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Participatory Management and Sustainable Use of Groundwater

A Review of the Andhra Pradesh Farmer-Managed Groundwater Systems Project in India

V. Ratna Reddy, Paul Pavelic and M. Srinivasa Reddy

Groundwater issues addressed

- ☑ Groundwater over-abstraction
- ☐ Groundwater quality/human health
- ☐ Salinity issues/intrusion
- ☐ Land subsidence
- ☐ Ecosystem degradation
- ☑ Food security/livelihoods

Type of interventions

- ☑ Legal initiative/regulation
- ☑ Policy
- ☑ Technology application
- ☑ Local initiative

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GROUNDWATER SOLUTIONS INITIATIVE FOR POLICY AND PRACTICE

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Front cover photograph shows the collective monitoring of groundwater levels under the Andhra Pradesh Farmer-Managed Groundwater Systems (APFAMGS) project in India (*photo:* Jacob Burke, formerly Food and Agriculture Organization of the United Nations [FAO]).

About the Groundwater Solutions Initiative for Policy and Practice (GRIPP) Case Profile Series

The GRIPP Case Profile Series provides concise documentation and insight on groundwater solution initiatives from around the world to practitioners, decision makers and the general public. Each case profile report covers a contemporary intervention (innovation, technology or policy) or a series of applied groundwater management-related approaches aimed at enhancing groundwater sustainability from an environmental and socioeconomic perspective at local, national or international level. Integrated analysis of the approach, background, drivers, stakeholders, implementation, experiences and outcomes are discussed with a view to illustrating best practices, factors that could lead to success or failure, and wider applicability.

Abstract

English

This GRIPP Case Profile assesses whether the proactive involvement of rural communities in the management of groundwater positively contributes towards sustainable resource use. The assessment uses the long-term (2003-2013) *Andhra Pradesh Farmer-Managed Groundwater Systems* (APFAMGS) project in India as a case study. Implemented across seven districts, the assessment is based on a critical review and synthesis of existing literature and complementary field visits conducted five years after project closure. APFAMGS worked towards creating awareness and bringing about behavioral change to achieve sustainable groundwater use, primarily for irrigation. The approach focused on knowledge transfer and capacity building to set up participatory processes conducive to informal management measures, and technologies supporting participatory hydrological monitoring and crop water budgeting. In addition, awareness creation in relation to demand as well as supply side management options was critical. The analysis suggests that APFAMGS has helped in filling the knowledge and information gaps on groundwater resources among local farming communities. Some degree of long-term reduction in groundwater pumping was observed, but the attribution to the project is not clear, and effects on reducing groundwater level declines may be limited and localized. The APFAMGS approach of participatory groundwater management (PGM) fell short in terms of equity considerations, with implications for the institutional sustainability of the approach. The study provides policy guidance for adopting more inclusive PGM-based institutions on a wider scale.

French

Ce profil de cas GRIPP évalue si l'implication proactive des communautés rurales dans la gestion des eaux souterraines contribue positivement à l'utilisation durable des ressources. L'évaluation utilise comme étude de cas le projet à long terme (2003-2013) de systèmes d'eaux souterraines gérés par les paysans d'Andhra Pradesh (*Andhra Pradesh Farmer-Managed Groundwater Systems*-APFAMGS), en Inde. Mise en œuvre dans sept districts différents, l'évaluation est basée sur un examen critique et une synthèse de la littérature existante et sur des visites complémentaires sur le terrain effectuées cinq ans après la clôture du projet. Le projet de systèmes d'eaux souterraines gérés par les paysans d'Andhra Pradesh visait à sensibiliser et modifier les comportements afin de parvenir à une utilisation durable des eaux souterraines, principalement pour l'irrigation. L'approche s'est concentrée sur le transfert de connaissances et le renforcement des capacités dans le but de mettre en place des processus participatifs propices à des mesures de gestion informelles, et des technologies soutenant la surveillance hydrologique participative et la budgétisation de l'eau des cultures. En outre, la sensibilisation aux options de gestion de la demande et de l'offre était essentielle. L'analyse suggère que le projet de systèmes d'eaux souterraines gérés par les paysans d'Andhra Pradesh a contribué à combler les lacunes en matière de connaissances et d'informations sur les ressources en eaux souterraines parmi les communautés agricoles locales. Un certain degré de réduction à long terme du pompage des eaux souterraines a été observé, mais l'attribution au projet n'est pas claire, et les effets sur la réduction de la baisse du niveau des eaux souterraines peuvent être limités et localisés. L'approche APFAMGS de la gestion participative des eaux souterraines n'a pas été à la hauteur des considérations d'équité, avec des implications pour la durabilité institutionnelle de l'approche. L'étude fournit des orientations politiques pour l'adoption d'institutions plus inclusives basées sur la gestion participative des eaux souterraines à une plus grande échelle.

Spanish

Este Perfil de caso del GRIPP evalúa si la participación proactiva de las comunidades rurales en la gestión de las aguas subterráneas contribuye positivamente al uso sostenible del recurso. La evaluación utiliza como estudio de caso el proyecto de larga duración (2003-2013) sobre *Sistemas de aguas subterráneas gestionadas por campesinos de Andhra Pradesh* (APFAMGS) en la India. La evaluación, aplicada en siete distritos, se basa en la revisión crítica y síntesis de la bibliografía existente y en visitas adicionales sobre el terreno realizadas cinco años después de la finalización del proyecto. El APFAMGS tenía como objetivo concienciar y producir cambios de comportamiento para lograr un uso sostenible de las aguas subterráneas, principalmente para el riego. El enfoque se centró en la transferencia de conocimientos y el fortalecimiento de capacidades para establecer procesos participativos susceptibles de favorecer medidas de gestión informales, así como en las tecnologías de apoyo al seguimiento hidrológico participativo y a la evaluación de las necesidades de agua para los cultivos. Además, fue fundamental sensibilizar acerca de las opciones de gestión de la demanda y abastecimiento de agua. El análisis indica que el APFAMGS ha contribuido a colmar las lagunas de conocimiento e información sobre los recursos hídricos subterráneos entre las comunidades agrícolas locales. Se ha observado cierto grado de reducción a largo plazo del bombeo de aguas subterráneas, pero no está claro si esto es atribuible al proyecto, y los efectos en la reducción del descenso del nivel de las aguas subterráneas pueden ser limitados y localizados. El enfoque del APFAMGS para la gestión participativa de las aguas subterráneas presentó limitaciones en lo que se refiere a los aspectos de equidad, con implicaciones para la sostenibilidad institucional del enfoque. El estudio proporciona orientación para promover a mayor escala instituciones más inclusivas y basadas en la gestión participativa de las aguas subterráneas.

