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Institutional Performance of Collective Irrigation Systems: A Fuzzy Set Qualitative Comparative Analysis in the Nile Delta of Egypt

Ahmed Soliman [1,2,*], Andreas Thiel [2] and Matteo Roggero [1]

[1] Faculty of Life Sciences, Humboldt-Universität zu Berlin, Invalidenstraße 42, 10115 Berlin, Germany; matteo.roggero@hu-berlin.de

[2] International Agricultural Policy and Environmental Governance, University of Kassel, 37213 Witzenhausen, Germany; thiel@uni-kassel.de

* Correspondence: solimana@hu-berlin.de or soliman.ame@gmail.com

Abstract: Egypt, akin to many countries in the global South, has striven to promote collective management to overcome the challenges of irrigation management since the 1990s. Establishing shared pumping stations (SPSs) has been one of the cornerstones helping farmers better manage water for irrigation. Operating SPSs successfully poses collective action problems, for which there is no single set of solutions. This paper utilizes fuzzy set qualitative comparative analysis (fsQCA) to identify which conditions or configurations are sufficient or necessary for well-operated SPSs. The study draws on empirical data gathered through semi-structured interviews from 45 cases, located in Kafr El-Sheikh Governorate in Egypt's Nile Delta. Results show that three different paths are sufficient to ensure well-operated SPSs. These are: (1) the condition of effective rules related to allocation, monitoring, and sanctions; (2) the configuration of small group size of SPSs and large irrigated sizes of SPSs; or (3) the configuration of adequate water supply and appropriate location of the SPS command area. The paper concludes that neither group size nor resource size alone explains the outcome of collective action, while a combination of both factors does. Similarly, an adequate water supply is essential to enhance users' engagement in collective actions only when resource location characteristics do not provide alternative water sources for irrigation.

Keywords: Egypt; collective action; irrigation systems; fuzzy set qualitative comparative analysis

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Citation: Soliman, A.; Thiel, A.; Roggero, M. Institutional Performance of Collective Irrigation Systems: A Fuzzy Set Qualitative Comparative Analysis in the Nile Delta of Egypt. *Sustainability* **2021**, *13*, 1103. https://doi.org/10.3390/su13031103

Academic Editor: Giuseppe Todde

Received: 17 December 2020
Accepted: 18 January 2021
Published: 21 January 2021

1. Introduction

Over the past few decades, it has become clear that the performances of common pool resources (CPRs), such as irrigation systems, are shaped by the combinations of biophysical, social, and institutional factors [1–6]. The literature on the governance of CPRs identifies many factors that are associated with the successful management of CPRs. Based on a meta-analysis of multiple small-scale case studies of CPR management worldwide, Ostrom [2] suggests eight design principles found with the robust management of CPRs. However, scholars have debated the interpretation of Ostrom's design principles and their role in the evaluation (or design) of CPR governance. For example, Cox et al. [7] and Dell'Angelo [8] support the idea of applying these principles as a diagnostic tool to explore the core factors influencing a CPR setting. Yu et al. [9] find that Ostrom's design principles in a totalitarian context such as China are not enough to understand local irrigation institutions, and more attention should be paid to contextual factors. Wang et al. [10] also suggest that it is vital to examine the configuration between these principles in context when applying Ostrom's design principles.

To evaluate the governance of CPRs, one should think about other elements, in addition to the eight design principles, such as applying sophisticated research methods [11] or leaving more room for the influences of technical infrastructure [12]. More varying combinations of research methods and empirical settings are also necessary to evaluate outcomes of CPR governance [11,13,14]. It is also crucial to consider the configurational nature of factors, proposed to explain the sustainable use of CPRs—that is, the effect of one factor depends on the state of one or more factors [15]. In his influential work, Agrawal [5] presents examples of how one can investigate these explanatory factors in the format of configurational relationships. Schlager [16] also indicates that the CPR theory seems simple on the surface, but it involves considerable complexity, which can be disentangled by examining configurational relationships between factors contributing to the theory.

Nonetheless, limited empirical research, in terms of configurational thinking, has been conducted to discern how the interaction effect between multiple CPR factors influences the likelihood of success in governing CPR [10,17,18]. For example, understanding the interaction effect between a resource system's geographical area and its number of users is overlooked in the CPR literature [19]. The influence of how much water available for irrigation on collective irrigation management has been much investigated without paying enough attention to the effect of water quality on collective actions. This paper contributes to the issues mentioned above by employing fuzzy set qualitative comparative analysis (fsQCA). The fsQCA unpacks CPR factors and their different configurations that are more likely to achieve successful collective actions to manage collective irrigation systems in Egypt, a less represented country in the field of comparative studies on water governance [14].

Specifically, through a process of iterative refinement informed by theoretical predictions and our empirical knowledge, we specify five factors as influential CPR concepts for the performance of shared pumping stations (SPSs), i.e., collective irrigation systems, in the Nile Delta. These factors include institutions (understood as rules of the game), group size (conceptualized as the number of users), resource size (conceptualized as the geographical area), water supply (conceptualized as water quantity and quality), and resource location attributes. In this paper, we investigate these factors at the farmers' level and treat other levels, e.g., national water policies' politics, as constant since our comparable cases/SPSs are located in the same geographical area. Briefly, our study focuses on the following questions: (1) Under what circumstances do SPSs operate well in a collective manner? (2) How do the five investigated factors interact with each other and stimulate farmers to sustain the operation of SPSs? By addressing these questions, we aim to: (1) advance existing knowledge about how the variation in both group size and resource size impacts on CPR governance; (2) provide a deeper understanding of how varying degrees of water quantity and quality affect individual incentives to participate in collective actions; (3) understand the challenges of collective actions in a context where irrigation systems have been managed for decades on an individual basis.

The remainder of this article is structured as follows. Section 2 provides a background on irrigation management in Egypt and identifies the hypothesized conditions linked to CPR performance. Section 3 describes the research method, tools, and analysis. We then present the results of the fsQCA in Section 4 and discuss them in Section 5. In the conclusion, we outline the implications of this study.

2. Literature Review

2.1. Egyptian Irrigation Management Context

Agriculture in Egypt's Nile Delta and Valley is entirely irrigated agriculture, representing 2.25 million hectares [20]. Nile water is delivered to farmers' fields through extremely complex irrigation canals networks. According to Law 12/1984 on irrigation and drainage, the Ministry of Water Resources and Irrigation (MWRI) is responsible for formulating national water policies and managing irrigation canals until branch canals (BCs), preceding tertiary canals (a tertiary canal is called *Mesqa*) in the hierarchical order of irrigation canals. The *Mesqa* is owned by a group of farmers who benefit from irrigation and are responsible for its maintenance [21]. Farmers, also on their own costs, have to pump water from *Mesqa*s or in some cases from BCs to their farm-ditches (a farm-ditch is called *Marwa*).

Since the 1950s, farmers in the Nile Delta have mainly applied three local pumping technologies to deliver water to their fields. Firstly, farmers used an animal-driven wheel (called *Saqia*) to lift water from *Mesqa*s to *Marwa*s, which conveys water to their fields by gravity. A group of farmers owns the *Saqia*. Its operation and maintenance entirely depend on collective actions between farmers. Secondly, after around two decades, farmers, driven by socioeconomics and institutional changes [21] (Ch. 4), gradually started to replace *Saqia*s with individual irrigation pumping machines (IPMs). Unlike *Saqia*s, the operation and maintenance of IPMs are achieved individually by farmers. Additionally, using *Saqia*s for irrigation was among MWRI policies to regulate irrigation at the local level while using IPMs for irrigation has been by farmers and under the absence of MWRI control over local water management [21]. Therefore, thirdly, MWRI with recommendations and financial support of various international donors has intervened since the 1990s to replace IPMs with shared pumping stations (SPSs). MWRI involves farmers in the design and establishment of SPS through Water Users' Associations (WUAs) and transfers the management of SPS to WUA members. MWRI's intervention has been driven by its interest to control over-pumping associated with IPMs, "improve" local irrigation management, and recover its control over it [22]. Moreover, MWRI has adopted the diffusion of SPSs throughout the country as a national policy to "modernize" irrigation in the Nile Delta and Valley [23].

SPS infrastructure is mainly composed of a buried pipe (SPS intake), an underground cement tank, central diesel or electric pump(s), and a buried distribution network controlled by shared valves. The SPS is linked to a *Mesqa* or a BC through the SPS intake [21]. As a part of establishing the SPS, MWRI changes the *Mesqa* structure from an open earthen canal to an underground pipe, but this change does not always take place for all *Mesqa*s due to some difficulties beyond MWRI's capacity (for more details, see [20] (p. 15)). By law 213/1994, the SPS is recognized as a common property belonging to a group of farmers whose lands are irrigated via the SPS, and each SPS has its own WUA in charge of managing it.

The performance of WUAs and their role in governing SPSs in the Nile Delta is highly controversial in the literature. Some studies argue that WUAs make a significant contribution for better water allocation and equity between farmers due to the rules of WUAs, stimulating farmers to participate in collective activities. Additionally, WUAs strengthen communication between farmers and MWRI officials [24,25]. In contrast, Gouda [21] finds that the performance of WUAs in the Nile Delta is poor due to the deterioration of social capital and changes in state, water, and agricultural policies since the 1950s. Molle et al. [23] find WUAs in the central Delta are inactive in practice and do not have a crucial role in managing SPSs. Instead, farmers opt to craft their own institutions to operate SPSs. In the context of this study, we do not also observe a significant function played by WUAs in governing SPSs. Therefore, our primary focus is on analyzing collective actions in the domain of SPSs and not WUAs.

2.2. Theoretical Arguments on the Determinants of Performance of CPR

The central attention of CPR theory is on the attributes of the physical world, the community, and the rules in use to elucidate collective actions, which is essential to handle CPRs' problems of appropriation and provision [2,16]. Appropriation problems arise as the resource units, generated from a CPR and characterized by their subtractability, are overharvested by resource users who have intense rivalries. Provision problems occur when it is costly to exclude those who do not contribute to sustaining the continuity of resource units from a CPR [26]. Ostrom and her colleagues clarify that as the resource users have the incentives to engage in collective actions, such as crafting water allocation rules, they can address the demonstrated CPR problems. In the context of this study, we view the SPS as a CPR. This SPS is a human-made irrigation system and is jointly used by multiple farmers (a collective-managed irrigation system) to pump irrigation water (subtractable resource unit) from the branch canal to farmers' fields, and it is nontrivial (but not impossible) to control irrigation rights of SPS farmers [26]. This research draws on CPR and collective action theories to decide on the factors that might explain well-operated SPSs. The empirical knowledge is simultaneously considered to refine and specify these theoretically informed factors. In the following, these explanatory factors, causal conditions, are briefly discussed.

2.2.1. Rules Related to Allocation, Monitoring and Sanction

Under Law 213/1994, farmers are required to develop their own set of rules for irrigation management in the SPS arena. The focus here is on the set of rules used by farmers to allocate water (water allocation rules), monitor individuals' actions during irrigation (monitoring rules), and impose punishment on the wrongdoers (sanctioning rules).

Failure to establish water allocation rules between appropriators, especially in a condition where water is valuable, is that of significant cause for collective action problems in irrigation systems [2]. Baldwin el al. [27] find distributional rules are more associated with water insufficiency conditions. Theesfeld [28] reports that misallocation of water between Bulgarian irrigators results in the failure of collective actions in managing irrigation systems.

Having well-agreed rules is not enough to ensure rule compliance between community members. Thus, as the community can invest in effective monitoring and sanction arrangements, CPR's appropriation and provision become more sustainable over opportunistic behaviors [29–32]. However, Cleaver [33] and Yu et al. [9] argue that well-built social capital may substitute for the function performed by monitoring and sanction devices to achieve better collective irrigation management. In the Nile delta, weakened social capital and a lack of leadership are observed between farmers in collective action for irrigation.

The political context also has a vital role in shaping local irrigation institutions [10,34]. Gouda [22] shows how water and agricultural policy changes since the 1950s significantly affect local water management in the Nile Delta. Nonetheless, this study concerns how rules and biophysical and social attributes may affect collective irrigation management (Table 1).

