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ORIGINAL ARTICLE

A complex transdisciplinary approach to achieve water sustainability: lessons from a case study in Morelia, Mexico

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Abstract
Although the theoretical–methodological complexity theory and transdisciplinary approach is increasingly accepted within sustainability science, its application at local-scale work with rural communities in the global south is still incipient and requires further research on its scope and limitations. The general objective of this work was to contribute to the knowledge on how a complexity and transdisciplinary approach applied to water problems at local scales can facilitate the process for water sustainability. The research took as study area the *ejido* of Coro Grande located in the municipality of Morelia, in the rural vicinity of Morelia City, capital of Michoacán State (Mexico). The theoretical–methodological scheme was based on the combination of the concepts of complexity–sustainability–transdisciplinarity to analyze the local water metabolism and generate actions to mitigate present and future water risk. The activities carried out involved a participatory diagnosis and the development of activities for the restoration of degraded environments with a double purpose: to generate conditions for the water sustainability of the system, and to promote the involvement of the population in a transdisciplinary research–action process. The results obtained show the effectiveness of the framework chosen to identify problems, achieve transformation in the short term, and improve both ecosystem functions and participation of the population in the solution of problems in the medium and long terms.

Keywords Complexity · Transdisciplinary research · Water sustainability · Sustainability science

Introduction

Currently, water sustainability is a fundamental objective of environmental management due to the importance of water in all the metabolic processes that take place in socio-ecological systems (SES) (Hermanowicz 2008), both in urban and peri-urban areas (Torres López et al. 2021; Yang et al. 2016), and rural areas mostly because of agriculture (Vos and Boelens 2014). To achieve water sustainability, it is essential to have information that allows characterizing the metabolism of the territorial system of interest, considering water as one of its central constituent elements (Madrid-López and Giampietro 2015). This implies climatic, ecological, and social processes that develop within it, taking into consideration the actors involved and their interests (Pahl-Wostl et al. 2008).

Despite this, the complexity of SES and the lack of resources in local institutions make it difficult to have access to detailed information about water issues in many regions of the planet. Even in situations with greater access to economic and technological resources, and where the State has institutions with a strong presence in water management, there are difficulties in configuring scenarios that tend to water sustainability. To take just one example, we can mention the water problems and conflicts faced by countries in the European Union (Morote et al. 2020; Rupérez-Moreno et al. 2017).

The problem of water sustainability is more acute within the context of the global south, such as in Latin-American

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countries, where the resources of the State and the institutions responsible for environmental management are limited and often insufficient (Riveros-Iregui et al. 2018). In Mexico in particular, it is usual not to have access to hydrological, climatological, and land use information about local territories. This is enhanced due to the diversity of land tenure and territorial management practices, where social (community and *ejidal*), private, and State tenure are combined, with multiple interests, often conflicting and influenced by the dynamics of globalization (Arreguín-Cortés et al. 2020; von Bertrab 2003; Wilder and Romero-Lankao 2005).

Furthermore, water sustainability will become harder in the near future as a consequence of climate change. It has been projected for Mexico that, by the decade centered on the year 2030, there will be an increase in mean annual temperature of 1.6 °C, and a decrease of 7% in precipitation, compared to the average of the period 1961–1990 (Sáenz-Romero et al. 2010). This highlights the need to improve the methodological procedures to generate information that allows federal, regional, and local decision-makers to develop policies and actions aimed at water sustainability that take into account the complexity of the system analyzed, the lack of information and resources in the context of the south, and that have social acceptance.

The potential of transdisciplinary research to contribute to the generation of information that enables decision-making for the management of SES has been recognized by several authors, since it is a practical research process that links academic knowledge, the expertise of the actors involved in management, and the knowledge of the local community (Folke 2004; Steelman et al. 2015). Transdisciplinarity—as opposed to disciplinary approaches that have proven to generate partial and insufficient solutions to current environmental problems in the global south (van Breda and Swilling 2019)—involves the co-production of knowledge and the co-design of research and management mechanisms that contemporary socio-ecological processes require (Mauser et al. 2013).

At the same time, there is a growing recognition of transdisciplinarity as a tool to contribute to sustainability (Thiam et al. 2021) and to the generation of information for decision-making (Renn 2021). However, as a participatory process, transdisciplinary research faces different challenges, for example, in conflictive situations around water management (Ocampo-Melgar et al. 2022; Ruggerio et al. 2024) or the work with wicked environmental problems (Lawrence et al. 2022), the involvement of marginalized communities in the process (Bou Nassar et al. 2021), and the lack of methods to integrate the knowledge of scientist and stakeholders (Pohl and Hadorn 2008), among others.

Both situations, the lack of information and resources in some regions of the world to address water problems, on one hand, and the challenges of the practice of transdisciplinary research, on the other hand, constitute a space of vacancy and opportunity to explore theoretical and methodological approaches to achieve water sustainability. Based on this, the main objective of this work was to contribute to the knowledge on how a complexity and transdisciplinary approach applied to water problems at local scales can facilitate the process for water sustainability.

