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Poverty and Sustainability Implications of Groundwater Based Irrigation: Insights from Indian Experience

A. Suresh[1] and S.S Raju[2]

[1]Division of Agricultural Economics, Indian Agricultural Research Institute Pusa, New Delhi-110 012, INDIA

[2]National Centre for Agricultural Economics and Policy Research, DPS Marg, Pusa, New Delhi-110 012, INDIA

Corresponding author: sureshcswri@gmail.com

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Abstract

Groundwater has become the main source of irrigation occupying more than 60 % of total irrigated area in India. While the fast development of groundwater based irrigation has helped to improve the livelihood security of rural population and reduce the poverty; it was at the cost of high level of energy intensification and negative externalities. In this backdrop, this paper estimates empirically the implication of groundwater based irrigation in India on rural poverty and groundwater sustainability. The results establish that a higher share of groundwater based irrigation in total irrigation strengthen the poverty reduction effects of irrigation. However, escaping poverty through unrestricted access to groundwater is not sustainable. Since the property rights on land accords unrestricted access to groundwater, location specific regulations need to be devised for sustainable management of groundwater. Along with this, incentivising rainfed agriculture through price policies and market opportunities; and promotion of watershed based agricultural planning are critical for sustainable agricultural development.

Keywords: Groundwater irrigation; poverty; sustainability; India

Development of irrigation has been considered as one among the major strategies to improve the agricultural production, notably food crops, and to reduce the rural poverty in India. Following this strategy, huge flow of investment has been provided from the start of planned development for creation of irrigation potential. The cumulative investment on irrigation development from the first five year plan in 1951 to the eleventh plan ended on 2012 amounted to ₹ 34.8 trillion, at 1993-94 prices (GoI, 2010). Consequently, the net area under irrigation expanded from 20.85 million ha in 1950-51 to 63.26 million hectares (mha) in 2009-10 (GoI, 2011). Correspondingly, the share of the net irrigated area as a percentage of net cropped area has increased from 17.5 to 44.6 % during the same period.

Excessive dependence on groundwater

In the initial five year plans, the focus was on development of major and medium irrigation projects depending on surface water. However, in later years the focus shifted to development of minor irrigation.

The ultimate irrigation potential of the country is estimated to be about 140 million hectares comprising of 58.5 mha from major and medium irrigation sources and 81.5 m ha from minor irrigation sources. About 79% (64.1 m ha) of the minor irrigation potential is anticipated to be groundwater based. It is observed that by the end of the fifth five year plan (1975), the total irrigation potential in India was 52.0 mha, of which the share of groundwater based irrigated area accounted for 36 %. During the sixth to tenth five year plans an irrigation potential of 71.3 mha was additionally created. Of this, the groundwater based irrigation accounted for about two third share, thereby raising the overall share of groundwater based irrigation potential in total irrigation potential created up to tenth plan to 54% (GoI, 2010). This fast development of groundwater based irrigation has made significant impact on the resource use, agricultural productivity and ground water sustainability (Table 1).

Table 1: Trend in irrigation, associated usage of inputs and value of output in Indian agriculture, 1970-2010

S. N.	Variable	1970-71	1980-81	1990-91	2000-01	2009-10
1.	Net cropped area (Million ha)	140.9	140.3	143.0	141.3	140.0
2.	Net irrigated area as per cent of net cropped area (%)	22.1	27.6	33.6	39.1	45.2
3.	Cropping intensity (%)	117.7	123.1	129.9	131.1	137.3
4.	Area irrigated through groundwater resources (Million ha)	11.9	18.3	24.7	33.3	39.0
5.	Groundwater irrigated area in total irrigated area (%)	38.3	47.3	51.4	60.3	61.7
6.	Fertilizer consumption in agriculture (nutrient NPK, kg/ha)	13.1	32.0	67.6	90.1	137.8
7.	Electricity consumption for agriculture ('000 GWh)	-	17.8	50.3	84.7	119.5
8.	Share of agriculture in total electricity consumption (%)	-	18.6	26.4	26.8	21.0
9.	Diesel consumption for agriculture (million tonnes)	-	0.8	2.0	3.1	4.5
11.	Share of agriculture in total diesel consumption (%)	-	8.0	9.3	8.1	7.5
12.	Value of output from agriculture (₹ '000/hectare) (at 2004-05 prices)	12.8	15.2	18.6	23.3	27.3

Data source: Computed from Agricultural Statistics at a Glance (GoI), various issues; Ministry of Water Resources, Government of India; National Accounts Statistics, Central Statistical Organisation, Government of India, New Delhi; Various issues of Energy, Centre for Monitoring Indian Economy.