2.2.2. Group Size

Group size has been frequently studied in the CPR literature with heterogeneity. In this study, however, we only consider group size since we could not find an important role played by heterogeneity. Scholars disagree on how group size affects collective outcomes. Some scholars argue that as the group size governing CPRs decreases, the chances to achieve high levels of collective action are increased owing to overriding free-riding problems and lowering transaction costs—e.g., Olson [35] Araral [19], Zhang et al. [36], Huang [37], McCord et al. [12], and Miao et al. [38]. In contrast, other scholars argue that a large group size may have the advantage of potential economies of scale by which the average costs associated with resource provision and incurred by resource users may decrease as the number of users increases (Meinzen-Dick et al. [39], Wang et al. [40], and Wang and Wu [41]). This disagreement shows that group size has mixed roles. It is crucial to determine which influences collective outcomes in a particular context and how other contextual factors might mediate the influence of group size [42,43].

Moreover, as noted by Meinzen-Dick et al. [39] and Araral [19], researchers, studying the effect of group size on CPR governance, do not differentiate group size conceptualized as the number of actors from group size conceptualized as geographical area—i.e., resource system size. This mis-conceptualization of group size weakens the analysis, as indicated by Araral [19], because, for example, an irrigation system may be utilized by a large number of irrigators having small land sizes, while another may be used by a smaller number of irrigators having larger land sizes.

Therefore, this paper distinguishes between group size as the number of users and resource system size as the geographical area. We consider both factors in the fsQCA analysis to discover how they may have a configurational effect on the SPS performance and how they may interact with other studied factors to affect collective actions in SPSs. In Table 1, we formulate the research hypothesis in terms of group size.

2.2.3. Resource Size

There is a lack of consensus on how the resource size, in terms of geographical area, affects the likelihood of collective action in the context of CPR governance. Some studies clarify that farmers can engage in collective irrigation activities as the irrigated size decreases because of a higher ability to observe free riders and less coordination needed to craft rules [19,44,45]. Other studies, however, show that large irrigation systems have a higher opportunity of supporting successful managing CPR [46–48]. The authors indicate that higher demand for water and higher expected income owing to scale economies provide incentives for individuals to develop cooperation required for collective irrigation management. Interestingly, some authors argue that irrigation systems in hectares do not affect irrigation collective actions [3,36,49]. In this study, we formulate the research hypothesis about resource size, as shown in Table 1.

2.2.4. Water Supply

There is much consensus among scholars on how much water available in the irrigation canal affects collective irrigation performance. The emergence of collective action is observed when water is moderately scarce and neither extremely abundant nor severely scarce [19,40,44,50,51]. Scholars apply different concepts, e.g., water scarcity, water availability, and water supply, to describe how water quantity differences affect the collective action outcome. In a setting such as the Nile Delta, water quantity in the irrigation canals is much influenced by drain water reuse (this point is elaborated more in Section 3.3.1). Focusing on the differences in water quantity without paying attention to its quality differences is not enough to explain the collective action outcome [52,53].

In the CPR literature, the concept of water quality is mostly discussed from the angle of institutional arrangements or policy instruments that are (not) found ameliorating water quality—e.g., [54–57]. However, here we do not examine such an angle to understand resource users' or the state's efforts to improve water quality. We do not find that the resource community or the state plays any role in improving irrigation water quality in the study area. Some interviewed respondents report "improving the quality of irrigation water is the responsibility of our state and not our task because it is the state who has to do it". From the state side, improving water quality in the study area demands financial, technological, and institutional capabilities which are beyond the state capacity [52]. Instead, we conceptualize differences in water quality and its quantity as crucial inputs for the factor of water supply in order to understand how both inputs may affect collective irrigation management (Table 1).

2.2.5. Resource Location

The influence of resource location on collective irrigation management has been mostly explained in the literature from two angles. The first one compares the performance of collective actions between upstream and downstream users. It has been found that upstream users perform better than downstream users because the latter has a lower water quantity, providing less incentive to participate in collective actions [40,41]. In contrast, some other studies (e.g., [49] (p. 15) and [34]) argue that downstream users have a higher level of collective actions than upstream users because insufficient water stimulates tailenders to be involved in collective actions to increase water supply. The second angle investigates the cooperation between upstream and downstream users to manage their common resource (e.g., [58–60]). It has been found that different factors might explain why upstream users cooperate with downstream users, such as the degree of interdependency between them or the interest of upstream users to maintain the resource infrastructure against the potential vandalism of downstream users.

Table 1. Research hypotheses.

Factor	Hypothesis
Rules related to allocation, monitoring, and sanction	The presence of rules—devised to allocate water, monitor actions, and sanction noncompliance—is paramount to sustain the CPR appropriation and maintain the resource system infrastructure.
Group size	In terms of a group number, small group size increases users' willingness to engage in collective activities.
Resource size	In terms of geographical area, small resource size may be more likely to support users in participating in collective irrigation management.
Water supply	When resource users have sufficient (neither abundant nor severely scarce) water quantity and quality, the likelihood of collective action increases.
Resource location	In the context where resource location does not provide alternative sources for extracting water, resource users are more likely to engage in collective actions [31,61].

In sum, it might be concluded that the effect of resource location on collective irrigation management has been viewed as the classification of upstream and downstream locations, which reflects how much water is available at each location. Therefore, we would argue that the effect of resource location on users' behavior might be examined by looking at how the spatial attributes of resource location generate differences in how much water is available between users. In our study, we view the factor of resource location as the spatial attribute of resource location, providing alternative methods for extracting water. We assume the existence of alternative sources for irrigation is a latent factor for the resource location (Table 1).

3. Materials and Methods

3.1. Study Region

The study was conducted in Kafr El-Sheikh (KES) Governorate, located in the Nile Delta of Egypt and overlooking the Mediterranean Sea. KES is the largest governorate within the Nile Delta. It is one of the three important agricultural governorates in the country, with a total cultivated area of around 0.25 million hectares. The strategic crops in KES are rice, cotton, sugar beet, and wheat. The total population of KES in 2018 was approximately 3.4 million, and nearly 76% of this estimate live in rural areas [20]. Agriculture in KES entirely relies on irrigation, with about 70% of irrigated land of KES depending on the Meet Yazid (MYZ) canal for irrigation water. The length of MYZ is approximately 63 km, and it starts in another adjacent Delta governorate and flows north into El-Burullus Lake in KES.

We selected KES and specifically the irrigated region of MYZ within it for our research as: (a) KES is well-known for its complexity of irrigation systems and experiences with water shortage problems as it is located at the tail-end of the River Nile [21]; (b) the irrigated region of MYZ has a moderate history of operating SPSs compared to other areas in the country. Therefore, this study region provides wide and diverse empirical cases to unravel—from an institutional perspective—under what conditions farmers approach collective challenges of irrigation, especially in the summer season during which water is hardly available.

3.2. Cases Selection Approach and Data Collection

The selection of SPSs draws on the most similar systems designs approach (MSSD) [62]. In MSSD, the cases are chosen based on variations in their outcomes that might result from differences in some explanatory factors, but meanwhile they share some commonalities. In the study region, there are about 1080 SPSs, as indicated by the director of the Irrigation Advisory Services department (IAS) who was interviewed in 2017 (IAS is among the Ministry of Water Resources and Irrigation (MWRI) representatives in KES and theoretically responsible for forming and monitoring WUAs). Selecting a purposeful sample of intermediate-N cases out of this population was quite challenging, particularly as IAS does not have information on the performance of SPS operations (note: for best practices, fsQCA is commonly applied to small- or intermediate-N cases, so that one can employ in-depth case knowledge—which might not be available in large-N cases—to elucidate the causality relations observed in the findings. However, the discussions about applying large-N fsQCA are still open in the literature [63]). Alternatively, we found that agricultural extension engineers (AEEs) of the Ministry of Agriculture and Land Reclamation (MALR) have local knowledge by which they could aid us in case selection. This local knowledge has been acquired due to their closeness to farmers, an integral part of their work that does not include managing water supplied to SPSs. Hence, we considered AEEs as neutral, who might have no interest in providing distorted information on the performance of SPS operations. Accordingly, with the assistance of AEEs, forty-five SPSs were chosen in the study region based on the following criteria: the performance of SPSs varied between well- and not well-operated SPSs and the SPSs showed differences in irrigated size, group size, location of the command area, water supply, and rules. Additionally, the chosen SPSs had similarities such as the technology of establishing and operating the SPS, local irrigation knowledge of pre-SPSs (i.e., *Saqia*s and individual irrigation pumping machines), and geographical and climatic characteristics. Table A1 in Appendix A provides a summarized description of the studied SPSs.

Concerning data collection, Yin [64] recommends using a bundle of tools for the case study data collection. This study used public documents, observations, and mainly semi-structured interviews to collect the required data. We utilized public documents, e.g., gray reports completed by international donors and local research institutes, to understand different factors affecting local water management. Observations provided knowledge about SPSs infrastructure conditions, location characteristics, and interviewees' interactions during the interviews. Semi-structured interviews were conducted with key informants—farmers who were most involved in the SPS activities. The content of the semi-structured interviews was guided by factors discussed in Section 2.2. All farmers' interviews were conducted in isolation from MALR helpers at the field site to minimize the risk of distorting farmers' responses. We also asked representatives of MWRI and MALR at the KES level about their opinions on SPSs' roles in irrigation water management. Data collection was undertaken in three phases: the first phase in March 2017, the second phase in August 2017, and the last one between February and April 2018. After collecting data, we coded, summarized, and prepared the data for the analysis, demonstrated in the following section.

3.3. Fuzzy Set Qualitative Comparative Analysis

This study focuses on understanding the configurational nature of factors, hypothesized to explain well-operated SPSs. Ragin [65] shows the configurational nature is one central feature of causal complexity, which is defined by three attributes: equifinality, conjunctural/combinatorial causation, and causal asymmetry and is assumed to result in the observed phenomenon. Therefore, set-theoretic methods such as fsQCA are appropriate methodological approaches to address the causal complexity explaining the outcome of interest. More precisely, the existing study utilizes fsQCA to identify causal conditions or their different configurations linked with well-operated SPSs.

The fsQCA is a set-theoretic method and originates from qualitative comparative analysis. In fsQCA, the relations between causal conditions and the outcome are conceptualized as fuzzy set relations. Fuzzy set relations are assessed using fuzzy algebra. A fuzzy set can be a causal condition, i.e., an explanatory factor or an outcome. Each case study has a continuous membership score (between 0 and 1), expressing the degree of membership in the fuzzy sets and simultaneously reflecting the degree of the qualitative difference between the investigated cases [66]—this book is recommended by authors for comprehensive knowledge about the fsQCA. These relations are analyzed to identify individual conditions or configurations necessary or sufficient for an outcome [67]. For the sake of simplicity, a condition (X) is sufficient for (a subset of) the outcome (Y) when across all cases the membership score of (X) is smaller than or equal to the membership score of outcome (Y)—i.e., X $\leq$ Y. Conversely, a condition (X) is necessary for (a superset of) the outcome (Y) when X $\geq$ Y. To evaluate the fuzzy set relations, Ragin [65] mainly introduces two measures: consistency and coverage measures. The consistency measure indicates the degree of fuzzy set relation—i.e., a subset or superset relation between a tested condition and an outcome. The coverage measure shows the empirical importance of a tested condition for explaining an outcome.

3.3.1. Operationalizing the Conditions and the Outcome

One of the key features of fsQCA is that it enables researchers to iteratively move between their theoretical and empirical knowledge [67,68]. By doing so, one can identify and refine the conditions and their measures explaining the investigated social phenomenon in terms of set-theoretic relations (ibid). The number of conditions should be controlled in fsQCA [62], so that one can alleviate the issue of logical remainders—that is, logically possible configurations of conditions in the analysis that are not observed empirically [69]. Accordingly, we identify five conditions explaining our outcome of interest.

- Measuring the outcome: well-operated SPS (WOS)

Using qualitative interview data, we measured the outcome WOS as the number of provision activities observed in the SPS. When resource users are willing to invest in provisioning activities, e.g., maintenance work, to sustain their resource system's capacity, they can perform collective actions needed to overcome the provisions problems, indicated in Section 2.2. We assumed that the more provisioning activities that are provided, the greater farmers' abilities to govern the SPS operation [2]. Table 2 shows the provision activities used to evaluate WOS.

- Measuring the five conditions

The first condition, effective rules related to allocation, monitoring, and sanction (EFR), was evaluated by three measures as illustrated in Table 2: water allocation rule (WAL); monitoring rules for shared valves of irrigation network (MON); sanction rule (SAN).

The second and third conditions, small group size (SGZ) and small irrigated size (SIZ), are the only conditions which had measures, shown in Table 2, relying on quantitative data, collected from SPSs' official records.