Our work propones a complexity–transdisciplinary–sustainability research framework and takes as a study area the *ejido* of Coro Grande located in the municipality of Morelia, in the rural vicinity of Morelia City, capital of Michoacán State (México). The framework was applied to achieve a complex understanding of the local water metabolism (WM) and to develop participatory action research activities within a transdisciplinary approach to achieve local water sustainability in the medium and long term.

Material and methods

Study area

Coro Grande is an *ejido* located in the northwest rural area of the municipality of Morelia, 31 km from Morelia City, capital of Michoacán State (Mexico). It is located at an altitude of approximately 2,150 m above sea level (Fig. 1). The *ejido* is a form of social land tenure that was granted to the landless peasants after the Mexican Revolution—about one-half of the Mexican territory comprises community-based land tenures, mainly *ejidos* (Morett-Sánchez and Cosío-Ruiz 2017). It is also the most important form of social organization in rural Mexico. The land comprising the *ejido* is classified in three types: human settlement land (which is allocated to the *ejidal* village), common use land (that can be used by all *ejidatarios* under collective decisions), and parceled land (the individual plots assigned to each *ejidatario*) (Duhau 2010).

It has a population of approximately 453 inhabitants that reside in a rural village within a human settlement area of about 200 ha. Apart from the year 2000 where the population decreased 20%, since 1990, the population of Coro Grande has remained relatively stable (Table 1).

Human settlement area

There are 150 homes in the human settlement area, 111 of which are inhabited. There is a high school and a basic education school (elementary and preschool). There is also a primary health-care center with basic infrastructure. For specialized health care, the population must go to the Tzintzimacato Health Center, located 20 km from the town. The village's infrastructure includes a recreational area and the *ejidal* house, which is used for meetings and assemblies.

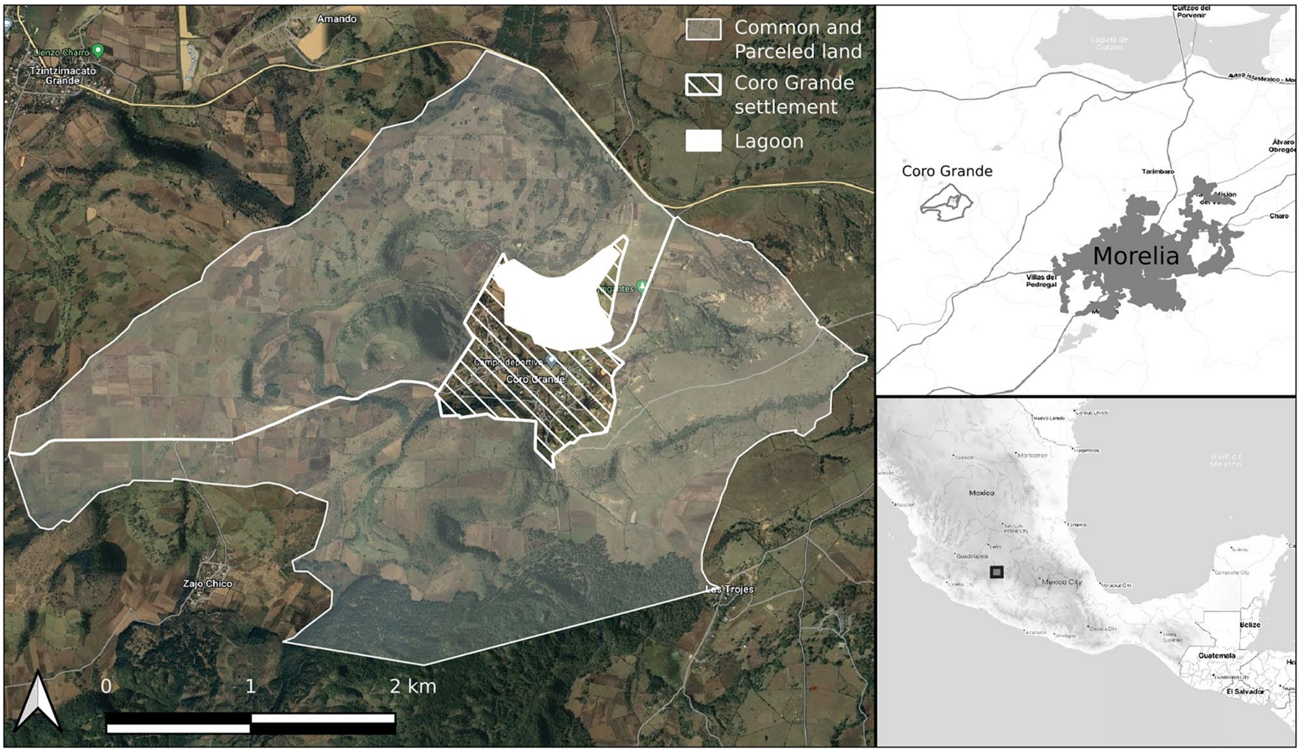

Fig. 1 Study area: *ejido* of Coro Grande, Morelia, Michoacán, México (19°45′37.6″ N, 101°24′05.2″ W)

