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Rainfed Agriculture and Use of Groundwater: Winners and Losers - A Review of Literature of Experiences in India

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Abstract

Rainfed areas play a vital role in India's agriculture as they provide livelihood to 60% of the country's population and contribute substantially to its GDP. The productivity of rainfed areas is adversely affected by the increasing variability in rainfall. Climate change over the past few years has made rainfed agriculture precarious, with the impact being most harsh on small farmers. Rainfed area programmes implemented by the Governments over the last few decades to increase their productivity resulted mainly in increasing access to groundwater which are more beneficial to farmers who could afford them and less to those who depended solely on rainfall. These developmental initiatives are also not sustainable where governance systems are not strong. In contrast, there are well documented case studies across the country of rainfed crops being protected by the sustainable use of groundwater during critical dry spells. This paper reviews recent literature on rainfed agriculture, climate change and groundwater, with focus on productivity, sustainability and innovation to protect rainfed crops with limited groundwater resources. If the lessons learned from such experiments are incorporated into the design of rainfed area development programmes, greater benefit would accrue to rainfed areas and its farmers.

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Introduction

Rainfed agriculture is facing severe resource constraints globally. Up to 80% of the world's agrarian land is rainfed, and 70% of the world's staple food, particularly in developing countries and the areas which do not see development, originates

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from the huge scope of rainfed agriculture.[1] Rainfed areas, which make up over 60% of the total agricultural land in India, contribute about 60% of the country's agricultural GDP in spite of facing constraints of poor soil health, high soil erosion, low moisture content and less productivity.[2] It was noted that the subsistence nature of agriculture in rainfed lands in India for small and marginal farmers lacks in development action.[3] Even with these problems, these rainfed areas still provide the base livelihood option for these people; and, there is high potential to improve the productivity and strengthen the livelihoods.

While there are efforts to make rainfed agriculture a viable enterprise, the changes in rainfall pattern and climate change effects are negating the results. Climate projections indicate a rise in annual mean temperature, worsening hydro meteorological droughts and reducing agricultural productivity of rainfed crops. Human-induced changes in cropping patterns and climatic changes, including extreme events, may further exacerbate regional water scarcity and food security challenges semi-arid region.[4] As a study[5] pointed out, farmers are aware of changes in climate and perceive its impact, particularly such as loss in crop yields and increased cost of cultivation, but they are unable to take up required adaptation measures. There are several efforts by government and civil society to improve the productivity of the rainfed areas, focusing mainly on watershed approaches to develop the resources. Unfortunately, the results/ benefits of these programmes and initiatives largely reached those who have some advantage in terms of land and irrigation facilities. This resulted in a situation where the rainfed lands, that are actually dependent only on rainfall, remained as rainfed without much improvement in their condition; the irony is that they are technically and programmatically part of 'saturated areas' and considered as 'treated areas' with those developmental interventions.

The efforts to develop rainfed lands over the years had several objectives related to expected results. The notable benefits of these initiatives could be seen mainly on three fronts. These include – increase in the cropping area, improvement in water, particularly groundwater availability and changes in cropping intensity. Even in the case of these results/ benefits, the sustainability and equitable distribution of the interventions still remained unanswered. Some of the factors could be less consciousness on judicious use of resources, absence of required community level or institutional level regulatory protocols and insufficient community action. The meta analysis[6] of over 300 case studies across places from India has strengthened the argument.

Although the yield of rainfed crops depends on a variety of factors, water is a prerequisite for increased production. Due to climate change and with the advancements in technology, farmers' dependence on groundwater has increased and it has become one major contributor for agricultural growth in India.[4] Groundwater has been in use since several centuries in India, but its rise has been particularly observed from the 1970s. As noted,[7] unplanned groundwater extraction in recent decades has resulted in rapid depletion of groundwater levels and gradually it is becoming a scarce resource. The Common Property Resources (CPRs) tend to be exploited more intensively compared to Private Property Resources. This indicates a higher rate of resource use and depletion for CPRs, due to the shared and less regulated nature of these resources.[8] As groundwater is an invisible common resource, its over exploitation is leading to multiple negative effects on the livelihoods of the rural poor in rainfed areas. To correct this situation, the studies[9,10] have suggested better irrigation practices, promotion of less water intensive crops (replacing paddy); and, a decentralized groundwater management and governance framework, engaging stakeholders and a good understanding of technicalities of groundwater behavior, to mitigate the negative impacts of groundwater depletion on agriculture. The rapid increase in groundwater usage necessitates innovative and comprehensive approaches to managing groundwater resources. Besides traditional methods new strategies must be developed.[11] Soil and water conservation activities, coupled with protective irrigation during dry spells, are key in rainfed cropping systems to safeguard small and marginal farmers from the vulnerabilities of climate change effects.[12] To ensure the sustainability and resilience of agricultural systems, integrated approaches for both adapting to and mitigating climate challenges must be encouraged.[13] Indeed, both government and civil society organizations in