The fourth condition, adequate water supply (AWS), is measured by two measures: adequate water quantity (AWQ) and adequate water quality (AWL). In the study area, water is not an abundant resource, and there is a lack of quantitative data to measure the degree of water shortage. After summarizing qualitative interview data, however, we noticed that SPS farmers exercise four actions to cope with water shortage (also indicated by Molle et al. [21]). We used these actions, listed in Table 2, as sub-measures for measuring AWQ. Tang [3] indicates that when CPR users face insufficient water supply, additional costs generated by this water insufficiency hinder the cooperation between users and lessen collective action necessary for a successful CPR. Therefore, we assume that the more actions exercised to discipline water shortage, the more information and communication between farmers are required to resolve water inadequacy and emerged conflicts, the lower the value of AWQ assigned to the case. As to AWL, we find that the state reuses untreated agriculture drain water at two sequential phases to substitute water shortage [52]. Phase (A): at the main level Meet Yazid canal (MYZ); Phase (B): at different levels of branch canals (BCs) of MYZ, depending on the BC water shortage degree, i.e., the state does not need to implement Phase (B) in some BCs. Farmers are concerned about the BC water quality because poor water quality decreases the agricultural production, affects the usage of pesticides, and makes farm produce less marketable [21,52,53]. The interviewed respondents also confirmed these consequences of poor water quality, which affect their engagement in the SPS collective actions. Despite a lack of quantitative data on the BC water quality, we operationalize AWL based on whether or not the state implements Phase (B). The interviewed farmers perceive that the less drain water combined with BC water, the better the water quality.

The fifth condition, appropriate location of SPS command area (LOC), is estimated by two measures as indicated in Table 2: proximity to an open irrigation canal (OIC) and proximity to an agricultural drain canal (ADC).

Table 2. Measures of the outcome and the five conditions.

	Measures
WOS	Provision activity (A): Contribution to operation and maintenance fees (presence/absence). The presence of (A) means that farmers contribute to (A) regularly and perceive it as an unchallenging task, while the absence of (A) means that farmers contribute to (A) irregularly and perceive it as a challenging task. Provision activity (B): Contribution to cleaning the stand tank and intake pipe of SPS (presence/absence). The presence of (B) means that farmers collectively contribute to (B) based on a clear plan, while the absence of (B) means that there is no clear plan for providing (B); farmers clean the stand tank and intake pipe of SPS individually and accidentally. Provision activity (C): Contribution to sustaining the proper discharge capacity of pumps [1] and/or protecting pumps from burglary [2] (presence/absence). The presence of (C) means that farmers are willing to provide (C), while its absence means that farmers are unwilling to provide (C).
EFR	Water allocation rule (WAL): WAL acknowledges variations in the topography of farmers' lands within an SPS (yes/no). WAL acknowledges exogenous problems [3] (yes/no). Monitoring rules for shared valves of irrigation network (MON): The existence level of water stealing action (high, medium, low, not found). Sanction rules (SAN): Willingness to institutionalize SAN (very high, high, medium, low).
SGZ	Number of farmers within the SPS.
SIZ	Total irrigated area by the SPS, feddans (1 feddan = 0.42 ha).
AWS	Adequate water quantity (AWQ): Action (A): Farmers cultivate their summer crops early or lately (presence/absence). Action (B): Farmers utilize individual irrigation pumping machines (IPMs) either collectively or individually to extract shallow water from the BC. Water is shallow when its level in the BC is lower than the SPS intake level—meaning that it is technically impossible to pump through the SPS (presence/absence). Action (C): Farmers utilize IPMs collectively or individually to extract water directly from the agricultural drain canal (presence/absence). Action (D): Farmers ask the local irrigation authority to increase water quantity in the BC (presence/absence). Adequate water quality (AWL): High: The BC water is not combined with drain water after Phase (A). Low: The BC water is combined with drain water after Phase (A)—i.e., Phase (B) is implemented.
LOC	Open irrigation canal (OIC): The location of SPS command area does not have access to an OIC (yes/no). Agricultural drain canal (ADC): The location of SPS command area does not have access to an ADC (yes/no).

[1] Examples: (1) replacing the insufficient pumps, in terms of discharge capacity, with sufficient pumps; (2) providing electricity to the SPS room; or (3) buying additional pump as an auxiliary pump which is used only in emergencies, such as sudden electricity cut, a sudden breakdown of pumps. [2] Examples: (1) transferring the diesel pumps to farmers' houses to protect them against burglary or (2) reinforcing the building of the SPS room and the gate of the SPS room to protect pumps from burglary. [3] Exogenous problems are sudden problems that may take place during an irrigation turn, such as electricity cut, pump failure, or explosion of a pipeline of irrigation network.

3.3.2. Calibrating Data as Fuzzy Sets

Calibration is at the core of fsQCA, and its final result is that each case has a membership score per fuzzy set, i.e., a condition or an outcome, [67]. In this study, we applied two different calibration methods: a qualitative calibration method (QCM), introduced by Basurto and Speer [70], and a direct calibration method (DCM), introduced by Ragin [67]. The main difference between QCM and DCM is that the former can only be used to calibrate qualitative data as fuzzy sets. However, the latter is developed to calibrate quantitative data as fuzzy sets. Thus, we used the DCM to calibrate the measures of the conditions: effective rules related to allocation, monitoring and sanction (EFRs), adequate water supply (AWS), and location of SPS command area (LOC) and the outcome of well-operated SPSs. The measures of the conditions of small group size and small irrigated size were calibrated based on DCM. Generally, there are the key principles that should be considered during the calibration process in QCM and DCM: (1) the entire calibration should be transparent, replicable, and informed by the theoretical and cases' knowledge; (2) labeling the fuzzy sets should be consistent with their content and their scale arrangement; (3) before translating the data into fuzzy set scales with their definitions, the main qualitative anchors should be specified. These include: the point of full membership (a score of 1), the point full non-membership (a score of 0), and the crossover point (a score of 0.5). For illustration, the condition of small group size of SPS could be scored 1 (fully small group size), 0 (fully non-small group size), or 0.5 (neither small group size nor non-small group size).

Following Ragin [67] and Basurto and Speer [70], we labeled the fuzzy sets, formulated the definitions to their fuzzy-scale range, and specified the locations of qualitative anchors in line with our theoretical concepts of interest and empirical insights, as shown in Table A2. After that, we assigned membership scores for all measures of the five conditions and the outcome (Table A3).

Each case, shown in Table A3, must have a single membership score per condition and an outcome to make the data ready for the analysis. However, conditions such as EFR, AWS, and LOC have more than one membership score per case. We aggregated, therefore, the membership scores of all measures of each condition into a single membership score for each case. As indicated by Goertz [71], selecting the proper method of aggregating measures was mainly guided by the examined research hypotheses and the theoretical concepts. We chose to apply the minimum aggregation method by which the minimum score of aggregated measures is calculated [67]. The reason lies in our research hypotheses, previously presented in Section 2.2. For example, the location of the SPS command area is considered as an appropriate location (i.e., LOC = 1) only when farmers do not have access to both an open irrigation canal (OIC = 1) and an agricultural drain canal (ADC = 1). To fulfill this requirement, the minimum value of both aggregated measures should be considered—i.e., LOC = min (OIC, ADC). Although taking the average of these measures gives the same result, we stuck to the minimum value because for other measurements, that have continuous scores, taking their average may give results that contradict the theoretical assumptions of our tested conditions. Similarly, water supply is adequate only when farmers have access to adequate water quantity (AWQ) and adequate water quality (AWL), formulated as AWS = min (AWQ, AWL). Rules related to allocation, monitoring, and sanction are observed as effective rules only when farmers craft rules to allocate water (WAL) and enforce them by monitoring rules for shared valves of irrigation network (MON) and sanction rules (SAN), formulated as EFR = min (WAL, MON, SAN). As a result, we generated the final membership scores for all cases, as illustrated in Table A4.

Although taking the average of these measures gives the same result, we stuck to the minimum value because for other measurements with continuous scores, taking their average may provide results that contradict the theoretical assumptions of our tested conditions.

4. Results

After calibration, we used the R package QCA [72] to perform fsQCA and identify the individual conditions and the configuration that may cause the outcome of a well-operated SPS (WOS). According to Ragin [65] (p. 20) and Schneider and Wagemann [66] (p.231), firstly, we examined cases with the necessary conditions followed by the sufficient conditions for the outcome WOS. The findings from the analysis are presented in the following subsections.

4.1. Necessary Conditions for Well-Operated SPS

Table 3 presents findings from the analysis of necessity. To decide which hypothesized condition is necessary for the outcome to occur, Schneider and Wagemann [66] (p. 278) and Greckhamer et al. [69] emphasize the consistency values for potential necessary conditions should not be less than 0.90. Therefore, we applied the consistency value of 0.90 as a threshold to decide on the necessary conditions. It is clear from Table 3 that all consistency values are less than 0.90; therefore, neither the presence of the hypothesized conditions nor their absence is necessary for the well-operated SPS.

Table 3. Analysis of individually necessary and sufficient conditions.

Hypothesized Conditions [1]	Necessity Analysis		Sufficiency Analysis	
	Consistency	Coverage	Consistency	Coverage
The presence of effective rules related to allocation, monitoring and sanction (EFR)	0.688	0.902	0.902	0.688
The presence of small group size (SGZ)	0.699	0.613	0.613	0.699
The presence of small irrigated size (SIZ)	0.536	0.597	0.597	0.536
The presence of adequate water supply (AWS)	0.550	0.786	0.786	0.550
The presence of location of SPS command area (LOC)	0.438	0.731	0.731	0.438
The absence of effective rules related to allocation, monitoring and sanction (efr)	0.473	0.512	0.512	0.473
The absence of small group size (sgz)	0.341	0.623	0.623	0.341
The absence of small irrigated size (siz)	0.573	0.727	0.727	0.573
The absence of adequate water supply (aws)	0.499	0.506	0.506	0.499
The absence of location of SPS command area (loc)	0.562	0.517	0.517	0.562

[1] In fsQCA, uppercase letters refer to the presence of the condition (e.g., effective rules related to allocation, monitoring and sanction (EFR)), while lowercase letters refer to the absence of the condition (e.g., efr).

4.2. *Sufficient Conditions for Well-Operated SPS*

The next step in fsQCA is the sufficiency analysis, conducted in two phases. The first phase investigates which individual condition is sufficient for the outcome of a WOS. The second phase aims to find out the different configuration of conditions that are sufficient for the same outcome. The results from the analysis are illustrated in the next subsections.

4.2.1. Individual Conditions

Table 3 shows the results of the individual sufficiency analysis. Ragin [73] (p. 121) indicates that a consistency threshold of 0.80 or higher is recommended to assess the sufficient relations. Hence, conditions that qualify as sufficient for the outcome of a WOS are determined based on their consistency scores being higher than or equal to 0.80. As can be seen from Table 3, only one condition, the effective rules related to allocation, monitoring, and sanction (EFR), is sufficient for a well-operated SPS, with a consistency score of 0.902. The coverage value (0.688) of EFR shows relatively high empirical relevance. That is, the coverage of WOS by EFR accounts for around 70% of the sum of membership scores in WOSs.

As a triangular form, one should plot the sufficient conditions (or configurations thereof) against the outcome [65] (p. 47). Therefore, for each case, we plotted the membership score in the EFR against the membership score in the WOS, as depicted in Figure 1. In this figure, SPSs, located on or above the main diagonal, are consistent with sufficiency since they fulfill the requirement for sufficiency (EFR $\leq$ WOS) as indicated in Section 3.3. Nonetheless, not all of these cases are relevant to discussing why EFR is sufficient for WOSs since some cases show weak rules (cases with EFR < 0.50). Thus, we focused on the cases located in the upper right corner of Figure 1 (0.50 < EFR $\leq$ WOS) to clarify how EFR accounts for WOS, as shown in Section 5.1.

By contrast, it reveals from Figure 1 that five cases are below the main diagonal. These cases are responsible for the lower level of consistency (0.902). However, Ragin [73] highlights that in fsQCA, it is usually challenging to obtain ideal sufficiency relations due to the nature of social science data—some flexibility should be considered. Hence, we suggest that SPS22, being closest to the main diagonal, supports the sufficiency relation. It is also worth noting that SPS25 and SPS44 are contradictory cases since they contradict the sufficiency relation—that is, although EFR is present, a WOS is not achieved. Schneider and Wagemann [66] emphasize that researchers should draw attention to contradicted cases. In Section 5.1, we discuss why such contradicted cases exist.