Table 1 Changes in the population growth in Coro Grande (1990–2020)

Population	Year			
	1990	2000	2010	2020
Male	219	166	206	222
Female	213	174	221	231
Total	432	340	427	453

Source: Censos Nacionales de Población y Vivienda de INEGI-México (1990, 2000, 2010, 2020)

In terms of services, the village has electricity and mains water in 110 dwellings. Mains water is drawn from a common well and is distributed by gravity from a single 20,000-1 tank (community cistern). The most important deficiencies in infrastructure and public services are: deficient cell phone and Internet coverage, the lack of street lighting, the lack of pavement and sidewalks in different streets of the village, and the lack of a wastewater treatment system. Also, although the village has a low marginality index and a low social gap index, over 60% of the population above 15 years have not completed basic education and almost 40% of the population lives in overcrowded conditions.

Common use and parceled land areas

The common use and parceled land areas cover approximately 1,400 ha. Part of the land is for common use and the rest is divided into individual plots for 75 families who are mainly engaged in agriculture and cattle ranching. Farming is oriented toward corn and beans for self-consumption, and cattle ranching is mainly focused on extensive cattle raising.

Methodological approach

Figure 2 shows the complexity–transdisciplinary–sustainability research framework applied to the work. The research aimed to achieve a complex understanding of the local water metabolism (WM) based on the conceptual proposal of García (2006) and the approach proposed by Madrid and Velázquez (2008), and to design and implement participatory action research activities within a transdisciplinary framework (Lang et al. 2012; Norström et al. 2020) to achieve local water sustainability in the medium and long term. The definition of water sustainability assumed in the research was proposed by Rugerio and Massobrio (2019) and is based on a strong sustainability criterion where the ecosystem's functions cannot be replaced by artificial technology (Ruggerio 2021).

The research involved the main actors related to water resources management in the region. The participants were

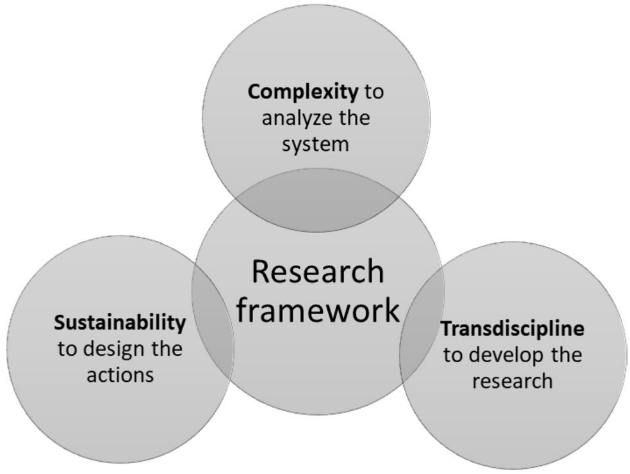

Fig. 2 Framework applied to the research process

academic researchers from the Centro de Investigaciones en Geografía Ambiental (CIGA) and the Instituto de Investigaciones en Ecosistemas y Sustentabilidad (IIES), belonging to the Universidad Nacional Autónoma de México (UNAM); officials and staff of the Secretariat of Rural Development and Environment of the Municipality of Morelia (Michoacán, México); and representatives and members of the Coro Grande Community (study area).

The methodological process was organized into two main stages: (a) the development of a diagnosis of water sustainability and the elaboration of a conceptual model of water metabolism; and (b) the design and implementation of management actions to promote water sustainability. Activities of each stage were carried out simultaneously between October 2020 and February 2021.

Diagnosis and conceptual model of water metabolism

We assume that the socio-ecological system under study is a complex system integrated by a diversity of components that interact with each other (Daron et al. 2015; Rounsevell et al. 2021), triggering processes that modify the natural hydrological cycle and configure the local water metabolism (Madrid-López and Giampietro 2015).

The objectives of the diagnosis were: (a) to identify and analyze the main processes that make up the water metabolism; (b) to identify the situations that compromise the water sustainability of the study area; and (c) to identify the water risk situations for the population in the face of these situations. For this purpose, secondary information was used, in-depth interviews were conducted with key stakeholders, participatory mapping workshops were held, participant observation was carried out in community assemblies—convened for the presentation of the project and its different stages—and environmental recovery activities programmed within the framework of the project were implemented.

The information obtained in the diagnosis was an input for the development of a conceptual model of water metabolism (Madrid and Velázquez 2008). In this approach, the system under study is considered a water metabolizer that uses its reservoirs and water inputs from its environment for its reproduction. To develop the model, the main water inputs and outputs of the system were identified, as well as the main metabolic processes—both anthropic and natural—that use water and affect its availability in quality and quantity.