Hindi

यह GRIPP केस प्रोफाइल इसका मूल्यांकन करती है कि क्या भूजल प्रबंधन में ग्रामीण समुदायों की अग्रसक्रिय सहभागिता संसाधनों के संवहनीय उपयोग की ओर सकारात्मक योगदान देती है। यह मूल्यांकन भारत में दीर्घकालिक (2003-2013) *आंध्र प्रदेश किसान-प्रबंधित भूजल प्रणालियाँ* (APFAMGS) परियोजना का एक मामला अध्ययन (केस स्टडी) के रूप में उपयोग करता है। सात जिलों में कार्यान्वित किया जा चुका यह मूल्यांकन, वर्तमान साहित्य की आलोचनात्मक समीक्षा और संश्लेषण और परियोजना बंद होने के पाँच वर्ष बाद किए गए अनुपूरक क्षेत्रीय दौरों पर आधारित है। APFAMGS ने विशेष तौर पर सिंचाई के लिए, भूजल के संवहनीय उपयोग की प्राप्ति हेतु जागरूकता फैलाने और व्यवहारिक परिवर्तन लाने के प्रति काम किया। यह पद्धति अनौपचारिक प्रबंधन युक्तियों के लिए सहायक सहभागी प्रक्रियाएँ, और सहभागी जलवैज्ञानिक निगरानी और फसल-जल के बजट-कार्य का समर्थन करने वाली प्रौद्योगिकियाँ सेट अप करने हेतु ज्ञान बाँटने और सामर्थ्य विकास की ओर केंद्रित थी। इसके अतिरिक्त, माँग के साथ-साथ आपूर्ति के प्रबंधन विकल्पों के संबंध में जागरूकता बढ़ाना अति-सूक्ष्म था। यह विश्लेषण संकेत करता है कि APFAMGS ने स्थानीय कृषि समुदायों में भूजल संसाधनों के बारे में ज्ञान और जानकारी के अंतराल को पूरा करने में मदद की है। कुछ हद तक भूजल पंपिंग में दीर्घावधिक गिरावट देखी गई थी, लेकिन परियोजना का आरोपण स्पष्ट नहीं है, और भूजल के स्तर में गिरावट को कम करने के प्रभाव सीमित एवं स्थान-परिसीमित हो सकते हैं। APFAMGS की सहभागी भूजल प्रबंधन (PGM) पद्धति समानता की मान्यताओं के मामले में पीछे रह गई, जिससे पद्धति की संस्थागत संवहनीयता के लिए निहित परिणाम देखने को मिले। यह अध्ययन एक बड़े पैमाने पर अधिक समावेशी PGM-आधारित संस्थान स्वीकार करने के लिए नीति निर्देश प्रदान करता है।

1. Progress in groundwater management in India

The disconnect between natural ecosystems and human systems represents a major bottleneck for sustainable management of natural resources (Sayers et al. 2016). This is particularly apparent in arid and semiarid environments that are heavily dependent on groundwater resources for livelihoods based on irrigated agriculture. Despite being a common-pool resource, groundwater development is primarily in the hands of private individuals (i.e., people acting only through self-interest and not representing any group, company or organization), because groundwater rights are linked to land rights in India (Saleth 1996). As a result of this and the high capital investment needed, groundwater development is undertaken by landowning, wealthier households aiming to profit from irrigated agriculture. The adverse impacts of groundwater overexploitation are, however, often disproportionately borne by small and marginal farmers, because they cannot afford to drill deeper as groundwater levels drop (Reddy 2005). This is particularly the case in areas occupied by hard rock aquifers, where drilling costs are higher. The failure of groundwater wells, one of the reasons for farmer suicides in India, is, in part, an outcome of these externalities, especially in drought-prone areas (Deshpande 2002; Reddy and Galab 2006).

Until recently, no concrete efforts were made in India to bring groundwater under an appropriate system of management. The national model groundwater bill of 1970[1] largely serves as a guideline for documenting and notifying the status of groundwater development, while any regulatory and enforcement mechanisms are under the authority of individual state governments. Still, at the state level, groundwater has not been included in the more important water management initiatives, such as water users' associations (WUAs).[2] However, with rapidly increasing groundwater use and mounting signs of widespread depletion, state policy interventions have attempted to better manage the resource. Related policy advances vary across different states and union territories depending on the status of groundwater development and the socioeconomic and policy context.[3] Various formal approaches and methods, including demand management[4] and supply management,[5] have been implemented to restore groundwater levels. Despite the greater focus on groundwater, the impact of those efforts has been limited primarily due to the lack of enforcement, and where successful, the scalability depends highly on the socioeconomic conditions and political environment (Shah 2014).

The failure of formal regulatory approaches has led India to experiment with informal, participatory groundwater management (PGM) initiatives[6] over recent decades (Shah 2014). Various participatory or community-based groundwater management interventions have been tried in different parts of India (Box 1). While some of these initiatives are funded by state governments, others are funded by bilateral funding agencies and local nongovernmental organizations (NGOs). Although most of these are small-scale initiatives (Verma et al. 2012; Reddy et al. 2014; Shah 2014; Sravanthi et al. 2015), some state governments in India are taking a keen interest in supporting and scaling up these initiatives, but not through formal institutions.[7]

[1] The model groundwater bill was subsequently revised in 1972, 1996, 2005, 2011 and 2017 (GoI 2020a).

[2] Participatory irrigation (via WUAs) has become a widespread strategy in Asia, Africa and Latin America to facilitate decentralization of the role of governments and enhancing the role of primary stakeholders in irrigation management. This, in principle, reduces public expenditure on irrigation, improves productivity, and helps to maintain irrigation systems. In India, a number of states (e.g., Andhra Pradesh, Rajasthan and Odisha) initiated WUAs during the late 1990s and early 2000s. For instance, Andhra Pradesh has created 10,790 WUAs covering the entire command area (including canal and tank systems, but not groundwater irrigation systems) of the state at a cost of INR 5,000 crore (USD 710 million) with support from the World Bank (Reddy and Reddy 2005).

[3] States such as Telangana continue to pursue supply side management (development of surface irrigation and recharging of groundwater), while some states, such as Andhra Pradesh, are supporting participatory groundwater management (PGM) initiatives.

[4] Formal institutions for demand management include market-based approaches (e.g., private property rights, which respond to market instruments, pricing of water and energy, etc.), technology-based approaches (e.g., subsidies for micro-irrigation and other water-saving technologies), and non-market-based (direct and indirect) command-and-control regulations. Important regulations include institutional credit restrictions, minimum separation distance between wells, and registration of/licenses for well development and drilling companies.

[5] Formal institutions for supply management include managed aquifer recharge (MAR) interventions, such as check dams, farm ponds, percolation tanks, etc. These are not referred to as formal institutions. They are mostly technical approaches, but adhering to the Indian strategy for MAR (CGWB 2020).

[6] Informal groundwater management institutions are those that evolve at the local level through community initiatives and often promoted (supported) by NGOs. The scale of these institutions is typically limited to a few villages. Informal regulations include restrictions on the area under water-intensive crops (paddy, sugarcane, etc.), construction of new bore wells, etc.

[7] For instance, the Government of Andhra Pradesh (GoAP) continued APFAMGS under a new project titled *Groundwater Governance through Panchayat Raj Institutions in Andhra Pradesh* (GwGPRI-AP) with support from the Food and Agriculture Organization of the United Nations (FAO) during the period 2015-2016.

Box 1. Evolution and examples of participatory groundwater management in India.

Participatory groundwater management (PGM) initiatives commenced in the early 1970s. The chronology of initiatives is summarized below:

1972: Pani Panchayat is a system of equitable distribution of water through a people's council started by Mr. Vilasrao Salunke in the village of Naigaon, which lies in the highly drought-prone Purandhar subdistrict in Pune, Maharashtra. Nowadays, Pani Panchayats can be found all over the state.