India have experimented on these lines, through several pilot projects engaging local communities to protect groundwater and rainfed crops.

The present paper is an attempt to look at the existing literature on the above discussed topics. It tries to present the complexities in rainfed areas and rainfed agriculture, effects of changes in rainfall pattern, climate variations and groundwater availability and the impact of various programmes intended to develop rainfed areas. It also tries to look at the role of community in sustainable use of the improved resources and convergent efforts among the line departments so as to capitalize the inherent potential of rainfed lands. This paper also tries to project some innovative efforts for sustainable and judicious use of groundwater and productivity improvement of land and crops. It is intended that this paper will serve as precursor to the conduct of a study on integrating social and technical aspects in using groundwater to protect rainfed agriculture.

This review paper is organized into 7 sections. After the introduction in section 1, section 2 explains the significance of rainfed agriculture, features of rainfed areas and the current and future potential of rainfed agriculture in India. In section 3, climate change and variability, concerns and impacts of climate variability on rainfed areas and rainfed farmers are presented. In section 4, the rise in groundwater use over time and its overexploitation, and its management are reviewed. In section 5, overview of efforts to improve the potential of rainfed areas and who benefited from these are discussed. In section 6, innovative experiences for protecting rainfed crops through sustainable use of groundwater is presented. Concluding remarks constitute section 7. A table in Appendix I summarizes 26 of the key papers on impacts of mainstream programs in rainfed areas in India, reviewed in this paper.

Rainfed Agriculture in India – Features and Potential

In the Indian context, rainfed agriculture can be observed in diverse soil types, agro-climatic and rainfall conditions extending from 400 mm to 1600 mm per year.[1] These areas are part of both high rainfall regions and low rainfall regions. The topography of rainfed agricultural lands in the country are generally undulated with diverse slopes; as a result, the fertile topsoil is washed away and the land deteriorates over time.

The rainfed lands with low rainfall have limited resources, low moisture and are prone to erosion. With low and unreliable rainfall, it is very difficult to conserve soil and moisture in these lands and it is also an expensive affair.[3] In addition, a study,[14] has pointed out that low cropping intensity, high investment costs, low productivity, and less usage of modern technology, etc. are some of the major problems in rainfed agriculture. Unpredictability and variability in rainfall have a severe impact on rainfed crops, which makes it difficult to assess how much yield can be harvested. Rising temperatures and consequent droughts, along with limited irrigation water, pose significant challenges to agricultural productivity in rainfed areas.[15]

In India, about 69.5% of the net sown area falls under dry and rainfed agriculture; about 42% of the total food grain production comes from these lands,[3] 91% of coarse grains,[16] 91% of pulses and 80% of oil seeds are produced from rainfed areas.[1] The rainfed agriculture provides employment to about 60% of the population and contributes 21% to the country's GDP,[17] which makes India rank first among rainfed agricultural countries.[1,3,14,16] A study[18] estimated that by 2025, 33% of food grain production will come from rainfed lands. As noted in a study,[17] as the food grain requirement in the country grows, the productivity of rainfed lands also needs to be increased by 100% in the next 20 years to attain food security. As noted,[19] Rainfed areas are highly diverse, ranging from resource-rich areas with good agricultural potential to resource-poor areas with much more restricted potential. In the less favorable regions, the productivity growth has been lagging behind, leading to widespread poverty and degradation of natural resources. It is crucial that rainfed areas with low productivity and limited potential receive greater emphasis in public investments to address these challenges and promote sustainable development.