Management actions to achieve water sustainability

The diagnosis and the conceptual model of water metabolism provided a qualitative understanding of the water cycle, its local modifications, and the ecosystem processes involved. Based on this information, activities for the recovery of degraded areas were projected and developed to generate future scenarios of water sustainability. The actions began to be implemented during the research and are projected to continue in the medium and long term. The recovery activities were mainly three: (1) the recovery of the lagoon's water tributaries and banks to increase their depth; (2) fish seeding in the lagoon; and (3) the reforestation of eroded areas affected by extensive cattle ranching and deforestation.

Results

Pre-diagnosis activities

To carry out a transdisciplinary process, we started with a series of meetings and activities focused on consolidating a work team. The first meetings were held between researchers from CIGA-UNAM and the Secretary of Rural Development and Environment of the Morelia City Council, where the general work procedure was agreed upon and field visits were made to identify a potential work area.

The *ejido* Coro Grande was chosen, due to its socio-ecological conditions, level of organization, and the predisposition of the community actors to participate in a transdisciplinary research process. The first contact was established with a community referent who is a municipal authority in charge of law enforcement. Through him, the *ejidal* commissariat (president, secretary, and treasurer) were summoned. Following the research objectives, the main topic to be worked on with the representatives was oriented toward the evaluation of problems related to water such as water supply and access infrastructure, water availability affected by anthropic processes, droughts, and floods.

The work proposal was accepted by the *ejidal* representatives, but they expressed the need for approval in the general assembly (which is the highest authority of the *ejido* and composed by all *ejidatarios*). It was agreed that it would be carried out with open participation of all interested parties. The meeting was held in December 2020, with the participation of researchers from the UNAM team, municipal officials, *ejidal* representatives, and *ejidatarios*. As water scarcity is a growing problem in the region and *ejidatarios* recognizes it, the work proposal was unanimously accepted. However, the participation was not very numerous. This situation highlighted the need to generate specific work activities that encourage broader participation.

The main results of the pre-diagnosis stage include the identification of problems related to the growing scarcity of water, such as the loss of crops, difficulties in raising livestock during the dry season, and the intermittent supply of water to the houses farthest from the village. The progressive loss of the Coro Grande lagoon during the dry season of consecutive years was also identified as a problem. *Ejidatarios* mentioned that the lagoon was used in the past for fish farming, but this activity was discontinued due to the decrease in the depth of the water body, to the point that in recent years the lagoon dried up completely during the dry season.

Diagnosis and conceptual model of water metabolism

Figure 3 shows the conceptual model of water metabolism for the study area constructed from the diagnostic activities. The most representative flows and processes are described below.

System water inputs, reservoirs, and outputs

Inputs The main input of water to the system is rainfall, which supplies both the surface reserves and the recharge of the aquifers. The annual precipitation regime has a marked rainy season between April and October (summer season) and a dry season with little to no precipitation during the rest of the year.

Anthropic inputs of water into the system are mainly from beverages for human consumption and food