1975: Mr. Kisan Baburao Hazare's (popularly known as Anna Hazare) model of watershed management in the village of Ralegan Siddhi in Maharashtra was identified as a successful program that has since inspired many followers.

1985: The rainwater harvesting initiative led by Mr. Rajendra Singh of the NGO Tarun Bharat Sangh in Alwar district, Rajasthan, built over 8,600 *johads* (rainwater storage tanks that collect and store water throughout the year) and other water conservation structures that helped to improve water security for more than 1,000 villages in Rajasthan.

1995: Under the Maharashtra government's *Adarsh Gaon Yojana* scheme, the Hiware Bazar watershed program spearheaded by Mr. Popat Pawar became a model to follow.

2000s: The APFAMGS project encouraged farmers to collect local data that can be used to make collective decisions on groundwater management.

Other ongoing participatory approaches have been undertaken by, for example, the following:

- Foundation for Ecological Security (FES), an NGO in Anand, India, focuses on the micro-watershed scale for water balance analysis and planning groundwater use along with communities in Rajasthan, Madhya Pradesh and Andhra Pradesh.
- Advanced Center for Water Resources Development and Management (ACWADAM), a civil society organization in Maharashtra, India, and Samaj Pragati Sahayog (SPS), a grassroots initiative in Madhya Pradesh, India, are working on knowledge-based, typology-driven aquifer management strategies similar to those of Pani Panchayats.
- Barefoot College in Tiloniya, Rajasthan, focusing on social work and research, is making use of a water budgeting tool known as Jal Chitra.
- Centre for World Solidarity (CWS), a voluntary organization founded as a Public Trust in Andhra Pradesh, focuses on the water-energy-food nexus in optimizing resource use and resilience for farmer communities (Mohan 2012).

These participatory initiatives have collectively led to national-level policy changes and programs. In particular, a rebalancing from supply-side to demand-side management with a distinct focus on sustainability, multi-disciplinarity and multi-dimensionality in water sector institutions, such as the Central Water Commission (CWC) and Central Ground Water Board (CGWB).

Source: GoI 2011.

The *Andhra Pradesh Farmer-Managed Groundwater Systems* (APFAMGS) project[8] is the largest-ever and longest-running community-led participatory groundwater management initiative in India. APFAMGS was implemented between 2003 and 2013 and covered 650 habitations including 6,500 households in seven drought-prone districts (Anantapur, Chittoor, Cuddapah [today referred to as Kadapa], Kurnool, Mahbubnagar, Nalgonda and Prakasam) in the erstwhile state of Andhra Pradesh (Figure 1).[9] Due to its apparent success, principles and practices followed by the project are being integrated into new government programs in India (GoI 2011). A detailed examination of the impacts of the long-term APFAMGS initiative would help inform the discussion on the broader potential of the PGM approach to achieve sustainable use of groundwater.

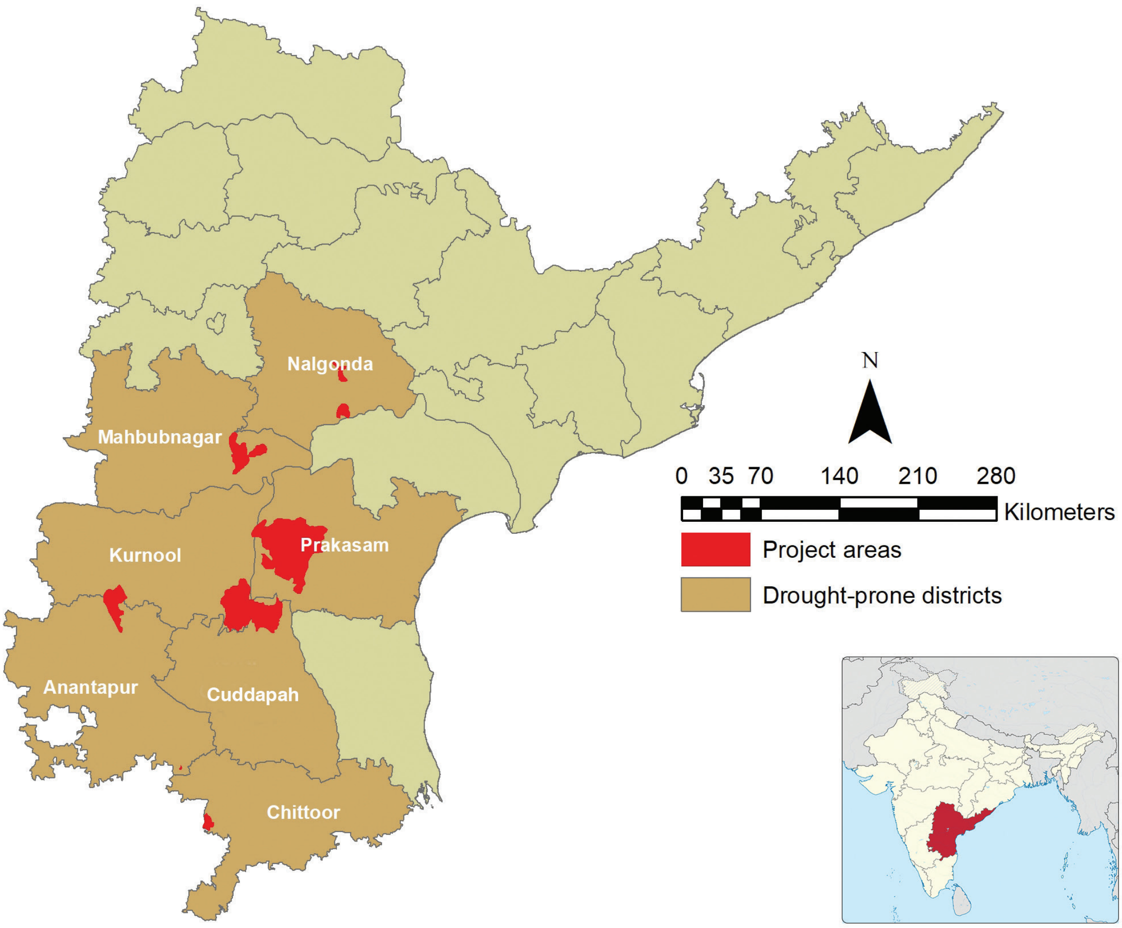

Figure 1. Map of Andhra Pradesh, India (pre-2014) showing the areas covered by the APFAMGS project.

Source: Modified from FAO 2010.
Notes: The brown areas indicate the drought-prone districts where APFAMGS was implemented. The state boundaries for Andhra Pradesh changed in 2014 with some project districts situated in what is presently the state of Telangana.

[8] While names have changed under different phases of the project, the terms 'APFAMGS' or 'APFAMGS Project' remain the most well-known and are used, interchangeably, throughout this case profile.

[9] In February 2014, the Andhra Pradesh Reorganization Act, 2014, was passed by the Parliament of India for the formation of the Telangana State comprising 10 districts that were previously under the state of Andhra Pradesh. The reorganized Andhra Pradesh consisted of 13 districts along the Indian coast of the Bay of Bengal (*source:* https://en.wikipedia.org/wiki/Andhra_Pradesh).