Impact of Climate Change on Rainfed Areas and Concerns

Climate change is the change in the normal weather over time and it reflects variations in temperature, rainfall, and wind. As discussed,[16] the fact remains that human activities directly or indirectly contribute

to change in global weather in addition to natural climate change which is evident from the data of the past few decades. Climate change will worsen future water scarcity, driven by increasing temperatures, variable rainfall patterns, diminished groundwater recharge, and declining groundwater levels.[20,21] There is considerable concern about the consequences of climate variability on agricultural yields. The studies[16,22] have pointed out that India has a fair chance of experiencing one of the most severe agricultural productivity misfortunes on the planet as per the changes in weather patterns noticed and situations visualized.

In India, nearly three-fourths of rainfall in rainfed areas is the result of the south west monsoon. The variations in rainfall and its improper distribution is making rainfed farming unmanageable. Over the past 20 years, droughts have significantly affected rainfed farmers.[23]

The sporadic dry spells in the life cycle of the crop, most importantly during the crucial growth phases, are negatively impacting rainfed agriculture.[1] Crops could be damaged either fully or partially because of longer periods of moisture stress. As point out,[16] there is no need for a big drought to severely damage crops and hamper the economy; even a dry spell like a small drought is enough during the crucial times of the crop growth. Late onset and early withdrawal of rainfall,[3,24] badly timed rainfall and extended dry spells at times of crop development3 are major climate gambles for crop yields.

A study[16] revealed that most small farmers found low rainfall to be the main reason for their low crop yields. As per the perception of the farmers, the losses in crop yields as a result of insufficient and irregular rainfall are more when compared to the low crop yields caused due to pests and diseases.[24] Though there are threats of crop losses, sub-optimal yields and not much-secured livelihoods because of unpredictable patterns of the seasonal rainfall, a study[1] noted that these rainfed lands have a significant possibility for development.

As discussed,[16] farmers are acquainted with the fact that effects of climate change are the reason for reduced crop yields and reduced net income under rainfed conditions. As a result, some farmers have quit agriculture and shifted to other occupations, while others have adopted technologically optimistic coping mechanisms to counter the adverse effects of climate change. They also noted that small and medium farmers are more susceptible to climate change, they are also the ones grappling with various mechanisms to deal with adverse weather effects as compared to large farmers. They further observed the impact of climate change on the social and economic affairs of rural families. It was noted that while some farmers are approaching private moneylenders for loans to palliate the income losses, more and more people are switching away from their farming activities. The adverse effects of weather are on the rise leading to both short and long term problems ranging from low yield and loss of income to complete abandonment of agriculture, which require quick policy responses.

Groundwater: An Unregulated Common Resource

India is one of the biggest groundwater using countries in the world. Groundwater has been used for agriculture for several centuries; it is viewed as a secured source over surface water and serves as a dependable buffer to farmers in critical times of drought.[25] The complex relationships and effects of human actions, climate patterns, and the natural hydrological cycle on the amount and quality of groundwater, varying across different geographical areas and over time.[26] During climatic variations, if this precious resource is not available, farming communities will be compelled to look for alternate livelihood.[27] About 68% of agricultural families in India having tube wells belong to small and marginal farmer's categories.[27] A study[28] notes that the share of groundwater is 84% of the total extent of irrigation in India. It explains the criticality of groundwater, not just for agriculture but also for ensuring the livelihood of farmers.

Groundwater offers farmers a flexibility in use besides being treated as a dependable source.[29,30] Change in land use pattern, financial support in the form of grants for digging wells and drilling bore-wells have increased pressure on groundwater use.[30] Highly fragmented and decentralized system where individual users extract groundwater independently and inefficiently, often leading to over exploitation.[11] With ever-growing demand for groundwater for irrigation and for decreased base flows, the groundwater levels have decreased significantly. The

World Bank noted that the availability of pumping technology and its affordability for small income families in India has boosted the unusual increase of groundwater use in the last few decades.[31] Easy access to credit for drilling and deepening the wells and also for the purchase of pump-sets in the rain-fed areas further facilitated the growth of groundwater irrigation to a large extent.[32] Government subsidies on electricity for irrigation and the availability of energy efficient pumps to lift the water from deeper levels have contributed to more extraction of groundwater in recent years.[33]