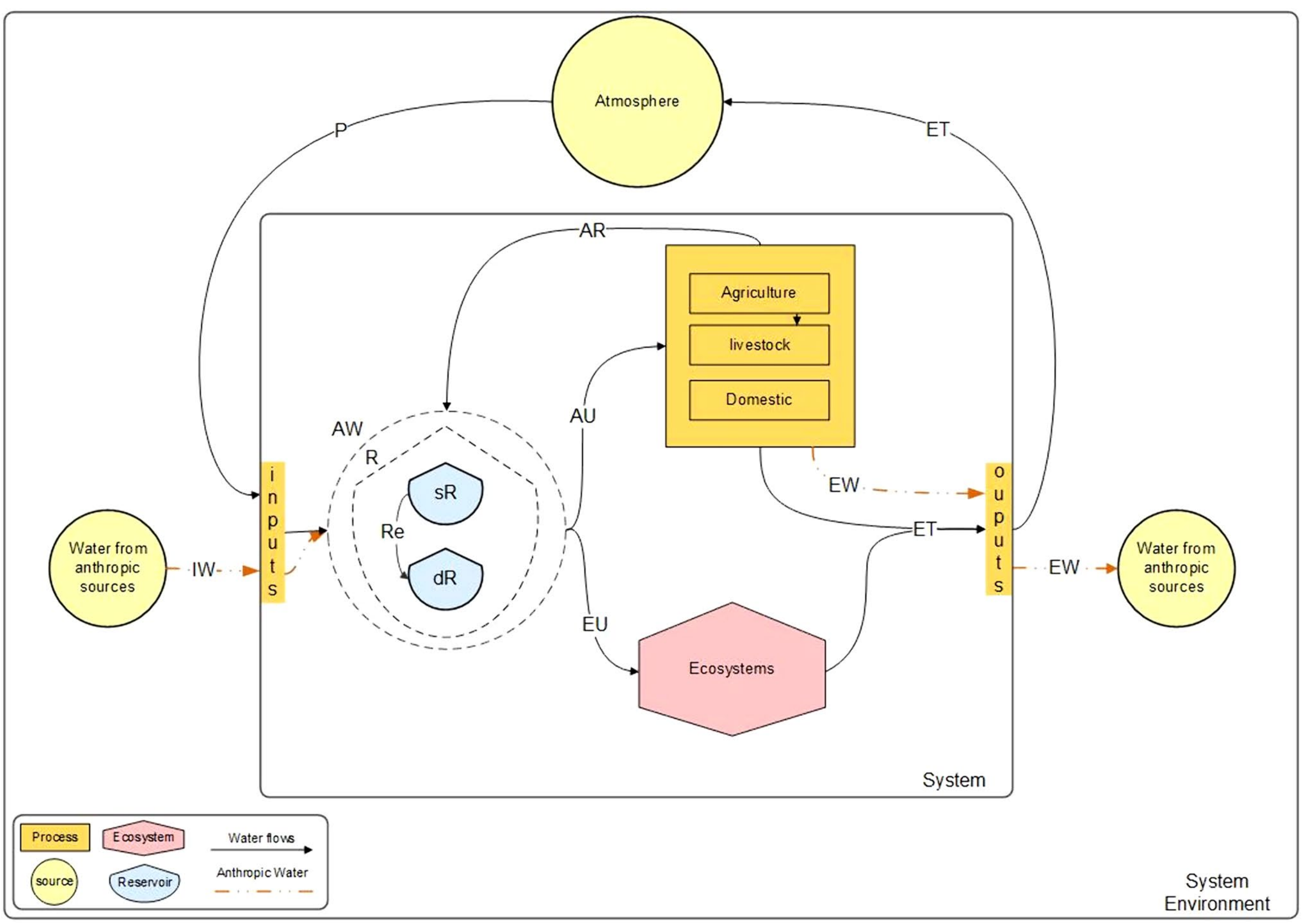

Fig. 3 Conceptual model of water metabolism. *IW* imported water, *EW* exported water, *AW* available water, *R* reservoirs, *sR* surface reservoir, *dR* deep reservoir, *Re* aquifer recharge, *EU* ecosystem water use, *AU* anthropic water use, *P* precipitations, *ET* evapotranspiration

purchased outside the community, although their proportion is not significant in terms of affecting the local water metabolism.

Reservoirs The community uses the lagoon as its main surface reservoir. It is a natural body of water formed by surface runoff from the surrounding hills and is a recharge zone for the aquifers in the area. To increase its depth, dikes of approximately 1.5 m aboveground level were built. However, deforestation and soil degradation due to overgrazing in the surrounding slopes caused a process of increasing erosion that manifests itself in large gullies and the dragging of sediments toward the lagoon, causing a progressive loss of depth.

As a complementary measure to the growing shortage of surface water, ponds were built in different parts of the *ejidal's* territory to supply water for cattle. Although the ponds are a complement, they are insufficient for the water demand during the dry season and the cattle must be supplied with water from the aquifer.

The aquifer is the main source of water for human consumption and domestic activities. The community has a deep extraction well—built by the Organismo Operador de Agua Potable, Alcantarillado y Saneamiento del Municipio de Morelia (OAPAS) and located at the edge of the lagoon—that supplies a 20,000 l cistern located on a hillside adjacent to the human settlement area.

Outputs The main water outputs of the system are evaporation from surface reservoirs and evapotranspiration in both crop areas and remnant native vegetation. Deep infiltration is the main source for recharge of the aquifer, so it is not considered an outflow of water from the system. However, there are no hydrogeological studies of the region, so there could be an outflow from the system due to aquifer mobility.

There are no surface water courses that drain to other basins, nor does anthropic activity generate a significant flow of virtual water outside the territory, since all production is mainly for self-consumption, except for cattle.

Water metabolic processes

Water metabolic processes can be separated into two groups: those due to natural processes in areas dominated by remnant native vegetation that have little anthropogenic intervention, and those areas that are heavily anthropized.

Ecosystem processes There are remnant areas of subtropical scrub, oak, and oak–pine forests. They are used to extract wood for fuel or to build fence posts to delimit rural plots and grazing areas. There are also communal areas dedicated to grazing that are heavily disturbed by cattle.

Anthropic processes Three anthropic processes involved in the water metabolism are the most important: (a) domestic water use; (b) agricultural water use; and (c) livestock water use. All three activities compromise water availability in both quantity and quality.

(a) Domestic water use

Water for domestic use is distributed through a network from the community cistern to the homes in the village core. The borehole is the only one in the entire community and *ejidal* territory and serves as a source of water supply for all uses during the dry season. The homes evacuate their excreta and wastewater to septic tanks, since there is no drainage network. Sub-surface runoff from the area where the village center is located converges, as does surface water, toward the lagoon, which is the main aquifer recharge area. The negative impact of wastewater reaching the lagoon, in particular as a potential source of groundwater pollution has not been studied, but pollution might be already happening.