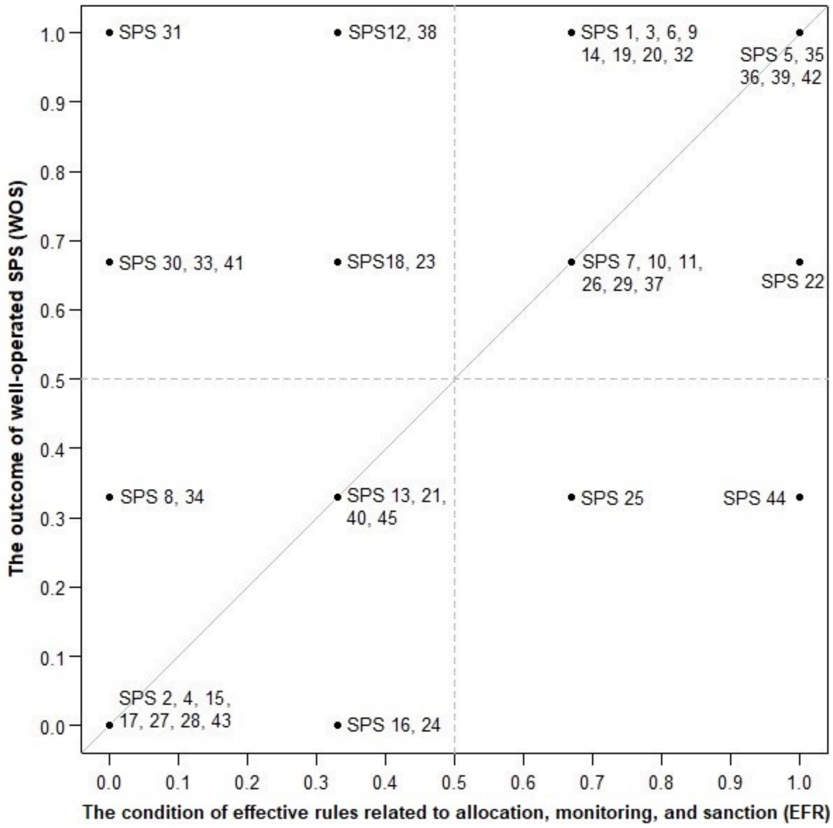

Figure 1. The individual sufficient condition (EFR) for the outcome (well-operated shared pumping station (SPS) (WOS)).

4.2.2. Configurations of Conditions

The analysis of configurations of conditions that might be sufficient for the outcome begins with generating the truth table, listing all possible configurations of conditions. The results, obtained from the truth table, are minimized through logical minimization analysis (LMA) to yield the overall solution formula, including the sufficient configurations for the outcome.

Since only one out of five conditions, the condition EFR, on its own is sufficient for the outcome WOS, we utilized the remaining conditions (i.e., SGZ, SIZ, AWS, and LOC) to build the truth table and find out which is an INUS condition for the same outcome (an INUS condition is a "single condition that is *insufficient* for producing the outcome on its own but which is a *necessary* part of a conjunction that, in turn, is *unnecessary* but *sufficient* for producing the outcome" [66] (p. 343). Note: INUS is an acronym for the first letter of the italicized words). The truth table results are presented in Table A5. As in Section 4.2.1, we employed the consistency threshold of 0.80 in the truth table to evaluate potential sufficiency relations between configurations of conditions and the outcome. As a result, five configurations of conditions (i.e., the first five rows of the truth table) are found to be linked to the WOS outcome. It is also noted that the last four rows of the truth table are logical remainders, indicated in Section 3.3.1. Ragin [67] suggests two alternative approaches, applied in LMA, to process the issue of logical remainders, i.e., "limited diversity": (a) one can carry out LMA without incorporating logical remainders. In this situation, the solution formula is complex and might be difficult to understand—which is the case found in this study; or (b) logical remainders can be incorporated in LMA by making assumptions about them. The assumptions, corresponding to the theoretical expectations ("easy counterfactuals"), lead to the intermediate solution formula, while assumptions not corresponding to the theoretical expectations ("difficult counterfactuals"), lead to the parsimonious solution. This study rests on the intermediate solution formula because it is the most interpretable based on our theoretical expectations.

Table 4 summarizes the results of minimizing the truth table. The intermediate solution formula identifies two alternative and sufficient configurations of conditions for well-operated SPSs: configuration1 includes cases with a small group size coupled with a large irrigated size as sufficient for a WOS; configuration2 includes cases with adequate water supply coupled with the appropriate location of the SPS command area as sufficient for a WOS. The coverage of WOS by the overall solution accounts for 52% of the membership in WOS. The raw coverage values are small in both configurations because when more than one configuration shares the same outcome, the calculated coverage values may be small, as indicated by Ragin [65] (p. 44). Additionally, the unique coverage values reveal that both configurations have similar unique contributions to covering the outcome. Similar to Section 4.2.1, we plot the results graphically as in Figure 2.

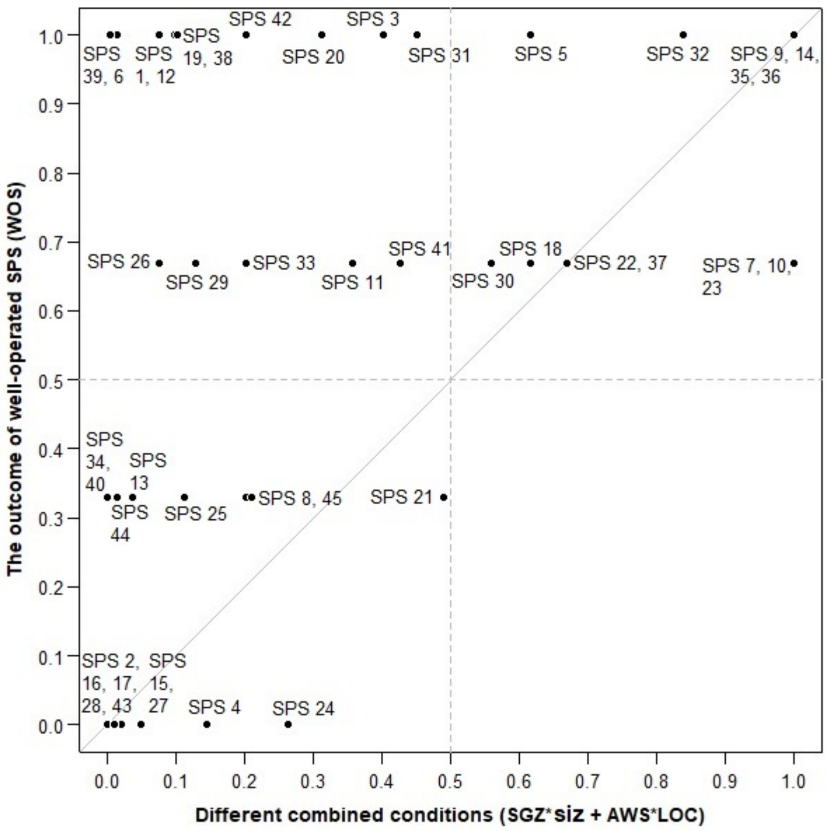

Figure 2. Sufficient configurations of conditions for the outcome (WOS).

Table 4. Analysis of sufficient configuration of conditions for well-operated SPSs.

	Intermediate Solution Formula [1]	Configuration1	Configuration2
	SGZ*siz + AWS*LOC→WOS	SGZ*siz→WOS	AWS*LOC→WOS
Consistency	0.890	0.917	0.881
Raw coverage	0.518	0.298	0.275
Unique coverage		0.243	0.220
Covered cases		SPS5, SPS18, SPS30, SPS32, SPS36	SPS7, SPS9, SPS10, SPS14, SPS22, SPS23 SPS35, SPS36, SPS37

[1] The multiplication and additions signs represent the logical "AND" and the logical "OR", respectively. The arrow represents the assumed link between the configurations of conditions and the outcome.

5. Discussion

This section discusses the results obtained in Section 4.2. As fsQCA is principally a case-oriented approach, we drew on case-level evidence to interpret the results.

5.1. Effective Rules Related to Allocation, Monitoring, and Sanction (EFR)

As depicted in Figure 1, the EFR condition is found to be sufficient for the outcome of a well-operated SPS (WOS) in twenty cases. Here, we discuss eleven cases, uniquely covered cases, while other cases, i.e., multicovered cases, will be discussed later under their relevant sufficient relations. These unique cases are SPS1, SPS3, SPS5, SPS6, SPS11, SPS19, SPS20, SPS26, SPS29, SPS39, and SPS42.

To allocate water between farmers in the highlighted cases, farmers crafted three types of water allocation rules (WAL). In each SPS, we found that farmers exercised only one WAL type (called *Warshat*). How farmers choose between different WAL types seems accidental or depends on the trial and error method. The primary similarity between WALs is that fixed time is assigned per unit area. Thus, each farmer has an irrigation time depending on his land size, while the essential difference between WALs is in the way that farmers organize irrigation turns between them. Accordingly, the first type of WAL includes the rule of "first come, first serve" and was found in SPS1, SPS11, SPS26, and SPS29. Farmers, exercising this simple rule, depend on mobile phones, a cheap way of communication, to organize irrigation turns. In the second type of WAL, observed in SPS3, SPS6, SPS19, and SPS39, farmers organize irrigation turns based on the crop type where priority is given to rice plots, and then other crops come later. The implementation of this rule type depends on the SPS operator, who is often selected by SPS farmers and is paid a monthly salary. The role of farmers is to monitor and make sure that water is delivered to their fields. Hence, farmers are not allowed to open the shared valves without prior permission from the SPS operator. Unlike the second type, in the third type of WAL, farmers of SPS5, SPS20, and SPS42 organize irrigation turns regardless of the crop pattern type. They split the SPS irrigated area into two or three subgroups, based on land topography or family relations. Each farmer within a subgroup has a number of irrigation hours. Unlike the second type of WAL, implementing the third WAL type is decentralized, where farmers of each subgroup arrange the time of opening and closing the shared valve.

To enforce *Warshat*, we found that farmers have crafted one of two key mechanisms of monitoring shared valves of irrigation networks (SVNs): a decentralized mechanism (in SPS26, SPS29, and SPS42); a centralized and decentralized mechanism (in the other eight SPSs). In the former, farmers on their own are responsible for monitoring SVN without locking SVN nor paying a watchman as is common in other SPSs. In the latter, in contrast, monitoring SVN is centrally mandated to the SPS operator while a farmer's role here is to observe whether or not the SPS operator monitors SVN. Additionally, only in SPS5 and SPS20 did we find that farmers put locks on SVNs to facilitate the SPS operator's monitoring task.

In all indicated SPSs, farmers crafted two basic sanction rules: the first rule is for those who do not contribute to the irrigation and maintenance fees, and this rule states that "no fees, no water through the SPS"; the second rule is for those who open the SVN without permission and steal water, and it states that "a water thief must pay a fine which is allocated to maintain pumps". However, the imposition of these rules differs between SPSs. For example, farmers of SPS5, SPS39, and SPS42 crafted a higher sanction rule, which is applied when they cannot enforce the sanction rules mentioned earlier. This sanction rule includes a written agreement between farmers by which violators pay a huge amount of money. We found that writing such an agreement is common practice for communities of these SPSs to enforce the rules. On the contrary, in the other cases, crafting such a sanction rule was found to be socially unacceptable. One respondent said that, "[...] it will be a shame to write an agreement between us [the SPS community] for punishing wrongdoers". Instead, farmers depend on pressure, exerted by people such as wise men in the village, to enforce the rules.

As indicated previously in Section 4.2.1, there are two contradictory cases: SPS25 and SPS44. The performance of these SPSs is low despite the existence of effective rules. Farmers of SPS25 were unwilling to improve their pumping capacity due to the fact that when the Ministry of Water Resources and Irrigation (MWRI) established this SPS, a group of farmers, representing 40% of irrigated land, did not want to share the SPS with the rest of farmers due to old conflicts between them. Hence, as highlighted by respondents, this conflict impedes their collective endeavors to increase the pumping capacity even in the presence of rules. In SPS44, uncontrolled urban expansion—especially after the 25 January 2011 revolution—has resulted in an increase in land prices that reduces farmers' motivation to invest in agriculture and collective actions of SPSs. Additionally, farmers of SPS44 have inferior access to water quantity and quality because the SPS is located downstream of the Meet Yazid canal (MYZ). Hence, as indicated by one of the respondents, these factors have an adverse effect on the expected benefits from agriculture and SPS performance despite the existence of rules.