The increase in groundwater use for irrigation in India has been more rapid since the 1970s'. A study[27] observed that the continuous and unsustainable extraction has led to a situation where 70% of the annual available groundwater is being used for irrigation and a study[33] further noted that this is a threat to the sustainability of groundwater. As per the Planning Commission, 2012 data, nearly 60% of the districts are experiencing groundwater related issues such as scarcity or low quality. As per Central Ground Water Board (CGWB) Reports on Assessment of Groundwater Resources[34–36] (2007, 2012, 2021), 63% of assessment units were reported as safe in 2019-20, which is a decrease from 73% noted in 2010-11. The percentage of over exploited blocks has increased from 15% in 2005-06 to 17% in 2019-20. Similar patterns were observed in semi-critical and critical areas as indicated in Table 1.

Table 1: Central Ground Water Board (CGWB)'s Assessment of groundwater resources – the percentage of increase in over exploted , critical and semi critical zones over time.

Year	Semi critical	Critical	Over exploited	Safe
2005-06	0.1	0.04	0.15	Not available
2010-11	0.09	0.03	0.14	0.73
2019-20	0.14	0.05	0.17	0.63

The unusual situation of groundwater management in India is the result of the following reasons: it is one of the biggest users of groundwater with a huge number of users across states, poor assessment of aquifer capacity; and minimal regulation.[31] Absence of regulations and undisciplined pumping resulted in aggravating this situation and as noted,[28] inadequate perception on the features of the groundwater resource has resulted in rapid growth of wells and indiscriminate use of groundwater. The competitive sinking of tube wells, overuse of groundwater that eventually led to extracting water from deeper levels with more energy pumps resulted not only in faster depletion of groundwater resources in several parts of the country but also in poor quality of the same.[10] While undisciplined groundwater use in rainfed areas has negative impacts on ecology, the competition in drilling wells to deeper depths has consequences such as indebtedness particularly on poor farmers.[32]

Groundwater is very vital that cannot go unmanaged ceaselessly, the effect of either absence or poor groundwater management is awful on the poor.[31] Incorporating demand management strategies with management tools such as encouraging less water demanding crops, governing groundwater withdrawal would work well for the poor.[33] The dependent communities themselves need to evolve required norms/ guidelines towards better management of groundwater resources. Additionally, sustainable groundwater management plans need to be evolved. As the study,[28] points out that there is a requirement for communities to understand groundwater behavior by demystifying groundwater knowledge and science. The study[27] also noted that protection of resources is not accomplished without users' collaboration and management. Thus, if the resource development and management plans are locally prepared by communities, there is better scope of cooperation among users to adhere to them. Choosing advanced and innovative technological solutions in irrigation could enhance water use efficiency.[37]

In India, groundwater management could be achieved by drawing in and encompassing three aspects related to groundwater. These are: (1) understanding the resource and its properties from the users' point of view, (2) socio-economic properties of groundwater requirement and effective, justified, sustainable supply to satisfy the needs; and (3) enabling diverse organizations and sectors such as science, technology, sociology and economics to work side by side[10] and of course, with a rich framework in place. The[28] Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) launched by the central government is aiming at providing secured irrigation to each farm by introducing the principles of groundwater management and fulfilment of this objective would be achieved only if there are proper management plans in place and in action.[28]

Efforts to Improve the Potential of Rainfed Areas: Winners and Losers

Periodic droughts in certain regions of the country lead to significant agricultural and livestock losses, and despite the government's substantial spending on relief efforts, the root problem of low productivity remains unsolved. The Hanumantha Rao technical committee report38 when discussing the history of developmental initiatives in India after independence, said that while ad-hoc relief works provided temporary relief by generating employment and purchasing power, they didn't address the underlying issues effectively. Frequent droughts leading to vulnerable livelihoods of people in rainfed areas triggered the rainfed areas development activities with watershed approach in India in 1970s'. Integrated watershed principles were followed till 1980's and necessary modifications were incorporated later on. During 1990s' the programme expanded across the country and the watershed programme became the largest participatory rural development programme. A National level Institution for land development called National Wasteland Development Board (NWDB) was established in 1985, which was renamed as Department of Land Resource Development (DOLR) in 1999. The mandate of this central body is to improve the productivity of rainfed and degraded lands in the country through implementation of Integrated Watershed Management Programmes. The National Rainfed Area Authority (NRAA) was established in 2006 to design special programmes and appropriate policies for holistic and sustainable development of rainfed areas.