(b) Agricultural water use

Agriculture, mostly corn and beans, in the area does not use supplemental irrigation because of the lack of irrigation infrastructure. Water availability compromises the crops annually, so they are used for self-consumption or as fodder for cattle. There is only one avocado producer in the area who has implemented an irrigation system for his crop and is supplied with rainwater or water from tanker trucks. There is also small production of prickly pear (*Opuntia* spp.) and agave that are better adapted to the local climate and do not require supplemental irrigation for their development.

In all cases, the agricultural activity uses agrochemicals applied manually by spraying. Although there is no measurement of the amount of products used, the producers report that it is necessary to increase the doses year after year due to the resistance of pests and weeds. This activity is expected to have a negative impact on water quality due to surface runoff of contaminants and groundwater contamination due to infiltration into the recharge zone.

(c) Livestock water use

Water use for livestock raising is considerable because this is the main productive activity in the community, and it was estimated that there are about 2,000 heads of cattle. Cattle are raised in extensive grazing systems in the *ejidatarios'* plots and in the common areas. There is also a smaller proportion of sheep, pigs, and horses that are raised in backyard areas of the household, although they also have access to common areas if their owners wish.

The cattle have free access to the lagoon and surface reservoirs for water consumption. However, in recent years, the lack of water in the dry season has led to the cattle being supplied with water from the community cistern. In addition, there is no control over the impact of overgrazing—with the consequent erosion processes—or surface water pollution.

Processes compromising water sustainability and generating local water risk

Due to the agricultural practices developed in the community and the lack of infrastructure for excreta disposal in the village center, the processes that originate in the domestic sphere and the productive processes compromise local water sustainability.

In terms of water risk, the main threats are potential contamination of surface and groundwater and water shortages during the dry season. Faced with these phenomena, the population is vulnerable due to the lack of infrastructure to guarantee the provision of drinking water and the lack of surface reservoirs of safe water for the dry season to supply all uses.

Management actions to achieve water sustainability

Considering that one of the main risks associated with water scarcity is ecosystem degradation caused by anthropic processes, it was agreed with the community to carry out activities to recover degraded areas. The most important activities were the recovery of the lagoon's banks and tributaries to increase its storage capacity, fish seeding in the lagoon, and the reforestation of gullies and other areas highly susceptible to erosion. These activities had a dual purpose: on the one hand, they addressed specific problems of ecosystem degradation and, on the other, they provided opportunities for integration and incentives for *ejidatarios* and other community members to participate.

Lagoon recovery

The total loss of the lagoon's water mirror during the dry season is a pressing problem for the community because it is the main source of water for livestock consumption. It also has an essential ecosystem function within the local water cycle because, as mentioned, it is the main recharge area for the aquifer that supplies the community.

In response to this and to the demand of the community leaders, an agreement was reached with the Secretary of Rural Development and Environment of the Morelia City Council (SEDRUMA) to recover the lagoon's banks and to clear up the main tributaries that supply the lagoon. To this end, the municipality carried out backhoe-dredging work for 30 days prior to the rainy season when the lagoon was completely dry (Fig. 4).

After the rainy season, in October 2021, it was observed that the work carried out significantly increased the extension and depth of the water body. Also, it had the effect of increasing the interest of community members in the project. It should be noted that the lagoon was maintained with water even during the dry season and until the rain came back in 2022.

Fish seeding

Fish seeding was aimed at recovering a series of ecosystem services that provided the community with an alternative source of protein and allowed for recreational activities (Fig. 5). A total of approximately 45,000 alevins of two species of common carp (*Ctenopharyngodon idella* and *Cyprinus carpio communis*) were seeded, provided by SEDRUMA and the Zacapu Aquaculture Center (Michoacán), which recommended the species because of their proven adaptation to the region's lake environment.

Reforestation

Reforestation was aimed at initiating the recovery of eroded slopes that had a considerable gully development. This process was triggered by the deforestation of the hills and cattle overgrazing. The material from these areas is carried away by surface runoff and causes the tributaries and the lagoon to silt up, progressively decreasing their depth.

Given that the area affected by erosion is very extensive, a demonstrative plot of approximately 3.1 h was fenced for the first year of work. The site was agreed upon by the *ejidatarios* in an assembly. It is part of the common grazing areas and, therefore, it was fenced to prevent cattle from entering. Approximately, 2,500 specimens of at least 8 different species provided by the Municipal Nursery of the Morelia City Hall and the IIES-UNAM nursery were planted: *Pinus greggii, Leucaena leucocephala, Albizia plurijuga, Fraxinus uhdei, Prosopis* sp*., Quercus castanea, Opuntia* spp., and *Agave* spp. The species were chosen based on climatic conditions, altitude, soil conditions, and the potential use of some of the species in agroforestry systems. Forty-five community members, researchers from the UNAM team, and municipal officials participated in the activity (Fig. 6).