5.2. Configuration of Small Group Size (SGZ) and Large Irrigated Size (ssz)

As shown in Section 4.2.2, small group size, of less than the average of 45 farmers, and large irrigated size, larger than the average of 50 feddans, are both linked to the outcome of well-operated SPSs. Five cases share this specific configuration (SGZ*ssz): SPS5, SPS18, SPS30, SPS32, and SPS36 (note: SPS18 and SPS30 are uniquely covered by this configuration while other cases are also covered by other sufficient relations. Thus, these multicovered cases are not discussed here except SPS32 because its positive outcome is strongly associated with this configuration). The first part of this configuration (SGZ) corresponds with our theoretical expectation that a small group size enhances users' willingness to engage in collective actions. However, the second part (ssz) deviates from our theoretical prediction posited in Section 2.2. Alternatively, this result might confirm the argument that a large irrigated size benefits from the economics of scale by which users can provide more resources to sustain their system [47,74]. Below, we draw the empirical data of some cases to give a better interpretation of these findings.

SPS32 has 25 farmers who have irrigated 64 feddans together since the year 2000. After receiving the SPS from the Ministry of Water Resources and Irrigation (MWRI), respondents said they faced difficulties in allocating water between them during the periods of limited water availability in the BC (mainly in the summer). The reason was that the two-diesel pump's low pumping capacity obstructed farmers from acquiring the required water quantity at the agreed irrigation time. Thus, farmers held several ad hoc meetings and agreed to raise funds by which they could buy an additional diesel pump, hence enlarging the pumping capacity of their SPS. Two key factors, as indicated by respondents, facilitate farmers to invest in enlarging the pumping capacity: (1) farmer's group size makes it easier for them to reach a consensus on raising funds to enlarge their pumping capacity; (2) farmers raise their mutual funds based on the irrigated size, and thus with a larger irrigated size and little cash contribution, they are more willing to provide earmarked funds to expand their ability to pump or fund other activities (for example, farmers were unhappy with the quality of the pumps' cement bases, which was built by MWRI. Hence, they were also able to raise funds to rebuild them). Farmers also reported that farming larger area makes them very keen to meet their water demand, maintain their expected benefits, and lessen the irrigation costs incurred due to reducing irrigation time.

In the other cases covered by the configuration (SGZ*ssz), a small group size and large irrigated size have positive roles in well-operated SPSs. In SPS18, the group size (28 farmers) did not hinder farmers from raising ad hoc funds to construct the power grid in the SPS house to operate the electric pump provided by MWRI and buy a new diesel pump instead of the stolen one. According to respondents, the raised funds could not have been possible without the reasonable payment made by farmers based on the irrigated size (54 feddans) and their interest to secure their water needs associated with their irrigated size—that is, the large irrigated size supported farmers to sustain their SPS. Akin to SPS32, the group size and irrigated area of SPS30 (28 farmers and 54 feddans, respectively) played a significant role in enlarging the pumping capacity and thus supporting good operation of the SPS.

The previous findings suggest that the configuration (SGZ*ssz) has two features: less transaction costs associated with small group size and reflected in rule agreement on pooling resources to maintain the CPR, and economies of scale associated with large irrigated size reflected in users' capabilities to provide more resources to support their good CPR governance.

We find the empirical data of some cases such as SPS2, SPS8, and SPS28 might provide insights into how the variation in group size and irrigated size influences the likelihood of collective actions within the SPS arena. We decided to discuss these cases, although our solution formula does not cover these cases, as shown in Table 4.

We compared SPS2 with SPS32, as both have the same large irrigated sizes (64 feddans). Unlike SPS32, SPS2 farmers could not raise funds to improve their pumps' insufficient pumping capacity, received from MWRI, because their large group size, 73 farmers, impedes their efforts to expand their pumping capacity. This indicates that the advantage of the scale of economies generated by a large irrigated size may only enhance the collective actions in the SPS arena if the SPS group size is small.

In SPS8, respondents reported that they could not enforce the water allocation rules, monitor shared valves of the irrigation network, and impose fines on infringers. Consequently, the stealing of water was prevalent in the summer season. One respondent indicated, "we fail most of the time to enforce our agreed rules. [. . .] We make huge efforts to raise station [SPS8] expenditures and mobilize farmers to participate in the station maintenance work because our number [52 farmers] in the station is large". This suggests that a larger group size makes the process of enforcing rules cumbersome.

Interestingly, the diesel pump of SPS28 fell down many times because many farmers have poor experience in the pumping operation. Each time, farmers were able to fix the pump failure as long as it was not costly to fix the pump. However, when a considerable increase in fees was needed to fix a huge pump failure, farmers refused to pay to fix the pump and stopped using it. Instead, farmers linked their individual irrigation pumping machines (IPMs) with the SPS underground irrigation network. This is because the SPS diesel pump does not irrigate a large area (20 feddan) and farmers could not afford its maintenance costs. This suggests that small-irrigated sizes generate smaller-scale economies, which is reflected in the farmers' inability to incur high pump maintenance costs. Meanwhile, less water demand associated with a small irrigated size does not provide more incentives, in comparison to large irrigated sizes, for farmers to maintain the SPS pump.

5.3. Configuration of Adequate Water Supply (AWS) and the Appropriate Location of the SPS Command Area (LOC)

The results presented in Section 4.2.2 show that the configuration (AWS*LOC) has a causal relationship with well-operated SPSs. Nine cases, listed in Table 4, cover this configuration, each of which is also covered by the sufficient condition EFR, except SPS23, which is uniquely covered by this configuration. Therefore, we discuss the nine cases in general and focus on the unique one to explain how the configuration (AWS*LOC) is sufficient for the studied outcome to occur.

Both parts of the configuration correspond to our theoretical predictions: access to adequate water supply makes users more motivated to engage in collective actions necessary for successful CPRs; the location of CPRs attributed to the nonalternative source for irrigation has a positive impact on its good governance. All SPSs sharing the configuration (AWS*LOC) have access to neither an open irrigation canal nor an agricultural drain canal. This means that farmers of these SPSs do not have the opportunity to use their individual irrigation pumping machines (IPMs)—in addition to the SPS—to obtain water from these alternative water sources. Meanwhile, the water quantity in these SPSs is moderately available in the summer season, as indicated by respondents. Its quality is relatively good since it does not produce the negative externalities, previously stated in Section 3.3.1. However, how do both conditions work in a combination in a manner that enhances a positive outcome?

In SPS23, the water supply is adequate. Farmers always make a trade-off between the SPS and the IPM to obtain water. The SPS's key benefit is that its irrigation costs are less than those of the IPM—also indicated by Abou Kheira [75]—while the latter is associated with fewer transaction costs because it does not require collection actions as in the SPS. Since farmers of SPS23 do not have access to alternative irrigation sources, the only choice is to engage in the SPS collection action to obtain water. This suggests that the nonexistence of alternative irrigation sources increases farmers' dependence on the SPS as the water supply is adequate.

Furthermore, some empirically relevant observations offer insights into how different degrees of water supply and/or (non)existence of alternative irrigation sources affect the performance of SPSs. We elaborate on these observations in the next three points.

First, poor water quality of "El-Mesk" canal does not incentivize farmers of SPS43 to invest their time into organizing collective actions. The poor water quality originates as the state has started to supply this canal with agricultural drain water to overcome severe water shortage. As a consequence, farmers' agricultural costs increased because farmers had to apply pesticides intensively to treat diseases—that they never experienced before—and sold their products in remote markets where consumers did not know the irrigation source. These claims are also indicated by some studies conducted in the Nile Delta [21,52,53]. This suggests that the poor quality of irrigation water generates lower payoffs which in turn have an adverse effect on collective irrigation management.

Second, although water is relatively available in the case of SPS13, the existence of alternative irrigation sources—two *Saqia* wells—reduces farmers' dependence on the SPS and in turn weakens its performance. According to respondents, famers do not have common interest in increasing their low pumping capacity of two electric pumps and enforcing rules as they always use their IPMs to obtain water from *Saqia* wells when there are conflicts over managing the SPS. This finding is consistent with the theoretical prediction of Lam [49], who posits that in a system where the water is sufficient, and its users are able to effectively govern it, the presence of alternative water sources may make users less dependent on this system.

Third, it is worth noting that in a scenario where both inadequate water and alternative water sources exist—which is the opposite of configuration (AWS*LOC)—users may be more able to contribute to collective activities of the CPR. This is because the alternative water source may supplement the insufficient water supply and expand users' expected payoffs of engaging in collective actions [49]. Interestingly, this scenario is observed in some empirical cases in which the outcome of WOS is present. More precisely, these cases are SPS5, SPS30, and SPS32, located in the fifth row of the truth table in Table A5. According to the respondents of these cases, the locational attributes of SPSs provide at least one alternative source for irrigation, which farmers use to cope with their water shortage in the summer season and which in turn increases farmers' willingness to participate in collective actions. Meanwhile, it is important to note that the sufficient condition effective rules related to allocation, monitoring, and sanction and/or the configuration small group size and large irrigated size can also explain the presence of the outcome WOS in these three cases. This suggests that it is very hard to argue that specific conditions or configurations are only important as opposed to other criteria to explain CPR performance. Instead, one should expect that the CPR performance is shaped by many factors intervening in a complex manner. It is still challenging to find a research method capturing this complexity.

6. Conclusions

This study examines the conditions and configurations linked to successful collective actions governing common pool resources (CPRs). The study involves collecting data from forty-five cases, chosen purposively within Egypt's Nile Delta. Fuzzy set qualitative comparative analysis (fsQCA) was applied as an approach to analyze the necessary and sufficient relationships between five conditions and the outcome of well-operated SPSs. Through an iterative process, informed by theoretical and empirical knowledge, we determined the conditions that may be more likely to support the well-operated SPS. These conditions are: effective rules related to allocation, monitoring, and sanction; small group size; small irrigated size; adequate water supply; appropriate location of SPS command area.

In the CPR literature, scholars, e.g., Kimmich and Villamayor-Tomas [15], emphasize the importance of investigating configurational relations between factors that might explain the outcomes of governing the CPR. We believe this study contributes to this aspect since our approach tests different configurations of conditions that may be sufficient for successful local management of CPR. Moreover, when one investigates resource size's role in the collective outcomes, it would be more beneficial for the collective action and CPR theories to discern how the variation in both the number of resource users and the irrigated land affects CPR governance [5,19,43,74]. We think this study provides empirical support for this argument. We find a causal link between irrigation systems, irrigating large areas and utilized by a small number of farmers, and good local governance.

The fsQCA results show that none of the tested conditions alone are necessary for the well-operated SPS to occur. However, only the condition of effective rules related to allocation, monitoring, and sanction on its own was found to be sufficient for achieving the well-operated SPS.

The configurational analysis shows that the configuration of small group size and large irrigated size is sufficient for a well-operated SPS. This finding suggests that farmers of SPSs, characterized by a small group size and large irrigated size, have the ability to engage in successful collective actions because a small group size benefits from fewer transaction costs associated with rule agreements. Meanwhile, a large irrigated size benefits from economies of scale by which farmers can provide more resources to maintain the SPS. Furthermore, another sufficient configuration was obtained: the configuration of adequate water supply and appropriate location of the SPS command area. This result implies that well-operated SPSs may be achieved as farmers have adequate water supply, and simultaneously the SPS location attributes do not provide alternative water sources, which in turn increase farmers' dependence on the SPS.

These findings may have important implications for the ongoing national policy of diffusing the SPSs throughout Egypt to "modernize" irrigation [23]. Firstly, farmers' participation in the design and implementation of future SPSs in Egypt should be more tangible and effective, particularly in discussing farmers' group size and the SPS irrigated size. Secondly, in the locations where the water supply is adequate, the state should effectively regulate the use of alternative water sources because this weakens the SPS's social performance.

Although our empirical insights are derived from a limited geographic area in Egypt, we believe that testing the hypotheses associated with this study in a less represented context in CPR governance research [14] provides valuable insights for CPR theory and water governance studies. Furthermore, looking at different contexts in other countries of the global South facing similar challenges to Egypt, the research findings may have implications for local CPR governance. Future research should focus on understanding how both the group size and resource size at different hydrological levels and contexts may affect collective actions and CPR management.

Author Contributions: Conceptualization, A.S. and A.T.; methodology, A.S. and A.T.; software, A.S. and M.R.; validation, A.S., A.T. and M.R.; formal analysis, A.S. and M.R.; investigation, A.S.; resources, A.S. and A.T.; data curation, A.S.; writing—original draft preparation, A.S.; writing—review and editing, A.S., A.T. and M.R.; visualization, A.S.; supervision, A.T. and M.R.; project administration, A.S.; funding acquisition, A.S. and A.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Yousef Jameel Foundation, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding authors.