Over the years, various schemes have been implemented as part of National Watershed Development Project for Rainfed Areas (NWDPRA), Integrated Watershed Management Program (IWMP), Integrated Wasteland Development Program (IWDP), Rainfed Area Development Program (RADP), Pradhan Mantri Krishi Sinchai Yojana (PMKSY), Agriculture Contingency Plans etc. for the development of rainfed areas. Soil and moisture conservation measures are being promoted as part of Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). The Participatory Watershed Development Programme, most popular among all the above, is conceptualized and implemented to conserve soil and moisture, undertake water harvesting practices, increase groundwater table and improve the productivity of rainfed lands. The main aim is to enable the rainfed communities to cope up with drought conditions and augment groundwater for agricultural purposes. Different work components such as area treatment, drainage line treatment, horticulture development, biomass and vegetation development etc are part of these watershed programmes. As part of the area treatment, soil moisture and water harvesting structures were promoted that included farm bunding, percolation tanks etc. Drainage line works included gully plugging, low-cost structures like loose boulder checks, rock fill dams, vegetative checks and check dams etc.

Studies conducted to evaluate impact of watershed programmes reveal remarkable positive changes in various aspects of farming and livelihoods of dependent communities of rainfed areas. The notable changes are increase in groundwater table, increase in irrigated area and increase in cropping intensity,[39–43] increased biomass and fodder availability.[43,44] Some studies,[41,45] revealed the availability of groundwater for longer duration including the post-monsoon period. There are also findings that observed the increase in groundwater levels in influence zones where watershed interventions like percolation tanks were constructed.[40–42,46]

While a study[47] noted that the results of watershed programme implementation are not the same across watershed areas, another study[48] pointed out that the downstream areas in watersheds are more resilient than upland areas. From these studies, it can be assumed that the farmers in the low lying areas reaped the benefits of watershed development. These beneficiaries were mainly the farmers who had their farm lands in the influence zones of water harvesting structures. These findings corroborate with a study,[49] reveals in their study that unless the access to water use is not widespread the results of the interventions from mainstream programmes may not address the impacts of agricultural droughts for all within a village. Another significant result of the watershed development programme is the increase in the number of borewells in watershed villages.[48,50,51] These new bore wells were dug to either maximize the benefit from increased groundwater table as a result of watershed interventions or to overcome the severity of drought conditions.

Based on these studies, it can be assumed in terms of agriculture, that the watershed programmes benefited most the followings; one, the farmers with agricultural land in low-lying areas of watershed who generally opted for water intensive crops; and second, those farmers who could afford to sink bore-wells and install pumping equipment. From this, it can be pointed out that the rainfed lands of upper and part-mid reaches of watershed area, which are generally of poor quality and completely dependent on rainfall, lagged behind in cornering the benefits of watershed interventions. This in a way is in contradiction with the intended objectives of the programmes designed for rainfed areas. Further, the effects of climate change over the past two decades has compounded the problems of these rainfed farmers. As several studies[2,52,53] have noted, untimely rains and dry spells seem to cause the main problem for rainfed agriculture, and this has several negative effects on the poor lands and the poor farmers of rainfed areas. Without a special focus on these, the objectives of the programmes designed for the development of rainfed areas will not be fulfilled.

While many of the studies indicate that there is a significant level of increase in groundwater in watershed villages, questions remain: How is it used? Who benefited with such an increase of groundwater availability? What about the sustainable use of this critical resource? Several studies indicate the following in regard to the questions above. Duration of water availability in the wells is increased;[41,46] addressed short dry spells;[54] with the increased water resources, additional land was brought into cultivation;[55,56] area under irrigation is increased;[39,41,46] cropping intensity is increased;39 water-intensive crops were grown, high-value crops that required more water were promoted;[51,56] permanent lifts were set up for paddy cultivation in some places,[55] there is a shift from traditional farming to commercial crops like paddy and wheat,[47] and, irrigated horticulture was taken up in some places.[48] The increased groundwater table in watershed villages motivated some better-off farmers to improve or extend their land for irrigated agriculture and sink new bore wells. This has resulted in longer hours of pumping of groundwater.[41,46,45]

For increasing the farmer's household income, irrigated horticulture was intensively promoted in some watershed villages.[48] It is also the same case with MGNREGA activities in some rainfed areas.[57,58] Crops like mango and citrus fruits were extensively promoted as part of horticulture. These plants need more water year after year as they grow and they need substantial quantities of water particularly before the flowering period which is water stress period in most of the low rainfall rainfed villages. In such scarce water conditions and drought periods, several farmers faced severe losses due to the drying up of their matured orchards.