2. Objectives and methodology of the APFAMGS assessment

The broad objective of this study is to establish whether PGM, as implemented through APFAMGS, has helped to promote sustainable use and management of groundwater through community empowerment in the form of knowledge sharing, awareness raising and capacity building. The specific objectives of the study are as follows:

1. Examine the APFAMGS approach to PGM and evolution of interventions over the entire project duration (2003–2013).
2. Review the performance and efficiency of APFAMGS interventions, during implementation and up to 5 years after project closure, in stabilizing resource availability, building resilience among communities, and distributional (equity-related) impacts at the household level.
3. Establish linkages with other existing or potential groundwater management and institutional approaches in India and derive insights for the development of appropriate (sustainable and equitable) resource management policies and strategies going forward.

This study builds on earlier assessments of APFAMGS during the implementation phase or immediately following implementation. While the earlier studies could capture the potential impacts more clearly, they could not address the sustainability of the interventions. This study looks at whether the prolonged interventions associated with APFAMGS have helped to usher in sustainable groundwater management practices, which would in turn reduce the pressure on groundwater resources in the area and enhance the sustained socioeconomic benefits to the communities. This outcome could be expected through behavioral and institutional changes that persisted even after the project. The assessment focuses on both biophysical and socioeconomic aspects using a mix of qualitative and quantitative approaches.

The hydrogeological impacts were assessed using secondary data collected at the district level. Firsthand information and observations were collected from project villages in two hydrological units (HUs).[10] These HUs were purposively selected as they are situated in the most drought-prone districts of Andhra Pradesh, i.e., Anantapur and Kurnool (for details, see Reddy and Reddy 2020). Besides interacting with village communities in the project areas, engaging with communities of neighboring villages offered counterfactual information. Apart from project documents and evaluation reports, a number of studies have reviewed and assessed the achievements and impacts of APFAMGS over the years (APFAMGS 2006; AFPRO 2007; FAO 2008, 2010; World Bank 2010; Reddy 2012; Verma et al. 2012; Das and Burke 2013; Reddy et al. 2014; Sravanthi et al. 2015).[11] In this case profile, the cumulative and long-term impacts of the project were captured through interviews conducted with the coordinating NGO Bharati Integrated Rural Development Society (BIRDS) and other implementing NGOs. Personal discussions were held with office bearers of APFAMGS and other programs. Also, key informant interviews were conducted with project implementing agencies. This type of firsthand information was gathered from the communities of five villages in two HUs (*Upparavanka* and *Vajralavanka*) situated in Peapally Mandal of Kurnool district and Gooty Mandal of Anantapur district. During the field visits, discussions were held with communities and individual farmers from APFAMGS and non-APFAMGS villages following a checklist of enquiries. The study assessed the long-term impacts of the APFAMGS approach and its sustainability in particular focusing on livelihood outcomes and climate vulnerability. Addressing the sustainability aspects over the long term (including after project closure) and the comparison between APFAMGS and non-APFAMGS communities are the value additions of this study.

[10] HU is used by APFAMGS to refer to a watershed.

[11] The studies carried out by World Bank (2010), Reddy (2012), Verma et al. (2012), Reddy et al. (2014) and Sravanthi et al. (2015) are independent assessments, whereas the others are reviews by parties directly involved.

3. The APFAMGS project: Origin and setting

The APFAMGS project originated as part of the *Andhra Pradesh Groundwater Borewell Irrigation Schemes* (APWELL) project, which was supported by the Royal Netherlands Embassy of India (RNE) and implemented during the period from April 1995 to March 2003 by local NGOs. For the first time in India, participatory hydrological monitoring (PHM) was introduced on a pilot scale[12] and later scaled up in 500 villages spread over seven districts in the erstwhile state of Andhra Pradesh (Figure 1). Many subsequent phases kept the project going up until 2013 with total funding of approximately USD 6.7 million (Box 2).

Box 2. The APFAMGS project: Concept, funding and evolution until today.

APWELL, the pilot project on PHM, led to the first phase of the APFAMGS project for a period of 30 months (July 1, 2003 to December 31, 2005) with funding of USD 2.9 million. APFAMGS was implemented by a network of local NGOs under the leadership of BIRDS in 500 villages spread over seven drought-prone districts (Anantapur, Chittoor, Cuddapah, Kurnool, Mahbubnagar, Nalgonda and Prakasam) of Andhra Pradesh and present-day Telangana. APFAMGS introduced a participatory approach to groundwater management for the first time in India at this scale. Subsequently, between 2004 and 2013, APFAMGS was managed and funded by different agencies:

2004: RNE transferred support for the APFAMGS project to FAO.

2005: FAO continued to support the project until December 2009, i.e., 4 years beyond the initial project closure date.

2010: The Global Environment Facility (GEF) along with FAO funded the Strategic Pilot on Adaptation to Climate Change (SPACC) under the name *Reversing Environmental Degradation and Rural Poverty through Adaptation to Climate Change in Drought Stricken Areas in Southern India: A Hydrological Unit Pilot Project Approach* at a total budget of USD 3.8 million (GEF: USD 0.9 million, FAO: USD 1.3 million and NGOs: USD 1.6 million) for a period of 3 years, i.e., until December 2013.

2015: After APFAMGS project closure, the state of Andhra Pradesh initiated a pilot project on *Groundwater Governance through Panchayat Raj Institutions in Andhra Pradesh* (GwGPRI-AP) in five districts (Anantapur, Chittoor, Cuddapah, Kurnool and Prakasam) for one year (2015–2016) with support from FAO.

2017: The APFAMGS 'pilot project' facilitated the long-term initiative *Andhra Pradesh Drought Mitigation Project* (APDMP) funded by the International Fund for Agricultural Development (IFAD). IFAD provided a loan of USD 75.5 million with a matching contribution from the state government (total project cost of USD 151.9 million) to implement the project in the same five districts (Anantapur, Chittoor, Cuddapah, Kurnool and Prakasam) for a period of 7 years (IFAD 2016, 2017).

Raising awareness and capacity building of communities dependent on groundwater were at the core of the APFAMGS project. Thus, groundwater users, or rather, selected trained volunteers, within each HU were equipped with the necessary equipment, skills and knowledge to support the management of groundwater resources in a sustainable manner. This was mainly done through monitoring and managing demand in light of the seasonally variable water availability. The approach provided the necessary means (equipment and knowledge to collect and analyze rainfall and groundwater data) to increase community understanding of groundwater resources. In the process of capacity building by the representative NGOs, the need to create awareness about water-use efficiency through the adoption of water-saving technologies and agricultural practices was also raised (Box 3).

[12] Besides PHM, the project provided 3,462 groundwater irrigation facilities to small and marginal well-owning farmers, bringing an additional area of 35,000 acres (approximately 14,150 hectares) under irrigation and covering about 14,000 small and marginal farming families. Farmers were trained to collect the hydrological data on a regular basis. The data were processed and stored for future use. In fact, the data are the property of the communities and may be purchased by researchers and institutions (Reddy et al. 2014). However, the quality of the data was found to be inadequate for the purposes of this study.

Box 3. Farmer training components of the APFAMGS project.

Awareness building components included the following:

- Facilitated discussions on the local groundwater situation in the HU and at the village level.
- Demystifying the science of climate and hydrology through farmer water schools.
- Introducing the concept of groundwater as a 'common good' and not simply private property.
- Carrying out participatory groundwater monitoring and crop water budgeting exercises and sharing this information across the HU.
- Providing information to farmers to encourage voluntary adoption of sustainable practices (reduce pumping, water-saving technologies, impacts of drilling new wells, crop diversification, best agrochemical management practices, etc.).