Acknowledgments: The authors acknowledge support by the German Research Foundation (DFG) and the Open Access Publication Fund of Humboldt-Universität zu Berlin. Ahmed Soliman would like to thank Yousef Jameel Foundation for the generous funding. Moreover, the authors are grateful to Rami Muhtaseb and Arvind Lakshmisha for their valuable English editing.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

SPS	Shared pumping station
fsQCA	Fuzzy set qualitative comparative analysis
CPR	Common pool resource
MWRI	Ministry of Water Resources and Irrigation
BC	Branch canal
IPM	Individual irrigation pumping machine
WUA	Water Users' Association
KES	Kafr El-Sheikh Governorate
MYZ	Meet Yazid canal
IAS	Irrigation Advisory Services department
AEE	Agricultural extension engineers
MALR	Ministry of Agriculture and Land Reclamation
WOS	Well-operated SPS
EFR	Effective rules related to allocation, monitoring, and sanction
WAL	Water allocation rule
MON	Monitoring rules for shared valves of irrigation network
SAN	Sanction rules
SGZ	Small group size
SIZ	Small irrigated size
AWS	Adequate water supply
AWQ	Adequate water quantity
AWL	Adequate water quality
LOC	Location of SPS command area
OIC	Open irrigation canal
ADC	Agricultural drain canal
SVN	Shared valves of irrigation network

Appendix A

Table A1. A summarized description of the studied SPSs.

Case	Creation Year	Name of Branch Canal (BC) [1]	Position of BC [2]	Distance from Intake (km)	Group Size	Irrigated Size [3]	Total No. of Interviewees
SPS1	2011	Mares El-Gamal	2nd	38.40	25.00	33.00	2
SPS2	2010	Mares El-Gamal	2nd	38.40	73.00	64.00	2
SPS3	2011	Mares El-Gamal	2nd	38.40	52.00	70.00	2
SPS4	2011	Mares El-Gamal	2nd	38.40	14.00	38.00	3
SPS5	2011	Mares El-Gamal	2nd	38.40	37.00	54.00	2
SPS6	2010	Left Ganabia No. 3	2nd	42.20	24.00	22.00	2
SPS7	2013	Right Ganabia No. 3	2nd	43.60	26.00	36.00	2
SPS8	2013	Right Ganabia No. 3	2nd	43.60	52.00	47.00	3
SPS9	2013	left Ganabia No. 4	2nd	44.00	24.00	42.00	3
SPS10	2013	Right Ganabia No. 4	2nd	46.30	25.00	30.00	3
SPS11	2011	El-Shorafa	3rd	41.30	29.00	46.00	2
SPS12	2011	El-Shorafa	3rd	41.30	24.00	33.00	2
SPS13	2013	El-Mafroza	3rd	41.90	31.00	28.00	2
SPS14	2013	El-Mafroza	3rd	41.90	41.00	35.00	3
SPS15	2012	El-Bashair	3rd	47.40	27.00	30.00	3
SPS16	2012	El-Bashair	3rd	47.40	7.00	24.00	3
SPS17	2013	El-Bashair	3rd	47.40	80.00	66.00	2
SPS18	2003	Dakalt	1st	41.00	28.00	54.00	2
SPS19	1999	Dakalt	1st	41.00	23.00	35.00	2
SPS20	1998	Dakalt	1st	41.00	49.00	90.00	2
SPS21	2003	Dakalt	1st	41.00	45.00	82.00	3
SPS22	2011	El-Mohet	3rd	49.15	20.00	42.00	2
SPS23	2010	El-Mohet	3rd	49.15	15.00	30.00	2
SPS24	2011	El-Mohet	3rd	49.15	31.00	43.00	3
SPS25	2014	El-Gemiza	2nd	55.90	15.00	36.00	3
SPS26	2014	Old Kom El-Roz	3rd	51.10	21.00	33.00	3
SPS27	2014	Old Kom El-Roz	3rd	51.10	36.00	30.00	2
SPS28	2014	Old Kom El-Roz	3rd	51.10	12.00	20.00	3
SPS29	2014	Old Kom El-Roz	3rd	51.10	30.00	37.00	2
SPS30	1999	El-Sant	3rd	55.30	28.00	52.00	2
SPS31	2006	El-Sant	3rd	55.30	46.00	58.00	2
SPS32	2000	El-Sant	3rd	55.30	25.00	64.00	3

Table A1. *Cont.*

Case	Creation Year	Name of Branch Canal (BC) [1]	Position of BC [2]	Distance from Intake (km)	Group Size	Irrigated Size [3]	Total No. of Interviewees
SPS33	2000	Bahr Abo Mostafa	2nd	51.20	52.00	61.00	3
SPS34	1998	Dal El-Qased	1st	42.60	96.00	126.00	2
SPS35	2000	Bosees	1st	47.50	65.00	90.00	2
SPS36	2000	Bosees	1st	47.50	42.00	91.00	2
SPS37	2000	Bosees	1st	47.50	79.00	118.00	2
SPS38	2000	Bosees	1st	47.50	56.00	88.00	3
SPS39	2002	El-Monshaa	2nd	54.90	72.00	105.00	3
SPS40	2002	El-Monshaa	2nd	54.90	129.00	130.00	2
SPS41	2004	Shalma	1st	50.10	18.00	48.00	2
SPS42	2002	Shalma	1st	50.10	52.00	122.00	3
SPS43	2004	El-Mesk	1st	59.50	68.00	130.00	2
SPS44	2007	Sidi Salam	2nd	58.30	30.00	22.00	2
SPS45	2006	East Sidi Salem	1st	63.00	40.00	41.00	2

Source: Data were collected from the respondents during the interviews while data of fourth and fifth columns were collected and calculated from Molle et al. [52]. [1] The branch canal is the irrigation canal branching off from the Meet Yazid canal (MYZ) and feeding water to the shared pumping station. [2] The position of branch canal (BC) is specified in proportion to MYZ. [3] Irrigated size is measured by feddan (1 feddan = 0.42 ha).

Table A2. Fuzzy set scales of the outcome and the five conditions.

Outcome/Conditions	Measures	Fuzzy Set Scale Definitions
Well-operated SPS (WOS)	• Provision activity (A): Contribution to operation and maintenance fees. • Provision activity (B): Contribution to cleaning the stand tank and intake pipe of SPS. • Provision activity (C): Contribution to sustaining the proper discharge capacity of pumps and/or protecting pumps from burglary.	1.00: All provision activities are observed. 0.67: Two provision activities are observed. 0.33: One provision activity is observed. 0.00: No provision activities are observed.
Effective rules related to allocation, monitoring, and sanction (EFR)	1. Water allocation rules (WAL)	1.00: SPS farmers craft WAL acknowledging both variations in the topography of farmers' land and exogenous problems during irrigation turns. 0.50: SPS farmers craft WAL acknowledging either variations in the topography of farmers' land or exogenous problems during irrigation turns. 0.00: SPS farmers craft WAL acknowledging neither variations in the topography of farmers' land nor exogenous problems during irrigation turns.
	2. Monitoring rules for shared valves of irrigation network (MON)	1.00: SPS farmers put locks on some of the shared valves of irrigation network (SVNs), pay a watchman (mostly the SPS operator), and/or conduct monitoring by themselves, with the result that they effectively prevent water stealing action. 0.67: SPS farmers put locks on some SVNs, and/or conduct monitoring by themselves, but water stealing action exists at low levels. 0.33: Although SPS farmers put locks on some of SVNs and/or conduct monitoring by themselves, water stealing action exists at a medium level. 0.00: Water stealing action exists at a high level because SPS farmers are not able to institutionalize any rule for monitoring SVNs.
	3. Sanction rules (SAN)	1.00: SPS farmers craft different levels of sanction rules, i.e., graduated sanction, and they are frequently willing to impose sanctions on wrongdoers. 0.67: SPS farmers craft a simple sanction rule at one level, such as enforcing provision rules or water appropriation rules, and they are frequently willing to impose sanctions on wrongdoers. 0.33: SPS farmers craft sanction rules, but they are moderately unwilling to enforce them. 0.00: SPS farmers craft sanction rules, but they are rarely willing to enforce them.
Small group size (SGZ)$^{+}$	Number of farmers within the SPS	1.00: Number of farmers is less than or equal to the average of 30 farmers. 0.50: Number of farmers is equal to the average of 45 farmers. 0.00: Number of farmers is large than or equal to the average of 60 farmers.

Table A2. *Cont.*

Outcome/Conditions	Measures	Fuzzy Set Scale Definitions
Small irrigated size (SIZ) +	Total irrigated area by the SPS, feddans (1 feddan = 0.42 ha)	1.00: SPS size is less than or equal to the average of 30 feddans. 0.50: SPS size is equal to the average of 50 feddans. 0.00: SPS size is large than or equal to the average of 75 feddans.
Adequate water supply (AWS)	1. Adequate water quantity (AWQ)	1.00: No action is taken because water is barely sufficient during the study period. 0.67: One action is taken to control the problem of water shortage during the study period. 0.33: Two actions are taken to control the problem of water shortage during the study period. 0.00: More than two actions are taken to control the problem of water shortage during the study period.
	2. Adequate water quality (AWL)	1.00: The BC water is not combined with drain water after Phase (A). 0.00: The BC water is combined with drain water after Phase (A).
Appropriate location of SPS command area (LOC)	1. Proximity to an open irrigation canal (OIC)	1.00: The location of SPS command area does not have access to an OIC. 0.00: The location of SPS command area has access to an OIC.
	2. Proximity to an agricultural drain canal (ADC)	1.00: The location of SPS command area does not have access to an ADC. 0.00: The location of SPS command area has access to an ADC.

+ For small group size and small irrigated size, we specify the point of full membership (a score of 1) and the point full non-membership (a score of 0) based on the local knowledge of the agricultural extension engineers of Ministry of Agriculture and Land Reclamation. Schneider and Wagemann [61] indicate that when assigning thresholds of the fuzzy set scale, researchers should rely on knowledge that is external to the data at hand. The crossover point (a score of 0.5) is specified as the middle point between both thresholds.

Table A3. Assigned membership scores of all measures of the conditions and the outcome.