Another notable point is the implementation of some unique, innovative activities to protect the rainfed crops in several watershed villages, even after completion of the watershed programme. These initiatives are implemented by several NGOs across the country, particularly focussing on groundwater management, groundwater pooling and water sharing for rainfed crop protection.[28,59] Such initiatives prove the point that neither the watershed development programmes, nor any other mainstream programme is successful in achieving their intended objectives of protecting rainfed lands and rainfed crops and, the outcomes are unsustainable. Balance between groundwater recharge and groundwater pumping is critical to

sustain the impact of these interventions. And such harmony and balance may be possible in rainfed areas, provided there are specific interventions and roles taken up by the community, supported by needed policy interventions. It is especially required in conditions of low rainfall. Whenever low rainfall is recorded, there are several instances of crop failures and farmers suffering losses. If there are continuous droughts the severity of losses get amplified.[48]

Regardless of government policies on groundwater use, it is clear that sustainable use of groundwater is not possible without the community understanding its significance and taking appropriate initiatives in that direction at village level. In this regard, a study[60] discussed the context of sustainable use of increased water and the role of community-based institutions in managing the resources and cited[28] some protocols for such field level processes. The study[61] stress that social regulations, along with technology, and community participation play a key role in groundwater governance. Such efforts related to regulations in drilling new bore-wells in a bilateral programme like Indo-German Watershed Development Program (IGWDP) were discussed,[62] but such efforts were significantly invisible in Government projects.

All these studies and observations stress the need for the communities to understand groundwater behaviour that enables them to properly assess available resources and formulate required social regulations. They also underline the need to take collective decisions on cropping patterns and water use policy and see that those decisions are implemented. For this, communities' capacities need to be strengthened during the process of programme conceptualization and implementation itself. Incidentally, no such efforts or experiences are visible in mainstream programmes, as far as this literature review is concerned.

The National Rainfed Area Authority (NRAA) has evolved a set of criteria for identifying and prioritizing rainfed areas at the national level.[63,64] Similar approach may be followed at watershed level which should enable watershed communities to identify vulnerable areas as per local context to prepare and implement plans exclusively for such areas to deal with drought and other sensitive situations. These plans could be different from traditional watershed plans which have more focus on surface water storage and groundwater augmentation. These plans should also be different in a way to utilize the increased water availability to protect rainfed crops from frequent droughts in sensitive zones within watershed boundaries.

Innovations for Protecting Rainfed Crops and Sustainable Use of Groundwater in Rainfed Areas

As discussed above, while the government was focusing on implementing watershed development and MGNREGA programmes in rainfed areas to overcome their inherent issues and concerns, along with addressing the adverse effects of climate variability, there were several initiatives at field level, steered by civil society and research organizations to critically address the issues related to protection of crops and sustainable use of groundwater. While a study[46] discussed about the criticality of strategies including watershed development and rainwater harvesting to protect rainfed agriculture from climate variability and increase its productivity, another study[32] mentioned the conjunctive use of wells with surface water bodies and participatory groundwater management experiments as part of social regulations. The results in crop yields with and without access to irrigation were discussed in other studies.[65] It was observed that farmers with irrigation sources have doubled the yields compared to rainfed farmers; in addition, these farmers were able to get two crops in a year.

In this context, this paper basically tried to focus on following initiatives – 1) Andhra Pradesh Farmer Managed Groundwater System, popularly known as APFAMGS; 2) Farm Pond Technology developed by CRIDA; and, 3) Water Sharing Pilots by Civil Society Organizations.