Capacity building components included the following:

- Farmer water schools adopted an informal and participatory approach to information sharing, group learning, and improving the skills and capacities of farmers. A total of 10,000 farmers attended the 300 farmer water schools and meetings which were organized every 15 days over a period of 5 years in all seven districts. Through these meetings, farmers were able to understand groundwater dynamics in their respective villages and the entire HU. Based on the new understanding, farmers voluntarily adopted appropriate modifications in their agricultural practices with the potential to lead to significant reductions in groundwater use. It must be noted that the farmer water schools were not continued in the latter phases of the project (i.e., after the first 5 years).
- PHM is a 'learning by doing' exercise that helps to create 'groundwater literacy'. Farmers were trained at farmer water schools to measure groundwater levels, rainfall, pumping capacity of bore wells and the water requirements for different crops. Fortnightly, water level monitoring was carried out by farmer volunteers (both female and male farmers) in 2,026 observation wells (around one well per square kilometer). Daily rainfall data were collected by farmers from over 190 rain gauge stations (one station per 5 km^2). Well discharge measurements were carried out by farmers in over 700 observation wells to assess the pumping capacity of the wells, well performance, etc. To become a PHM volunteer, farmers had to undergo training (covering four modules) at the farmer water schools, and only the successful candidates were eligible to become volunteers (unpaid). These volunteers were then provided with the necessary measurement tools, such as electrical water level indicator, stopwatch, calibrated bucket, etc. Hydrological monitoring records were maintained and exhibited for public viewing on display boards at strategic locations within the village. Additionally, seasonal groundwater quality monitoring (analyzing 16 parameters related to drinking water quality) was carried out in public drinking water wells and the results were displayed in public places in the village. In fact, these data are cleaned and digitized for future use and made available to others on a commercial basis.[12]
- Crop water budgeting is a technical exercise where farmers collectively make their crop plans each season based on water availability (groundwater for cropping and irrigation in both dry and wet seasons). The project did not advocate changes to the crops being cultivated and did not want to limit the crop choices available to farmers in a particular HU. Instead, the emphasis was on improving water-use efficiency. It was assumed that farmers have sufficient knowledge of crop management practices and markets to be able to make relevant decisions.
- Groundwater management committees (GMCs) and hydrological unit networks (HUNs) were established at the village and HU levels, respectively. These institutions met regularly to discuss various aspects of groundwater and were able to advise farmers on changes to crop pattern and other practices.
- Water-saving technologies, such as micro-irrigation, were promoted by linking with the government subsidy programs. State and central governments provide a subsidy on sprinkler and drip irrigation (75% to 90%). Despite the high subsidy, only large farmers could afford and avail the subsidy due to high capital costs of the irrigation systems. This in turn resulted in inequity in access to and adoption of the technology.
- No formal or informal regulation mechanisms were put in place. No separate project-derived subsidies to promote the adoption of demand management approaches or groundwater use regulations (e.g., restrictions on the area under water-intensive crops, construction of new bore wells, etc.) through official or social controls were implemented.

The APFAMGS districts are predominantly underlain by variably weathered granitic basement rocks with groundwater found predominantly under unconfined conditions (Garduño et al. 2009). The extent and productivity of the groundwater resources of these crystalline rocks are determined by inherent factors that include weathering depth, clay content and degree of fracturing. In favorable geomorphological settings, weathering and fracturing processes allow continuous relatively productive aquifers typically up to 25 meters thick in topographic lows. In less favorable settings, aquifers are thin and patchy and not very productive. Annual average rainfall ranges from 600 to 1,000 mm and is concentrated almost entirely within the monsoon season from around June to October. Rainfall amount, its intensity (Asoka et al. 2018), topography, soil infiltrability, and any catchment management and 'rainwater harvesting'[13] initiatives are key factors in the replenishment of groundwater resources.

4. Impacts of the APFAMGS project

4.1 Impacts on groundwater level at HU and district scales

In order to gain a degree of clarity on the linkages between groundwater resources and APFAMGS interventions, the most extensive groundwater monitoring data provided by CGWB were used. These data were from the five of the seven APFAMGS districts (Anantapur, Chittoor, Cuddapah, Kurnool and Prakasam), which were situated within the recently redefined state of Andhra Pradesh. The dataset covers an 18-year period between 1999-2000 and 2016-2017. Given that APFAMGS interventions were limited to areas outside of major surface water irrigation commands, only data from non-command (i.e., groundwater-irrigated) areas[14] are presented.

The aggregate groundwater situation across the APFAMGS districts has not improved. In fact, groundwater levels have deteriorated overall, with an average decline of about 0.2 m per year in the pre-monsoon 3-year moving average assessment (Figure 2). Moving average values for rainfall reveal a decreasing trend up to around 2004, followed by a brief increasing trend up to around 2007 and, finally, a longer decreasing trend up to 2017. Over these periods, both pre- and post-monsoon groundwater levels show similar sequential decreasing, increasing and decreasing trends. The consistent correlation between the filtered annual rainfall and filtered groundwater levels suggests that climate and rainfall-derived recharge have an important control on groundwater storage. This indicates that the impact of changes in groundwater recharge or pumping due to APFAMGS interventions has not had an overriding effect on the expected natural larger-scale rainfall-recharge pattern.

The number of wells in Andhra Pradesh (before the Reorganization Act, 2014) increased from 0.8 million (0.7 million dug wells and 0.1 million bore wells) in 1971 to about 2.2 million (1.0 million dug wells and 1.2 million bore wells)[15] by 2007 (GoI n.d.; GoI 1995; GoAP 2002, 2006a, 2006b, 2008a, 2008b). The area under groundwater irrigation increased from 0.8 million hectares (Mha) to about 2.8 Mha over the same period (1971–2007) (predominantly in rain-fed areas and not involving the replacement of surface irrigation). The area irrigated per well was almost constant, but water was drawn from greater depths as wells were deepened in response to falling groundwater levels (Reddy et al. 2016). The average density of actively operating wells in the state increased from five wells per square kilometer to 10 wells per square kilometer over the period from 1984 to 2007.[16] However, in hard rock areas, characteristic of the APFAMGS districts, the figure was over 20 wells per square kilometer, and in some pockets, it was as high as 100 wells per square kilometer, indicating the high reliance on groundwater in the APFAMGS areas. Reddy et al. (2016) showed that average groundwater levels declined rapidly in these highly developed local areas.

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[13] Rainwater harvesting and catchment management techniques strive to capture rainfall and maximize its retention in the subsurface (soil and groundwater) for ecosystem and human benefits, especially for agriculture (rain-fed or irrigated) (Sikka et al. 2018).

[14] Non-command areas account for about 25% of the net sown area at the aggregate level. Within the non-command areas, coverage of APFAMGS interventions account for less than 10% of the area.

[15] The number of wells for both years include functional and nonfunctional wells.

[16] The density had further increased to 14 wells per square kilometer by 2013-2014 (GoI n.d.; GoI 1995; GoAP 2002, 2006a, 2006b, 2008a, 2008b; GoAP and GoI 2011a, 2011b, 2012a, 2012b). For the later years, data are compiled from the Office of the Director, Department of Ground Water, Vijayawada, Andhra Pradesh, India.