Cases	Conditions									Outcome WOS
	EFR			SGZ	SIZ	AWS		LOC		
	WAL	MON	SAN			WQN	WQL	OIC	ADC	
SPS1	1.00	1.00	0.67	0.98	0.92	0.33	1.00	1.00	0.00	1.00
SPS2	0.00	0.33	0.00	0.00	0.16	0.67	1.00	0.00	1.00	0.00
SPS3	1.00	1.00	0.67	0.40	0.09	1.00	1.00	0.00	0.00	1.00
SPS4	0.00	0.00	0.33	1.00	0.85	0.67	1.00	0.00	0.00	0.00
SPS5	1.00	1.00	1.00	0.83	0.38	0.33	1.00	1.00	0.00	1.00
SPS6	1.00	1.00	0.67	1.00	0.98	0.67	1.00	0.00	1.00	1.00
SPS7	1.00	0.67	0.67	0.98	0.89	1.00	1.00	1.00	1.00	0.67
SPS8	0.50	0.00	0.33	0.20	0.61	1.00	1.00	0.00	1.00	0.33
SPS9	1.00	0.67	1.00	0.98	0.76	1.00	1.00	1.00	1.00	1.00
SPS10	1.00	1.00	0.67	0.98	0.95	1.00	1.00	1.00	1.00	0.67
SPS11	1.00	1.00	0.67	0.96	0.64	1.00	1.00	0.00	1.00	0.67
SPS12	1.00	0.33	0.33	0.98	0.92	0.67	1.00	1.00	0.00	1.00
SPS13	0.50	0.33	0.33	0.99	0.96	1.00	1.00	0.00	1.00	0.33
SPS14	1.00	1.00	0.67	0.98	0.90	1.00	1.00	1.00	1.00	1.00
SPS15	0.00	0.33	0.33	0.99	0.95	0.00	1.00	0.00	0.00	0.00
SPS16	0.50	0.33	0.33	1.00	0.98	0.00	1.00	0.00	0.00	0.00
SPS17	0.00	0.00	0.00	0.00	0.13	0.00	1.00	0.00	0.00	0.00
SPS18	0.50	1.00	0.33	0.97	0.38	0.67	1.00	0.00	1.00	0.67
SPS19	1.00	1.00	0.67	0.99	0.90	1.00	1.00	0.00	1.00	1.00
SPS20	1.00	1.00	0.67	0.31	0.01	1.00	1.00	0.00	1.00	1.00
SPS21	0.50	1.00	0.33	0.48	0.02	0.33	1.00	0.00	0.00	0.33
SPS22	1.00	1.00	1.00	0.99	0.76	0.67	1.00	1.00	1.00	0.67
SPS23	0.50	0.33	0.33	1.00	0.95	1.00	1.00	1.00	1.00	0.67
SPS24	0.50	1.00	0.33	0.94	0.74	0.00	1.00	0.00	0.00	0.00
SPS25	1.00	1.00	0.67	1.00	0.89	1.00	0.00	0.00	1.00	0.33
SPS26	1.00	1.00	0.67	0.98	0.92	1.00	0.00	0.00	0.00	0.67
SPS27	0.00	0.33	0.33	0.99	0.95	1.00	0.00	0.00	1.00	0.00
SPS28	0.50	0.00	0.00	1.00	0.99	1.00	0.00	0.00	0.00	0.00
SPS29	1.00	1.00	0.67	0.95	0.87	0.67	0.00	1.00	1.00	0.67
SPS30	1.00	0.67	0.00	0.97	0.44	0.67	0.00	0.00	1.00	0.67
SPS31	0.50	0.67	0.00	0.45	0.28	1.00	0.00	1.00	1.00	1.00
SPS32	1.00	1.00	0.67	0.98	0.16	0.00	0.00	0.00	0.00	1.00
SPS33	0.50	0.67	0.00	0.20	0.21	0.67	0.00	1.00	1.00	0.67
SPS34	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.33
SPS35	1.00	1.00	1.00	0.04	0.01	1.00	1.00	1.00	1.00	1.00
SPS36	1.00	1.00	1.00	0.64	0.01	1.00	1.00	1.00	1.00	1.00
SPS37	1.00	0.67	0.67	0.00	0.00	0.67	1.00	1.00	1.00	0.67
SPS38	1.00	0.67	0.33	0.10	0.01	0.33	0.00	1.00	0.00	1.00
SPS39	1.00	1.00	1.00	0.00	0.00	0.67	0.00	1.00	1.00	1.00
SPS40	0.50	0.33	1.00	0.00	0.00	0.33	0.00	1.00	0.00	0.33
SPS41	0.50	0.67	0.00	1.00	0.57	0.67	0.00	1.00	1.00	0.67
SPS42	1.00	1.00	1.00	0.20	0.00	1.00	0.00	1.00	0.00	1.00
SPS43	0.00	0.00	0.33	0.01	0.00	0.67	0.00	1.00	1.00	0.00
SPS44	1.00	1.00	1.00	0.95	0.98	1.00	0.00	1.00	1.00	0.33
SPS45	1.00	0.67	0.33	0.97	0.79	0.33	0.00	0.00	1.00	0.33

Table A4. Final membership scores of the conditions and the outcome for all cases.

Cases	Conditions					Outcome
	EFR	SGZ	SIZ	AWS	LOC	WOS
SPS1	0.67	0.98	0.92	0.33	0.00	1.00
SPS2	0.00	0.00	0.16	0.67	0.00	0.00
SPS3	0.67	0.40	0.09	1.00	0.00	1.00
SPS4	0.00	1.00	0.85	0.67	0.00	0.00
SPS5	1.00	0.83	0.38	0.33	0.00	1.00
SPS6	0.67	1.00	0.98	0.67	0.00	1.00
SPS7	0.67	0.98	0.89	1.00	1.00	0.67
SPS8	0.00	0.20	0.61	1.00	0.00	0.33
SPS9	0.67	0.98	0.76	1.00	1.00	1.00
SPS10	0.67	0.98	0.95	1.00	1.00	0.67
SPS11	0.67	0.96	0.64	1.00	0.00	0.67
SPS12	0.33	0.98	0.92	0.67	0.00	1.00
SPS13	0.33	0.99	0.96	1.00	0.00	0.33
SPS14	0.67	0.98	0.90	1.00	1.00	1.00
SPS15	0.00	0.99	0.95	0.00	0.00	0.00
SPS16	0.33	1.00	0.98	0.00	0.00	0.00
SPS17	0.00	0.00	0.13	0.00	0.00	0.00
SPS18	0.33	0.97	0.38	0.67	0.00	0.67
SPS19	0.67	0.99	0.90	1.00	0.00	1.00
SPS20	0.67	0.31	0.01	1.00	0.00	1.00
SPS21	0.33	0.48	0.02	0.33	0.00	0.33
SPS22	1.00	0.99	0.76	0.67	1.00	0.67
SPS23	0.33	1.00	0.95	1.00	1.00	0.67
SPS24	0.33	0.94	0.74	0.00	0.00	0.00
SPS25	0.67	1.00	0.89	0.00	0.00	0.33
SPS26	0.67	0.98	0.92	0.00	0.00	0.67
SPS27	0.00	0.99	0.95	0.00	0.00	0.00
SPS28	0.00	1.00	0.99	0.00	0.00	0.00
SPS29	0.67	0.95	0.87	0.00	1.00	0.67
SPS30	0.00	0.97	0.44	0.00	0.00	0.67
SPS31	0.00	0.45	0.28	0.00	1.00	1.00
SPS32	0.67	0.98	0.16	0.00	0.00	1.00
SPS33	0.00	0.20	0.21	0.00	1.00	0.67
SPS34	0.00	0.00	0.00	0.00	0.00	0.33
SPS35	1.00	0.04	0.01	1.00	1.00	1.00
SPS36	1.00	0.64	0.01	1.00	1.00	1.00
SPS37	0.67	0.00	0.00	0.67	1.00	0.67
SPS38	0.33	0.10	0.01	0.00	0.00	1.00
SPS39	1.00	0.00	0.00	0.00	1.00	1.00
SPS40	0.33	0.00	0.00	0.00	0.00	0.33
SPS41	0.00	1.00	0.57	0.00	1.00	0.67
SPS42	1.00	0.20	0.00	0.00	0.00	1.00
SPS43	0.00	0.01	0.00	0.00	1.00	0.00
SPS44	1.00	0.95	0.98	0.00	1.00	0.33
SPS45	0.33	0.97	0.79	0.00	0.00	0.33

Table A5. Truth table for analysis of sufficient conditions for the well-operated SPS.

SGZ	SIZ	AWS	LOC	Outcome	Consistency	Cases
1	0	1	1	1	1.000	SPS36
0	0	1	1	1	1.000	SPS35, SPS37
1	0	1	0	1	0.950	SPS18
1	1	1	1	1	0.849	SPS7, SPS9, SPS10, SPS14, SPS22, SPS23
1	0	0	0	1	0.834	SPS5, SPS30, SPS32
1	1	1	0	0	0.778	SPS4, SPS6, SPS11, SPS12, SPS13, SPS19
0	0	1	0	0	0.754	SPS2, SPS3, SPS20
1	1	0	1	0	0.744	SPS29, SPS41, SPS44
0	0	0	1	0	0.704	SPS31, SPS33, SPS39, SPS43
0	1	1	0	0	0.630	SPS8
0	0	0	0	0	0.520	SPS17, SPS21, SPS34, SPS38, SPS40, SPS42
1	1	0	0	0	0.392	SPS1, SPS15, SPS16, SPS24, SPS25, SPS26, SPS27, SPS28, SPS45
0	1	0	0	-	-	-
0	1	0	1	-	-	-
0	1	1	1	-	-	-
1	0	0	1	-	-	-

References

1. Wade, R. *Village Republics: Economic Conditions for Collective Action in South India*; ICS Press: San Francisco, CA, USA, 1994; ISBN 978-1-55815-387-5.
2. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; The Political Economy of Institutions and Decisions; Cambridge University Press: Cambridge, UK, 1990; ISBN 978-0-521-37101-8.
3. Tang, S.Y. *Institutions and Collective Action: Self-Governance in Irrigation*; ICS Press: San Francisco, CA, USA, 1992; ISBN 978-1-55815-179-6.
4. Baland, J.-M.; Platteau, J.-P. *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?* FAO: Rome, Italy; Oxford University Press: Oxford, UK, 1996; ISBN 978-0-19-829061-2.
5. Agrawal, A. Common property institutions and sustainable governance of resources. *World Dev.* **2001**, *29*, 1649–1672. [CrossRef]
6. Poteete, A.R.; Janssen, M.A.; Ostrom, E. *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*; Princeton University Press: Princeton, NJ, USA, 2010; ISBN 978-0-691-14603-4.
7. Cox, M.; Arnold, G.; Villamayor Tomás, S. A review of design principles for community-based natural resource management. *Ecol. Soc.* **2010**, *15*, 38. [CrossRef]
8. Dell'Angelo, J.; McCord, P.F.; Gower, D.; Carpenter, S.; Caylor, K.K.; Evans, T.P. Community water governance on Mount Kenya: An assessment based on Ostrom's design principles of natural resource management. *Mt. Res. Dev.* **2016**, *36*, 102–115. [CrossRef]
9. Yu, H.H.; Edmunds, M.; Lora-Wainwright, A.; Thomas, D. Governance of the irrigation commons under integrated water resources management—A comparative study in contemporary rural China. *Environ. Sci. Policy* **2016**, *55*, 65–74. [CrossRef]
10. Wang, Y.; Zhang, M.; Kang, J. How does context affect self-governance? Examining Ostrom's design principles in China. *Int. J. Commons* **2019**, *13*, 660–704. [CrossRef]
11. Agrawal, A. Studying the commons, governing common-pool resource outcomes: Some concluding thoughts. *Environ. Sci. Policy* **2014**, *36*, 86–91. [CrossRef]
12. McCord, P.; Dell'Angelo, J.; Gower, D.; Caylor, K.K.; Evans, T. Household-Level heterogeneity of water resources within common-pool resource systems. *Ecol. Soc.* **2017**, *22*, 48. [CrossRef]
13. Fleischman, F.D.; Ban, N.C.; Evans, L.S.; Epstein, G.; Garcia-Lopez, G.; Villamayor-Tomas, S. Governing large-scale social-ecological systems: Lessons from five cases. *Int. J. Commons* **2014**, 428–456. [CrossRef]
14. Özerol, G.; Vinke-de Kruijf, J.; Brisbois, M.C.; Flores, C.C.; Deekshit, P.; Girard, C.; Knieper, C.; Mirnezami, S.J.; Ortega-Reig, M.; Ranjan, P.; et al. Comparative studies of water governance: A systematic review. *Ecol. Soc.* **2018**, *23*, 43. [CrossRef]
15. Kimmich, C.; Villamayor-Tomas, S. Assessing action situation networks: A configurational perspective on water and energy governance in irrigation systems. *Water Econ. Policy* **2019**, *5*, 1–29. [CrossRef]
16. Schlager, E. Common-Pool resource theory. In *Environmental Governance Reconsidered: Challenges, Choices, and Opportunities*; Durant, R.F., Fiorino, D.J., O'Leary, R., Eds.; MIT Press: Cambridge, MA, USA, 2004; pp. 145–175.
17. Hamidov, A.; Thiel, A.; Zikos, D. Institutional design in transformation: A comparative study of local irrigation governance in Uzbekistan. *Environ. Sci. Policy* **2015**, *53*, 175–191. [CrossRef]
18. Baggio, J.A.; Barnett, A.J.; Perez-Ibarra, I.; Brady, U.; Ratajczyk, E.; Rollins, N.; Rubiños, C.; Shin, H.C.; Yu, D.J.; Aggarwal, R.; et al. Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles. *Int. J. Commons* **2016**, *10*, 417–439. [CrossRef]