Andhra Pradesh Farmer-managed Groundwater Systems (APFAMGS) programme was launched in 2003 in Andhra Pradesh, India.66 It is a knowledge and awareness building effort centred on the hydrological unit network (HUN). It could build awareness of farmers on groundwater and help them to make appropriate decisions on cropping patterns based on estimations of available groundwater, though there is no specific focus as such on utilizing

groundwater for protection of rainfed crops. An institutional mechanism in the form of Ground Water Committee (GMC) was tried out in this initiative to take and implement required decisions. As per a study[67] observation on this initiative that the sustainable utilization of resources does not happen just by increasing awareness levels of stakeholders on resources, but it requires necessary action on ground to bring them into practice.

In the context of farmers facing difficult situations and losing crops due to dry spells and climate variability, several studies[1,2,68–70] pointed out that couple of life-saving irrigations in critical times of crop growth will not only save crops, but growth in yields also will be remarkable. Research institutions like CRIDA came up with farm pond technology, to address the critical irrigation needs and provide lifesaving irrigation at critical times.[52] Based on the size of the farmer's available land, different sizes of farm ponds were suggested. These can be lined or left without any lining, depending on the soil type and seepage character. The water stored in these farm ponds during the rains could be utilized through lifting devices (diesel or electrical) to provide critical irrigation to the rainfed crops. Thus, farmers could protect their crops from drought conditions. While this seems to be a good solution, it involves higher costs in construction of ponds. Further, farmers need to allocate at least 2-5% of their farmland which normally small and medium farmers are reluctant to do. And, this source is used by a single farmer for his/ her own farm land. Thus, although this technology could provide a solution to protect the rainfed crop within the available resources and means, it had its limitations. Another initiative is water sharing pilots facilitated by civil society organizations,[2,31,53,59,71,72] with twin objectives of sustaining the better use of groundwater and protecting the rainfed crops. As part of this model, groundwater is shared between bore-well owned farmers and non-bore well farmers, in a patch of defined area. All the farmers in that area are encouraged to use efficient water utilization methods such as sprinklers and drip irrigation. Regulations were placed on the sinking of new bore-wells. There are two participatory approaches tried out as part of water sharing – one is *social regulation* approach and the other is collectivization of bore-wells. As part of the social regulation approach, bore-well owners were convinced to share water with their neighbouring farmers. In *collectivization of bore-wells*, the water from bore-wells from defined areas in a village is pooled and shared through a pipeline network within that area, both among the bore-well owners and non-bore well farmers. The main objective is to protect rainfed crops from droughts. These experiences seem to be promising in protecting rainfed crops even during unreliable and erratic climatic conditions, but as observed in a study,[59] for such initiatives, investment and leadership is required at the village level, and, as they are process and technology oriented, external facilitation is required.

The Participatory Groundwater Management (PGWM) initiatives taken up by non-profit organizations have succeeded in increasing groundwater tables across their pilot villages.[28] Managing groundwater effectively is very challenging because there is a pressing need to developing these resources, but there is limited understanding, awareness, and technical capability.[73] The concepts behind rules that emerged for increasing crop productivity are now valued in groundwater governance frameworks. The social regulation approach in managing groundwater resources is found to be effective both for the resource rich and resource poor, particularly marginal and small farmers, in stopping the drilling of new wells and enabling the sharing of water to protect rainfed crops in crucial stages of crop growth.[59] The innovation that involved laying out a pipeline network for irrigating rainfed crops provided critical irrigation at the crucial stages of crop growth not only saving crops but also increasing productivity.[2,28]

Such initiatives which involve water sharing between those having water resources (well-owners) and those without water resources (non-well owners) is not easy and involves a great amount of hard work, which not only addresses water management but also fairness in access.[59] Social regulation and water sharing initiatives have been successfully piloted in small patches/ areas in these pilot villages, but they did not cover entire villages.

To address the issues related to over-exploitation of groundwater and failure of rainfed crops and also for the need to manage the groundwater resources in a sustainable way, a study[10] stressed

on the need to take up innovations in agriculture sector with the collaboration of various actors with differing capacities and expertise including academic community, NGOs, Government.

Conclusion

Rainfed crops are very important for India and other developing countries. The lion's share of global food and other agriculture needs are met by rainfed crops. Food grains for the poor in developing countries are grown in large quantities from rainfed areas. In India, rainfed agriculture provides employment to over 60% of the population and rainfed crops contribute substantially to the country's GDP.