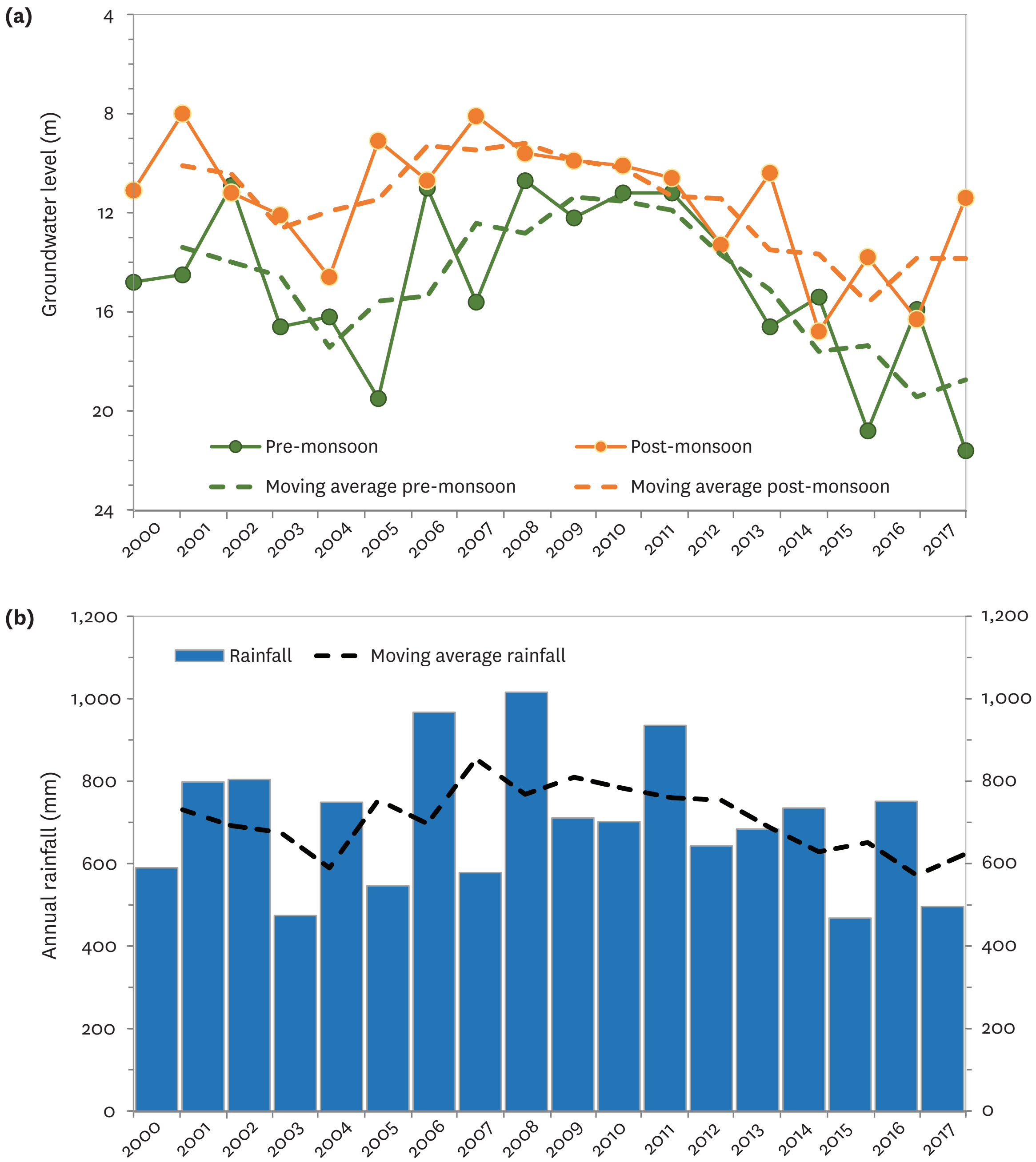

Figure 2. (a) Average groundwater level (depth below ground surface) in the non-command areas of five APFAMGS districts of Andhra Pradesh (Anantapur, Chittoor, Cuddapah, Kurnool and Prakasam), from measurements taken before and after the monsoon, and as 3-year moving averages from 2000 to 2017 (groundwater data are based on 1,565 observation wells); and (b) average annual (and 3-year moving average) rainfall from 2000 to 2017 measured in APFAMGS locations in the five districts.

Data sources: (i) Groundwater data: GoI n.d.; GoI 1995; GoAP 2002, 2006a, 2006b, 2008a, 2008b; GoAP and GoI 2011a, 2011b, 2012a, 2012b). For the later years, data are compiled from the Office of the Director, Department of Ground Water, Vijayawada, Andhra Pradesh, India. (ii) Rainfall data: GoAP (2001-2015) and GoAP (2016-2018).

Over the period from 1985 to 2016, rates of groundwater pumping for irrigation in the five districts, analyzed and as an aggregate across shallow and deep wells, increased dramatically, with the largest increases evident over the period between 1993 and 2002 (Figure 3). Since about 2002, the quantities of groundwater pumped have stabilized and, if at all, decreased in subsequent years. This decrease is potentially due to the decreasing trend in rainfall since 2008, which includes recent droughts in 2014-2015 and 2016-2017 that have reduced well yields as a result of poor groundwater recharge. Despite the extended drought conditions, the number and depth of wells have continued to increase.

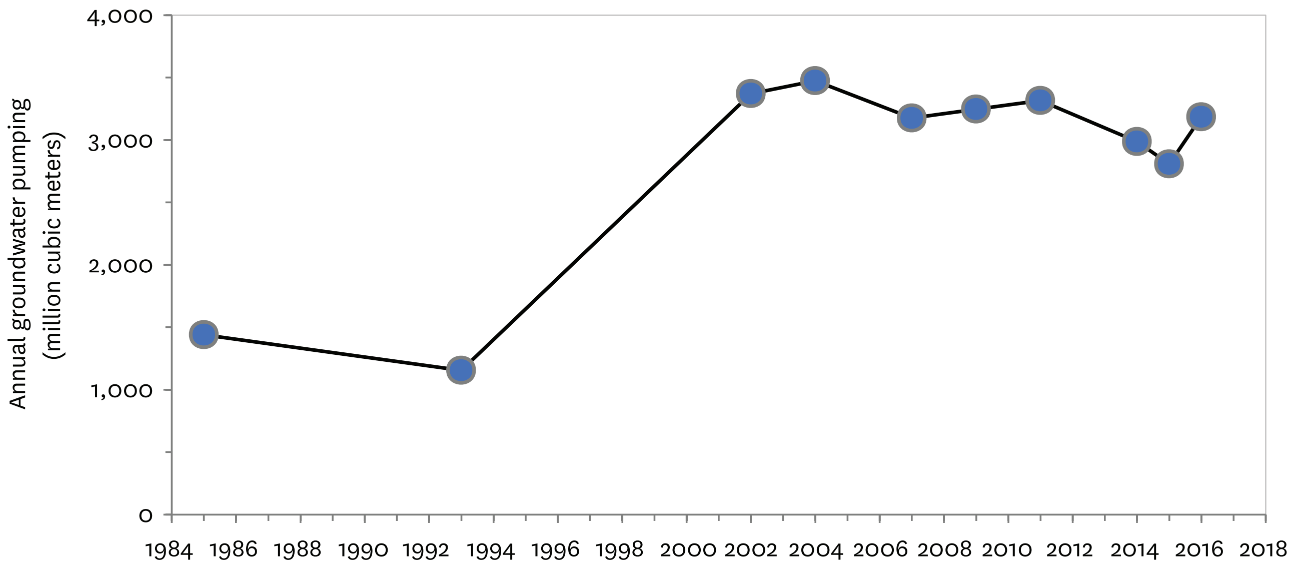

Figure 3. Trends in annual groundwater pumping in five of the seven districts where APFAMGS is implemented (Anantapur, Chittoor, Cuddapah, Kurnool and Prakasam).