19. Araral, E. What explains collective action in the commons? Theory and evidence from the Philippines. *World Dev.* **2009**, *37*, 687–697. [CrossRef]
20. Central Agency for Public Mobilization And Statistics. Egypt in Figures. Available online: https://www.capmas.gov.eg/Pages/StaticPages.aspx?page_id=5035 (accessed on 26 November 2020).
21. Molle, F.; Rap, E.; Al-Agha, D.E.; Ismail, A.; Abou El Hassan, W.; Freeg, M. *Irrigation Improvement Projects in the Nile Delta: Promises, Challenges, Surprises*; Water and Salt Management in the Nile Delta Project Report No. 4; International Water Management Institute (IWMI): Colombo, Sri Lanka; Water Management Research Institute (WMRI): Cairo, Egypt, 2015; p. 117.
22. Gouda, D.M. *Social Capital and Local Water Management in Egypt*, 1st ed.; AUC Press: Cairo, Egypt, 2016; ISBN 978-977-416-763-8.
23. Molle, F.; Rap, E.; Al-Agha, D.E.; El Hassan, W.A.; Freeg, M. Irrigation improvement projects in the Nile Delta: Promises, challenges, surprises. *Agric. Water Manag.* **2019**, *216*, 425–435. [CrossRef]
24. El-Kassar, G. Identification of best practice examples for irrigation and water harvesting in Egypt. In Proceedings of the Thirteenth International Water Technology Conference, Hurghada, Egypt, 12–15 March 2009.
25. Mohsen Aly, A.; Kitamura, Y.; Shimizu, K. Assessment of irrigation practices at the tertiary canal level in an improved System—A case study of wasat area, the Nile Delta. *Paddy Water Environ.* **2013**, *11*, 445–454. [CrossRef]
26. Ostrom, E.; Gardner, R.; Walker, J. *Rules, Games, and Common-Pool Resources*; University of Michigan Press: Ann Arbor, MI, USA, 1994; ISBN 978-0-472-09546-9.
27. Baldwin, E.; McCord, P.; Dell'Angelo, J.; Evans, T. Collective action in a polycentric water governance system. *Environ. Policy Gov.* **2018**, *28*, 212–222. [CrossRef]
28. Theesfeld, I. The downgrading effect of abuse of power on trust and collective action in Bulgaria's irrigation sector. In *Institutions and Sustainability: Political Economy of Agriculture and the Environment: Essays in Honour of Konrad Hagedorn*; Beckmann, V., Hagedorn, K., Padmanabhan, M.A., Eds.; Springer: Berlin, Germany, 2009; pp. 223–242. ISBN 978-1-4020-9689-1.
29. Cox, M. Applying a social-ecological system framework to the study of the taos valley irrigation system. *Hum. Ecol.* **2014**, *42*, 311–324. [CrossRef]
30. Villamayor-Tomas, S. Cooperation in common property regimes under extreme drought conditions: Empirical evidence from the use of pooled transferable quotas in Spanish irrigation systems. *Ecol. Econ.* **2014**, *107*, 482–493. [CrossRef]
31. Dhakal, T.; Davidson, B.; Farquharson, B. Factors affecting collective actions in farmer-managed irrigation systems of Nepal. *Agriculture* **2018**, *8*, 77. [CrossRef]
32. Wang, Y.; Zang, L.; Araral, E. The impacts of land fragmentation on irrigation collective action: Empirical test of the social-ecological system framework in China. *J. Rural Stud.* **2020**, *78*, 234–244. [CrossRef]
33. Cleaver, F. Moral ecological rationality, institutions and the management of common property resources. *Dev. Chang.* **2000**, *31*, 361–383. [CrossRef]
34. Ricks, J.I. Building participatory organizations for common pool resource management: Water user group promotion in Indonesia. *World Dev.* **2016**, *77*, 34–47. [CrossRef]
35. Olson, M. *The Logic of Collective Action: Public Goods and the Theory of Groups*; Harvard University Press: Cambridge, MA, USA, 1965; ISBN 0-674-53751-3.
36. Zhang, L.; Heerink, N.; Dries, L.; Shi, X. Water users associations and irrigation water productivity in Northern China. *Ecol. Econ.* **2013**, *95*, 128–136. [CrossRef]
37. Huang, Q. Impact evaluation of the irrigation management reform in Northern China. *Water Resour. Res.* **2014**, *50*, 4323–4340. [CrossRef]
38. Miao, S.; Zhu, X.; Heijman, W.; Xu, Z.; Lu, Q. Trust or control? The role of group size in governing small-scale irrigation facilities. *Rural Sociol.* **2020**, 1–28. [CrossRef]
39. Meinzen-Dick, R.; Mendoza, M.; Sadoulet, L.; Abiad-Shields, G.; Subramanian, A. Sustainable water users' associations: Lessons from a literature review. In *User Organizations for Sustainable Water Services*; Subramanian, A., Jagannathan, N.V., Meinzen-Dick, R.S., Eds.; World Bank Technical Paper; World Bank: Washington, DC, USA, 1997; pp. 9–93. ISBN 978-0-8213-3855-1.
40. Wang, Y.; Chen, C.; Araral, E. The effects of migration on collective action in the commons: Evidence from rural China. *World Dev.* **2016**, *88*, 79–93. [CrossRef]
41. Wang, Y.; Wu, J. An empirical examination on the role of water user associations for irrigation management in rural China. *Water Resour. Res.* **2018**, *54*, 9791–9811. [CrossRef]
42. Araral, E.; Mukherjee, M.; Qi, F.V.S.Y.; Orazgaliyev, S. Water commons: A critical appreciation and revisionist view. In *Routledge Handbook of the Study of the Commons*; Hudson, B., Rosenbloom, J., Cole, D., Eds.; Routledge: London, UK; New York, NY, USA, 2019; pp. 144–156.
43. Wang, R.; Tan, R. Patterns of rural collective action in contemporary China: An archetype analysis of rural construction land consolidation. *J. Rural Stud.* **2020**, *79*, 286–301. [CrossRef]
44. Fujiie, M.; Hayami, Y.; Kikuchi, M. The conditions of collective action for local commons management: The case of irrigation in the Philippines. *Agric. Econ.* **2005**, *33*, 179–189. [CrossRef]
45. Takayama, T.; Matsuda, H.; Nakatani, T. The determinants of collective action in irrigation management systems: Evidence from rural communities in Japan. *Agric. Water Manag.* **2018**, *206*, 113–123. [CrossRef]
46. Meinzen-Dick, R.; Raju, K.V.; Gulati, A. What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India. *World Dev.* **2002**, *30*, 649–666. [CrossRef]

47. Villamayor-Tomas, S. Understanding Robustness to Disturbance through the Theory of the Commons: Irrigation Water Governance and Socio-Ecological Robustness in the Gallego and Cinca River Watersheds, Spain. Ph.D. Thesis, Indiana University, Bloomington, IN, USA, 2012.
48. Sharaunga, S.; Mudhara, M. Determinants of farmers' participation in collective maintenance of irrigation infrastructure in KwaZulu-Natal. *Phys. Chem. Earth* **2018**, *105*, 265–273. [CrossRef]
49. Lam, W.F. *Governing Irrigation Systems in Nepal: Institutions, Infrastructure, and Collective Action*; ICS Press: San Jose, CA, USA, 1998; ISBN 1-55815-505-8.
50. Bardhan, P. Irrigation and cooperation: An empirical analysis of 48 irrigation communities in South India. *Econ. Dev. Cult. Chang.* **2000**, *48*, 847–865. [CrossRef]
51. Ito, J. Collective action for local commons management in rural Yunnan, China: Empirical evidence and hypotheses using evolutionary game theory. *Land Econ.* **2012**, *88*, 181–200. [CrossRef]
52. Molle, F.; Rap, E.; Al-Agha, D.E.; Zaki, N.; El-Gamal, T.; Abou El Hassan, W.; Meleha, M.; Yassa, E.; Ismail, A. *An Exploratory Survey of Water Management in the Meet Yazid Canal Command Area of the Nile Delta*; Water and Salt Management in the Nile Delta Project Report No. 2; International Water Management Institute (IWMI): Colombo, Sri Lanka; Water Management Research Institute (WMRI): Cairo, Egypt, 2013; p. 124.
53. Ghazouani, W.; Molle, F.; Swelam, A.; Rap, E.; Abdo, A. *Understanding Farmers' Adaptation to Water Scarcity: A Case Study from the Western Nile Delta, Egypt*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2014; p. 31.
54. Sarker, A.; Ross, H.; Shrestha, K.K. A common-pool resource approach for water quality management: An Australian case study. *Ecol. Econ.* **2008**, *68*, 461–471. [CrossRef]
55. George, A.; Pierret, A.; Boonsaner, A.; Valentin, C. Potential and limitations of payments for environmental services (PES) as a means to manage watershed services in Mainland Southeast Asia. *Int. J. Commons* **2009**, *3*, 16–40. [CrossRef]
56. Sangkapitux, C.; Neef, A.; Polkongkaew, W.; Pramoon, N.; Nonkiti, S.; Nanthasen, K. Willingness of upstream and downstream resource managers to engage in compensation schemes for environmental services. *Int. J. Commons* **2009**, *3*, 41–63. [CrossRef]
57. Villamayor-Tomas, S.; Fleischman, F.D.; Perez Ibarra, I.; Thiel, A.; van Laerhoven, F. From Sandoz to Salmon: Conceptualizing resource and institutional dynamics in the Rhine watershed through the SES framework. *Int. J. Commons* **2014**, *8*, 361. [CrossRef]
58. Lansing, J.S.; Miller, J.H. Cooperation, games, and ecological feedback: Some insights from Bali. *Curr. Anthropol.* **2005**, *46*, 328–334. [CrossRef]
59. Janssen, M.A.; Anderies, J.M.; Cardenas, J.-C. Head-Enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field. *Ecol. Econ.* **2011**, *70*, 1590–1598. [CrossRef]
60. Pham, L.T.; Otto, I.M.; Zikos, D. Self-Governance and the effects of rules in irrigation systems: Evidence from laboratory and framed field experiments in China, India and Vietnam. *Water Econ. Policy* **2019**, *5*, 1850009. [CrossRef]
61. Thapa, B.; Scott, C.A. Institutional strategies for adaptation to water stress in farmer-managed irrigation systems of Nepal. *Int. J. Commons* **2019**, *13*, 892–908. [CrossRef]
62. Berg-Schlosser, D.; De Meur, G. Comparative research design: Case and variable selection. In *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*; Rihoux, B., Ragin, C.C., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2009; pp. 19–32.
63. Rutten, R. Applying and assessing large-N QCA: Causality and robustness from a critical realist perspective. *Sociol. Methods Res.* **2020**, 1–33. [CrossRef]
64. Yin, R.K. *Case Study Research and Applications: Design and Methods*, 6th ed.; Sage Publications: Thousand Oaks, CA, USA, 2018; ISBN 978-1-5063-3616-9.
65. Ragin, C.C. *The Comparative Method: Moving beyond Qualitative and Quantitative Strategies*; University of California Press: Berkley, CA, USA, 2014; ISBN 978-0-520-28003-8.
66. Schneider, C.Q.; Wagemann, C. *Set-Theoretic Methods for the Social Sciences: A Guide to Qualitative Comparative Analysis*; Cambridge University Press: Cambridge, UK, 2012; ISBN 978-1-107-01352-0.
67. Ragin, C.C. *Redesigning Social Inquiry: Fuzzy Sets and Beyond*; University of Chicago Press: Chicago, IL, USA, 2008; ISBN 978-0-226-70273-5.
68. Berg-Schlosser, D.; De Meur, G.; Rihoux, B.; Ragin, C.C. Qualitative comparative analysis (QCA) as an approach. In *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*; Rihoux, B., Ragin, C.C., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2009; pp. 1–18.
69. Greckhamer, T.; Furnari, S.; Fiss, P.C.; Aguilera, R.V. Studying configurations with qualitative comparative analysis: Best practices in strategy and organization research. *Strateg. Organ.* **2018**, *16*, 482–495. [CrossRef]
70. Basurto, X.; Speer, J. Structuring the calibration of qualitative data as sets for qualitative comparative analysis (QCA). *Field Methods* **2012**, *24*, 155–174. [CrossRef]
71. Goertz, G. *Social Science Concepts, a User's Guide*; Princeton University Press: Princeton, NJ, USA, 2006; ISBN 978-0-691-12410-0.
72. Duşa, A. *QCA with R A Comprehensive Resource*; Springer: Berlin, Germany, 2019; ISBN 978-3-319-75667-7.
73. Ragin, C.C. Qualitative comparative analysis using fuzzy sets (fsQCA). In *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*; Rihoux, B., Ragin, C.C., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2009; pp. 87–121.

74. Agrawal, A. Small is beautiful, but is larger better? Forest-Management institutions in the Kumaon Himalaya, India. In *People and Forests: Communities, Institutions, and Governance*; Gibson, C.C., McKean, M.A., Ostrom, E., Eds.; Politics, Science, and the Environment; MIT Press: Cambridge, MA, USA, 2000; ISBN 978-0-262-07201-4.
75. Abou Kheira, A.A. Comparative assessment of new design criteria for irrigation improvement in Egypt. *Water Resour. Manag.* **2009**, *23*, 2317–2342. [CrossRef]