It was agreed with the community to continue with reforestation activities with trees provided by the state nurseries and plants that will be produced by the community. Students from the local high school participated in plant production as a school project and have already carried out irrigation activities for the trees planted in this first stage. Likewise, to strengthen the participation of women in the project activities, it was planned to incorporate workspaces aimed

Fig. 4 Recovery work on the banks and tributaries of the Coro Grande lagoon

at recovering activities traditionally carried out by women, such as harvesting and preparing food from prickly pear (nopales in Spanish) and magueys (*Agave* spp.). Approximately, 140 magueys and 100 nopales were planted in the pilot area.

Discussion

Our research used as a theoretical–methodological framework the combination of the concepts of complexity, transdisciplinarity, and sustainability to face the challenges and difficulties for water management in a context of a lack of information and resources.

First, taking into account that the use of models for water management is not free of difficulties when using them in participatory processes—since they are often designed for the expert knowledge of hydrologists or engineers and it is not easy to transfer them to situations of co-production of knowledge (Ocampo-Melgar et al. 2022)—we started our research using the complex systems analysis method developed by García (2006) in conjunction with the method for the analysis of water metabolism by Madrid and Velázquez (2008). It was possible to identify the main components of the SES and how they configure water risk situations for the local population and its activities.

The activities developed in this stage showed that both methods have an intuitive character that in their qualitative application can be easily understood by actors with different knowledge in a participatory process and in contexts with limited information available. Although the lack of local climatic, hydrological, and hydrogeological information did not allow the construction of a quantitative procedural model, the conceptual description was a relevant tool for understanding the main water-related problems. This is consistent with literature reports (Bou Nassar et al. 2021; Ocampo-Melgar et al. 2022; Wingfield et al. 2021), and we combined the diagnosis with the development of ecological restoration activities to solve the problems in the community. Restoration activities were fundamental to promote the commitment of the participants in the participatory action research process—enhancing transdisciplinary work—because they could see the results in the process itself.

Fig. 5 Fish seeding in the Coro Grande lagoon

Second, we used transdisciplinarity (Norström et al. 2020), both for diagnostic activities and for the formulation and development of management measures. Brandt et al. (2013) argue that transdisciplinarity faces five main challenges that we were able to identify during the process of developing our work. Below, we briefly discuss each of them and the measures taken by the team to solve them.

(a) Lack of coherent framing and integration of methods

The lack of a working approach that allows the integration of assessments and potential solutions to an environmental problem by researchers and professionals from different disciplines is one of the most important difficulties in a transdisciplinary process of diagnosis and formulation of proposals for action (Renn 2021). On the other hand, the integration of existing and ad hoc methods that allow the pooling of knowledge and the development of activities from different disciplines is another challenge in transdisciplinary research (Pohl et al. 2021; Pohl and Hadorn 2008). Visions and knowledge regarding reality are strongly conditioned by the theoretical and conceptual framework of researchers and professionals, since knowledge acquired in work and life experiences, as well as the imaginary regarding the society–nature relationship and common sense, among others, come into play.

In this regard, this work assumed the framework of complexity and "participation with protagonism" as the main tools for integration. The meetings prior to the fieldwork between the researchers and the municipal officials provided a space for the sharing and deliberation of the problems and the lines of work for their solution. Likewise, we encouraged the participation (including voice and vote) of as many *ejidatarios* as possible in the assemblies and the restoration activities developed, aiming that those involved in the project are the ones who carry them out. In other words, we want those involved to be "protagonists" in the evaluation of problems and the implementation of activities to solve them, differentiating this process from the traditional top-down intervention developed by the State and companies in many regions in the world.

Our work taught us that to address these differences, it is necessary to integrate knowledge with horizontal visions and a team coordination that acts as a moderator in the

Fig. 6 Forestation activities in the community Coro Grande

exchanges. The application of these principles allowed us to develop the activities while improving our understanding of SES in a participatory action research process. Also, the methods selected for the diagnosis and analysis of water metabolism facilitated the process.

(b) Research process and knowledge production

In this work, promoting participation with protagonism and the application of the complexity approach allowed an articulation between the working groups that guaranteed the development of the programmed activities and the co-production of knowledge regarding the local reality. However, the process was not free of difficulties that were manifested in at least two main aspects: (i) the difference of positions in the team regarding how to solve the problems identified in the diagnosis, for which we decided to prioritize the preference of the community—since they were the direct beneficiaries of the project—and carry out a joint evaluation of advantages and disadvantages of each strategy; (ii) the need to have expert knowledge to address ecological and social processes involved in the local water metabolism, for which we promoted the integration of different researchers and professionals from the institutions involved (UNAM and Morelia City Council) in the stages of the project.