Data source: GoI n.d.; GoI 1995; GoAP 2002, 2006a, 2006b, 2008a, 2008b; GoAP and GoI 2011a, 2011b, 2012a, 2012b). For the later years, data are compiled from the Office of the Director, Department of Groundwater, Vijayawada, Andhra Pradesh, India.

The available HU-level assessments in the APFAMGS areas do not provide a clear indication of an improvement in the groundwater situation. An independent study covering the period 2005-2008 identified that groundwater pumping had decreased only in 24 of the 63 HUs (Garduño et al. 2009). Another study examining the period from 2006 to 2011 noted a 20% or more decrease in groundwater pumping at 17 of the 63 HUs (Das and Burke 2013). The decrease in groundwater pumping was attributed to above-average rainfall over the period considered and not due to APFAMGS interventions. A groundwater balance analysis for the same period (2006-2011) showed that 56 of the 63 HUs remained in a so-called '*non-safe*' state of groundwater development, indicating that abstraction exceeds 70% of recharge (as per CGWB protocols). Thus, evidence of the hydrological impact of APFAMGS interventions suggests that the project had insignificant influence within the respective HUs. Finally, a farm-level study conducted across five villages in Nalgonda district in 2014 showed no significant difference in groundwater use between APFAMGs and non-APFAMGS areas (Sravanthi et al. 2015).

4.2 Impacts on farmer practices and outcomes

Groundwater availability has a direct bearing on the areas under *kharif* paddy cultivation (July to November) and *rabi* cropping (December to March). Crop water budgeting helped farmers understand the constraints to water availability and the effects of highly water-intensive paddy cultivation. Farmers' experiences showed that they incur crop and hence income losses when they do not follow the collective advice, i.e., reduce the area under water-intensive crops due to seasonal water shortages. Having knowledge of the constraints to groundwater availability faced by farmers prior to the cropping season in the project areas prompted the GMCs and HUNs to develop crop plans that addressed issues related to water use. This was directly attributable to APFAMGS interventions. Interestingly, the shift away from paddy to the cultivation of less water-intensive crops did not trigger the expansion of the area under irrigation. As mentioned earlier, the increase in the number of wells was due to decreasing groundwater levels rather than changes in cropping patterns.

Farmers have started to diversify cropping by shifting from paddy to alternative crops, i.e., pulses, oil seeds, fruits, vegetables, flowers, etc. This is in response to water stress and to also make the best use of available soil moisture (Garduño et al. 2009).[17] Market conditions for some of the crops (e.g., fruits, vegetables) have helped improve household income. A comparative assessment highlighted that APFAMGS villages were more resilient to climate-related risks than neighboring non-APFAMGS villages. For instance, investments in new wells and well deepening in the non-APFAMGS villages only occurred in the latter years of the project. Similarly, adoption of micro-irrigation is higher in APFAMGS villages (Reddy and Reddy 2020). Thus, evolving farmer practices could be attributed largely to APFAMGS interventions.

4.3 What happened after APFAMGS project closure?

New government programs or initiatives are prioritizing APFAMGS villages due to the communities' higher capacities and awareness coupled with stronger community institutions, such as GMCs, guaranteeing better outcomes and more efficient use of resources. The concentration of follow-up programs in the APFAMGS villages after 2013 has helped to enhance the impacts of the project. After project closure, the state of Andhra Pradesh continued to include APFAMGS approaches under different projects (Box 2), which also covered most of the APFAMGS villages. These new initiatives are scheduled to continue until 2025 (IFAD 2017). The more recent projects strive to promote sustainable groundwater use and management following the principles and practices of APFAMGS and could, therefore, be considered as follow-up projects. Besides continuing the earlier initiatives, these projects have helped to increase awareness among the communities and improve other practices, such as multiple/mixed cropping, critical irrigation,[18] mulching, and the use of chemical fertilizers, manure (vermicompost) and other natural inputs. Crop diversification has been spreading fast throughout the region in recent years due to increased water stress and favorable market prices for nontraditional horticultural and other crops, coupled with unfavorable market prices for traditional crops, such as groundnut. These crop diversification practices have helped farmers to stabilize or increase their yields and incomes and are likely to be sustained given the continued water stress and market conditions. In essence, farmers under APFAMGS have been capacitated in maximizing the agricultural output (crop yields and incomes) per unit of groundwater available on their farms, while not reducing overall use of the resource.

There is a firm basis for concluding that behavioral change among the communities in using and managing groundwater is a result of the project interventions and other contextual circumstances. Realization of the concept of sustainable groundwater use came earlier and to a higher degree in the APFAMGS villages than in other villages. Without the continuation of APFAMGS interventions after project closure and the favorable market conditions, these behavioral changes would likely not have taken place. The recent developments fostered through follow-up interventions (Box 2) have helped farmers to be aware and use the knowledge gained systematically. In some of these villages, farmers continue to make crop plans informally by applying the knowledge they gained from APFAMGS, even without collecting additional data. While these communities have the advantage of continued external support, no formal institutional arrangements are pursued, e.g., integrating GMCs with WUAs, giving WUA status to GMCs, or linking GMCs to the state groundwater department. The more recent APDMP being implemented by the Government of Andhra Pradesh, through the line departments, has identified PGM as a best practice. However, there is a need to link the existing

[17] I.e., the cultivation of (i) drought-resistant crops during seasons with low groundwater availability, and (ii) water-intensive but profitable crops when more water is available.

[18] Irrigation scheduling which focuses on periods important for crop growth.

informal community institutions to a formal structure with provision for funding, in order to protect the institutional network at the village level (social capital) and the groundwater support systems (natural capital) created in the region. At the same time, the new projects, while scaling out the initiatives, need to include all the APFAMGS villages in the program with an adapted set of interventions. The interventions could be in the form of updating the technical information from the field and keeping the communities informed, and creating motivation for adopting PGM.

The '*do it yourself*' approach with enhanced scientific knowledge has improved the awareness of well owners. This has increased resource-use efficiency but has not translated into sustainable groundwater use at any level - household, village or district - over the time frame assessed. This could be due to the absence of formal or informal regulations and collective initiatives, such as increased investments in managed aquifer recharge structures or sharing of water. This has resulted in perpetuating inequity, especially during drought years when groundwater levels tend to be deeper (Reddy et al. 2014). Marginal and small farmers are the first to be impacted by groundwater depletion as they have shallower bore wells compared to large farmers, and this affects their water availability for both domestic use and farming. Due to the lack of access to water, poor farmers are the first to quit farming in search of alternative income-generating activities (Reddy et al. 2020). In the absence of any tangible improvement in the groundwater situation, and since the project only focuses on farmers owning wells, APFAMGS interventions have failed to achieve equitable outcomes for all farmers.

