Agricultural Economics. She obtained her Masters' Degree in Agricultural and Rural Development from the Institute of Social Studies in the Netherlands, and her PhD degree in Agricultural Economics from the Faculty of Agriculture at Fayoum University in Egypt. Eman works at the Economic Analysis of Agricultural Commodities Dept, Agricultural Economics Research Institute (AERI). She coordinates and collaborates with other staff members in her department, other departments and AERI's Management to conduct research studies in the field of agricultural economics, with special focus on economic analysis of agricultural commodities, feasibility studies, credit assessment, project evaluation, and food security. In Addition, she participates in many of the research studies that AERI conducts in collaboration with international organizations including FAO, ICARDA, and IFAD. During her work at AERI, specifically from November 2000 to April 2004, Eman worked as a Chief Enumerator at the Multi-Sector Support Program (MSSP), a job that involved coordinating with the EU Short-term Impact Monitoring Specialist to accomplish the task of Impact Assessment of Credit extended by MSSP to beneficiaries who received loans for developing four sectors: Fish culture, Poultry Farms, Horticulture, and Irrigation & Drainage; then worked as Database Development & Operation Officer at the same Program. Besides her work at AERI, specifically in 2007, Eman started collaborating with the Food Security Information Center (FSIC) in conducting studies that aim at assessing the state of food security/insecurity in Egypt.

*Dr. Shaban A. Salem* is the head of economic affairs sector, ministry of agriculture and land reclamation, Egypt. He has interest and experience in various topics of agricultural economics and its application in the Egyptian agricultural sector. He is one of the well-experienced consultants in the area of agricultural finance, agricultural insurance, agricultural policy, long-term food security. He also has expertise in the management of water resources, rational water use, mainstreaming gender in water management, water policy, developing marketing policy, economic evaluation of agricultural projects, and financial efficiency of Egyptian farmers. He also consults the government on topics such as policy reform, changes in credit, investment, cooperatives, and rural finance on various sub-sectors of agriculture, marketing of agricultural commodities, reclamation of new lands, marketing, and constraints. Shaban earned his Ph.D. and MSc degrees in agricultural economics from Menoufia and Zagazig universities and has a post-doctoral experience at Georg-August university, Gottingen, Germany in rural micro finance. He has more than 45 years of work experience.

*Dr. Atef Swelam* is an Agricultural Research Officer, Office of Innovation of the UN-FAO. Prior to FAO, Dr Swelam was a Senior Scientist and Leader of the Irrigation Water Management Research Team at ICARDA. Atef has research interests and experiences that focus on sustainably improving water resources, intensifying, and diversifying small-scale farming in large irrigation schemes. Atef performed applied research to enhance irrigated ecosystem productivity, while preserving natural resources to address growing water scarcity, droughts, and declining water quality. Recently, he channeled his expertise towards improving small-scale farming system productivity at global scale through developing methodologies, tools, guidelines, policies to support national agricultural research systems to strengthen their efforts on AR4D delivery in an integrated and coherent approach for research and dissemination of proven technologies and practices. Atef earned his MSc in land and water management from IAMB, Italy, and a Ph.D. in agricultural engineering from University of Zagazig, Egypt. He has over 20 years of work experience in over 15 countries, published over 75 relevant publications including 30+ peer reviewed journal articles, 15+ peer reviewed conference articles, 4 books, 2 book chapters, and edited 1 book.

***Dr. Yigezu A. Yigezu*** is a Principal Scientist with the International Center for Agricultural Research in the Dry Areas (ICARDA). Yigezu has interest and experience in various topics in agricultural development including, production economics, technology adoption, out-scaling, and impact assessment, seed system analysis, value chain analysis, and bio-economic modeling of production systems. Yigezu earned a Ph.D. and MSc degrees in agricultural economics from Purdue University in USA. He has over 25 years of work experience in over 16 countries and over 100 publications including 40+ peer reviewed journal articles, 12 book chapters, and has co-edited 3 books.

## ORCID

*Bezaiet Dessalegn* http://orcid.org/0000-0001-9406-1389

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