(c) Practitioners' engagement

The commitment between researchers and professionals was fostered by the formulation of the main objective and the political decision to carry out work that generates a real contribution to the community. In most cases, academic work implies the need to contribute to the generation of academic knowledge and to comply with the demands that the system itself imposes on researchers in terms of publication production. This may lead to a differentiation between academic work and political work with social objectives developed by the State. Establishing that the main efforts of the work were aimed at contributing to the solution of community problems was key to achieving a cooperative link between state officials and researchers. It also facilitated community acceptance and achieved broad legitimacy for the development of the activities.

(d) Generating impact

To achieve transformative effects with concrete impacts, the team agreed to focus on activities that would generate positive social and environmental impacts for the community. The recovery of the lagoon and its tributaries guarantees a surface water reserve for local productive activities while recovering several key ecosystem services for local ecosystems; the planting of fish will provide the inhabitants with an alternative source of protein and allow the development of recreational activities that can lead to future tourism projects for the community; and the reforestation aims to prevent ecosystem degradation processes, strengthen productive activities, and generate conditions to develop environmental education projects by involving local schools.

It is crucial to highlight the importance of assuming the framework of strong sustainability for the proposed activities. Ruggerio (2021) argues that strong sustainability constitutes a paradigm for projecting potential future scenarios of the object of study analyzed and, based on them, building action strategies that contribute to achieving intergenerational and intragenerational equity and the conservation of key ecosystem functions of the SES.

We consider that the results obtained in this first stage contribute to these objectives for the following reasons: (a) the activities developed constitute a starting point and an opportunity to continue working with the community while advancing in the solution of problems that generate risk situations; (b) community referents identify UNAM researchers as interlocutors to continue working on these problems and incorporate knowledge in the process; (c) participation with protagonism generates bases and commitments on the part of those involved to sustain the activities initiated over time; (d) the development of the activities also constitutes a learning environment for the exchange of knowledge and the reconstruction of the social imaginary with respect to different types of members within the community, placing value on its socio-ecosystemic attributes; (e) and provides a framework for the projection of alternative futures to the hegemonic logic that prevails in the region and that favors the migration of people to the urban peripheries with the consequent uprooting of their community.

Finally, the low participation of non-*ejidatarios* and women in activities is worth mentioning. Non-*ejidatarios* are neighbors who live in the human settlement area because they own a house but were not part of the land allocation at the time the *ejido* was constituted. Although they are a minority in this community, the lack of participation of non-*ejidatarios* is a recurrent problem in rural communities in Mexico (Skutsch et al. 2018).

Women participated in the assemblies convened during the project and had an important role in selecting species for reforestation, while men were directly involved in field activities. Only in the activities developed jointly with the high school was the participation of female students achieved. This situation seems to respond to a differentiation of work in the community—where men mostly perform tasks related to agriculture and livestock—and to structural causes of segregation of the role of women in rural areas, as has been revealed in studies on the role of women in rural areas of Central America and Mexico (Ramírez 2011). However, further research is needed to promote conditions that will allow their full insertion. This is particularly important because this study, and others, have shown that restoration efforts, and in general activities related to ecosystem management in rural communities, are not gender neutral (Broeckhoven & Cliquet 2015; Gutierrez-Montes et al. 2012; Montagnini et al. 2008).

Conclusions and final comments

Returning to the main objective of this work: to contribute to the knowledge on how a complexity and transdisciplinary approach applied to water problems at local scales can facilitate processes for water sustainability, it is possible to conclude that the application of the complexity–transdisciplinary–sustainability framework allowed the understanding of the local water metabolism based on qualitative, locally produced data, identified the processes that compromise water sustainability in the medium and long term, identified potential water risk situations for the population, and developed a first pilot experience of working with social acceptance to solve water-related problems.

Due to the lack of basic information regarding the climatic and ecological conditions of the study area and the structural deficiencies of infrastructure and services that the community has, a continuation of the work initiated in this first stage is required to consolidate conditions for local water sustainability. This situation and the acceptance of the results obtained so far made it possible to generate a future scenario of joint work between UNAM, the State, and the community. It should be noted that it was planned to continue planting trees in other degraded areas of the community; to continue caring for the planted trees and monitoring their adaptation in the medium and long term by the Environmental Restoration Laboratory of IIES-UNAM; to continue with the work of clearing the lagoon's tributaries and strengthening its banks; and to maintain the water extraction well and the communal cistern, among other activities.

It should be noted that transdisciplinarity has constituted a teaching–learning process for all those involved in the project, which, in our opinion, constitutes a way of overcoming disciplinary and vertical approaches to traditional research. We consider that, without the participative and protagonist process of all the actors, the acceptance and involvement that facilitated the development and continuity of the proposed activities would have been difficult. Likewise, the challenge remains to promote greater mechanisms for the participation of women in all project activities, a situation that has already been acknowledged by local representatives.

Finally, it is important to highlight that we developed this work as a pilot experience of the application of our framework for the investigation and solution of local water problems in places with lack of information and resources, where it is necessary to improve the actions developed by the State and the communities to solve them.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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