More sustainable and equitable outcomes would require long-term support and formal linkages with relevant line agencies, such as the state groundwater department. Informal peer pressure from fellow farmers, convinced about the gains from sustainable groundwater management practices, did not work in the post-project period in the absence of any social or economic regulations. Moreover, since the APFAMGS approach does not include all farmers, the information-based awareness failed to reach the majority of farmers. This was because less than 50% of farmers in the region own a well, and was also due to the absence of water markets or water sharing arrangements (Reddy et al. 2016). This has an adverse impact on the sustainability of the approach, as the limited membership hinders the collective ownership and commitment to the common good, i.e., groundwater. Also, in the absence of any tangible benefits to farmers who do not own a well, they lack the incentive to support broader activities, such as rainwater harvesting.

Some of the initiatives in Andhra Pradesh after APFAMGS project closure have integrated the knowledge-based approach with social regulation. These interventions include the Social Regulations in Water Management (SRWM) by the Centre for World Solidarity (CWS), and the Andhra Pradesh Drought Adaptation Initiative (APDAI) by the Watershed Support Services and Activities Network (WASSAN) (Reddy et al. 2014). Though awareness building and data generation by the village communities were important components, the process was not adequate as evident from the issues of quality of data and its organization. The most important aspect of these two new initiatives (SRWM and APDAI) was to bring consensus among the communities to share water between well owners and non-well owners to protect their crops, especially during periods of highest water stress. Social regulations were put in place and included restrictions on the construction of new wells, and provision of protective irrigation to the plots of well owners and non-well owners through the irrigation backup[19] they receive in the event of failure of the groundwater well. Further, water losses during distribution were reduced by using sealed pipeline supply rather than open channels, and water-use efficiency was increased through the promotion of micro-irrigation at subsidized prices. Similar PGM approaches were implemented by two NGOs in Chittoor district of Andhra Pradesh - Foundation for Ecological Security (FES) and Jana Jagriti (JJ) - where awareness, regulation and incentives are combined. A recent study assessing the FES/JJ approach identified that groundwater management improves with increasing community awareness (knowledge about cropping patterns and the linkages to groundwater use) and social capital (where participants consider group gains) (Meinzen-Dick et al. 2016).

In all three initiatives (SRWM, APDAI and FES/JJ), social regulations had a clear effect in stopping the construction of new bore wells and helped a larger number of households, especially the marginal and small farmers, to benefit from sharing water with well owners (Reddy et al. 2014). This has led to increases in the cropped area under protective irrigation, thus minimizing crop losses. This also resulted in equity in the distribution of water and overall welfare improvement that could enhance drought resilience. The success of these initiatives is mainly due to the commitment and effort of NGO partners in the absence of any contribution from the farmers towards irrigation infrastructure (pipelines, micro-irrigation, etc.). Communities are often lured by the incentives (subsidies for micro-irrigation and pipelines) rather than their ownership of the interventions and commitment to sustainable groundwater management.

[19] When a farmer's well fails, they can access water from the well of a neighboring farmer.

5. Lessons for scaling out the PGM approach

This assessment clearly highlights that the PGM approach of APFAMGS has neither resulted in an improvement in the groundwater situation nor promoted sustainable groundwater management practices in the majority of HUs at the district level. The weight of evidence indicates that the APFAMGS approach has a positive influence on behavioral changes due to increased knowledge of groundwater among farmers that may bring about more efficient use of the resource and better and more secure crop production. This may have reduced overall pumping in project areas and slowed groundwater level declines, but the effect appears at best limited or localized. However, the approach falls short on goals of equity due to limitations associated with inclusiveness, incentives and social regulations. Recent experience from Andhra Pradesh with more integrated approaches indicates that knowledge creation together with regulations/incentives are required to make PGM effective in addressing increasing food demand and climate-related vulnerabilities in more equitable ways. Further, the role of women in the process needs further strengthening, as they play a significant role in farming, especially in the context of climate-induced crop pattern changes. In this regard, ensuring women's participation in village-level GMCs would help address gender-sensitive aspects of groundwater management. While incentives require a top-down approach (government providing necessary capital support, subsidies, agricultural pricing, etc.), social regulatory mechanisms should evolve from within the community. The experience so far indicates that the design of the approach needs to consider local needs in order to make it effective and suitable for scaling out. PGM is being scaled up at the national level in seven states under a new program *Atal Bhujal Yojana* with a focus on institutional strengthening and capacity building. This program has an estimated budget of USD 860 million with a matching contribution of USD 430 million from the World Bank over a period of 5 years (2020-2021 to 2024-2025) (GoI 2020b).

This study raises the larger question of '*how participatory are participatory initiatives?*' This needs to be understood in the changing socioeconomic and climatic context and community perceptions, i.e., participation is no longer viewed as a solidary activity by communities. Unless there are substantial economic gains to be made, proactive participation is difficult to materialize (Mansuri and Rao 2013). More importantly, factors related to political economy, which may include elite capture, regulatory capture, political discrimination or favoritism, etc., come to the fore as these initiatives expand. Social regulation is a difficult proposition in nonuniform communities, where politics and the common good may disconnect (Reddy et al. 2014). At the same time, it is also difficult to encourage farmers with larger landholdings, who are also politically more influential, to give up their higher degree of control on groundwater due to the awareness created.

Externally induced participation is unlikely to be sustainable in the absence of sustained tangible benefits and policy-backed incentive and regulatory mechanisms. While improving communities' awareness and knowledge about groundwater is a necessary precondition, it is not sufficient to make communities engage over the long term. Policy and legal support systems are required to ensure enhanced benefits and equity in their distribution. These include addressing the policy distortions in resource pricing (water and energy), output prices that favor water-intensive crops[20] and clearly defined property rights in order to make groundwater serve as a common-pool resource. When adopting and improving PGM-based initiatives such as APFAMGS on a wider scale, state governments need to consider the following aspects:

- Initiatives towards increasing the community's awareness and knowledge about groundwater by adopting scientific approaches with location-specific attributes is a precondition for improving the efficient use of the resource. However, it may not improve the groundwater situation over the long term, especially with continuing climate change.
- Integrating top-down incentive structures and bottom-up social regulatory mechanisms together with awareness building is likely to be effective in the short to medium term. These include price incentives for less water-intensive rain-fed crops, price stabilization (lowering price risk) for horticultural crops, pricing of water and energy by treating them as economic goods, and regulating groundwater pumping through community-based approaches, etc.
- Pricing policies still favor water-intensive crops, such as paddy, sugarcane and wheat.[21] These policies, complemented by free or subsidized power and water pricing policies, act firmly against the policy objective of sustainable groundwater management.

[20] Rice is still a preferred crop due to better market conditions. Only water scarcity can deter farmers from growing rice.

[21] Though 14 crops are listed in the minimum support price policy, effective implementation is enforced only for paddy, sugarcane and wheat (Reddy and Chiranjeevi 2016).

- Linking community-based institutions (e.g., GMCs) and existing administrative institutions (e.g., groundwater/ irrigation departments) with funds, functions and functionaries that could help sustain PGM initiatives. In this case, state government departments can take the lead in promoting and supporting the community actions at the local level.
- In the long run, ensuring equity in access to groundwater among farmers will require policy changes that recognize groundwater as a common resource. This calls for changing the property rights regimes and moving towards delinking land and groundwater rights.

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