Farmers who grow rainfed crops are mostly small and poor;[74] rainfed crops and rainfed agriculture are their main livelihood. Due to climate change, rainfall variations and recurring droughts in recent years, rainfed agriculture is becoming a difficult proposition for farmers. This situation is forcing small, marginal farmers to leave agriculture and migrate to other areas in pursuit of their livelihoods and there is a dire need to protect such a huge natural livelihood base of these resource poor farmers. It requires additional effort to enable resource poor farmers to make efficient use of available resources and also to improve the productivity of such resources. In this context, sustainable use of groundwater and protection of rainfed crops have become critical concerns. Indeed, there are small scale innovations in this direction which need to be strengthened and expanded into other areas. Community and policy level initiatives are required to achieve the objectives of sustainability and equitable usage of natural resources.

Availability of technology, government subsidies, easy access to credit, etc. have contributed to indiscriminate usage of groundwater. This exploitation has increased exponentially over the past few years and many parts of the country have been identified as critical areas. As per Ministry of Statistics and Program Implementation (MoSPI), Government of India, groundwater sources increased extremely over time, from 28.7% in 1950's to 62.4% in 2012-13. But as stated by a study,[75] most parts of India are still water stressed with 52% of the cropped area still remaining without any irrigation and some parts experiencing chronic stress. The root cause of the problem lies in the inability of people to understand groundwater as a common property. Therefore, both at community and policy levels, restrictions and norms should be enforced, such that, the use of groundwater should be judicious and equitable.

The impact of technology on resource utilization is enormous, but in the case of groundwater usage, the invention and use of pumping technology has spurred groundwater extraction beyond the limits of sustainable use of resources. The exercise of unlimited personal freedom in utilizing the common resource is proving to be a curse in many areas. The reasons for depletion of resources are many and intertwined. Groundwater use and determining priorities are complex issues that require collective decisions. In addition to the role of the state and civil society, community participation is critical for collective decision-making. Building capacities of the communities to understand the basic problems, and integrating technical aspects without ignoring social issues is crucial in ensuring sustainable groundwater use.

For capitalizing the benefits accrued from already implemented programmes in rainfed villages, there should be some concerted and coordinated efforts between the community and line departments in government (Ex: Department of Agriculture, Department of Groundwater Resources, Department of Rural Development, Department of Animal Husbandry, etc.). Such convergence could also include players such as Research Organizations, NGOs and be related to sharing of information related to climate data, groundwater behaviour, seasonal availability of water resources, proper infrastructure and appropriate cropping pattern.

From the experiences, however small scale they may be, it is evident that the sustainable use of resources is possible when developing a village plan that incorporates both social and technical aspects.[76] So far, it is visible from the literature that in the implementation of the programmes, priority has been given to increasing the moisture content in the soil and to augment the water resources, but hardly any practices have been found for the sustainable use of the increased resources.[77] Unless these aspects are included in the planning they

cannot be implemented in the future programmes. This approach could demonstrate pro-activism in managing natural resources for better livelihoods rather than a '*reactive response*' in times of crisis.[78]

The National Institution for Transforming India (NITI Ayog)[79] is recommending R&D in promoting latest technological options in the water sector so as to provide irrigation to all farms (*har khet ko pani*) particularly for rainfed farms with better water use efficiency (*more crop per drop*) and focusing on the sustainable use of limited groundwater sources with active involvement of communities. For solutions that can be easily adopted by the communities such as scaling up successful experiences of protecting rainfed crops using groundwater and developing participatory models to provide critical irrigation to the rainfed farm lands of the village as a unit with the available water resources, more research in the water and agriculture sector is required.

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As this manuscript does not involve the collection or reporting of data from human participants, informed consent was not required for this study. Therefore, no formal informed consent procedures were conducted.

Authors Contribution Statement
First author (Corresponding author)
Conducted extensive exploration of the literature relevant to the topic and prepared initial draft of manuscript.

Second author
Reviewed the draft, provided critical feedback and contributed to improving the clarity, overall quality and connectedness of the manuscript.

Third and fourth authors
Reviewed thoroughly the manuscript, offered valuable insights and suggestions to improve it.

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