Table 1 indicates that the irrigation development is associated with an increase in the cropping intensity and use of chemical fertilizers. Coupled with the increase in the share of ground water based irrigation in total irrigation, the share of energy inputs in agriculture has also increased. This is quite visible in the case of electricity and diesel. During 1980-81 to 2009-10, there was about six fold increase in the use of electricity and close to fivefold increase in the use of diesel for agricultural purposes. Such an input intensification has contributed significantly towards doubling the value of output in agricultural sector during the period. Nevertheless, this is marked by significant variations across states (Table 2). One important feature is that the stage of groundwater development has reached alarming level in many states, with serious negative externalities. It is noteworthy that the Central Ground Water Board of Ministry of Water Resources, Government of India (2011a) has classified more than 60 % of total assessment units in Haryana and Punjab under the critical and over-exploited category.

Irrigation development and poverty reduction

Irrigation development results in significant social outcomes of poverty reduction. Reviewing vast

Table 2. Irrigation development and associated variables, across states, 2009-10

State	Area under irrigation (%)	Cropping Intensity (%)	Fertilizer (kg NPK/ha)	Share of ground water Irrigation (%)	Electricity consumption for agricultural purpose (%)	Poverty (%)	Value of output from agriculture*	Stage of ground water development**
Andhra Pradesh	42.2	125.7	225.7	54.2	31.5	21.1	43.9	45
Bihar	63.7	140.5	165.6	69.0	13.1	53.5	34.0	39
Gujarat	42.1	108.1	147.2	77.0	25.7	23.0	29.9	76
Haryana	86.5	178.9	209.9	58.2	40.3	20.1	57.7	109
Himachal Pradesh	19.9	171.9	54.8	17.4	0.6	9.5	63.5	30
Karnataka	32.6	123.7	159.6	49.5	34.2	23.6	33.3	70
Kerala	18.6	128.4	95.9	37.3	1.9	12.0	65.7	47
Madhya Pradesh	46.0	143.0	81.4	67.8	26.8	36.7	25.2	48
Maharashtra	18.7	129.9	135.3	66.7	17.0	24.5	30.8	48
Odisha	39.1	163.4	57.6	19.7	1.2	37.0	33.8	18
Punjab	98.0	189.4	237.1	72.6	33.5	15.9	69.7	145
Rajasthan	34.5	128.1	48.3	74.2	39.4	24.8	14.9	125
Tamil Nadu	58.5	113.9	205.8	55.7	20.7	17.1	46.2	85
Uttar Pradesh	81.1	149.3	171.0	78.9	17.6	37.7	47.8	70
West Bengal	59.2	181.3	168.6	0.0	4.2	26.7	84.0	42

Note:*Rs. 000/ha, 2004-05 prices

** indicates the percentage of critical and over-exploited blocks for groundwater as a percentage of total assessed blocks.

Data Sources: Agricultural Statistics at a Glance,2013,GoI; National Accounts Statistics, Central Statistical Organisation, GoI, New Delhi; Central Ground Water Board, Ministry of Water Resources, GoI; Planning Commission, GoI.

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number of literature on the irrigation and poverty in Asian context, Hussain and Hanjra (2004) noted that there are strong linkages between irrigation and poverty reduction, both directly and indirectly. The direct linkages include higher yield, reduced risk, and higher and year round farm and non-farm employment. Chambers *et al.,* (1987) argued that access to basic productive resource like water is central to rural poverty alleviation. It enables attainment of higher yields while reducing the risk (Shah, 1993; Moench, 2003). This is particularly so in cases where other modes of irrigation are absent. However, marginal returns attained through increased use of groundwater based irrigation may fall short of additional costs in cases of severe groundwater depletion, and has inter- and intra-generational equity implications, notably in dry and hard rock regions (Nagaraj and Chandrakanth, 1995), where conservation of water is critical in ensuring long term agricultural growth. Area expansion under water intensive crops like paddy, sugarcane and vegetables is prevalent even in water scarce areas. The nature of property rights over the land provides unrestricted access to the owners to extract the ground water from the piece of land, and thus favours groundwater over-extraction. Besides the critical role in increasing production, the groundwater also serves the purpose of stabilisation role at against variability in water crises (Ranganathan and Palanisamy, 2004). Gemma and Tsur (2007) estimated this stabilisation value of groundwater to be more than one forth of total value of groundwater in Coimbatore district of South India. In an effort to extract water sufficient to cultivate most profitable crops, farmers resort to competitive deepening of wells. Increasing rates of failure of tube wells has been noticed in many rainfed regions, and have rendered large areas under unsafe category as far as potential for expansion of groundwater based irrigation is concerned (Kumar 2003). In a study on the impact of ground water over-extraction and quality deterioration in the state of Tamil Nadu in India, Janakarajan and Moench (2006) noted that the competitive deepening creates a new kind of inequity among well owners and between well-owning and non-well-owning farmers. In the above context this paper is undertaken with the objective of empirically estimating the poverty and sustainability implications of the groundwater based irrigation development in India.

Materials and Methods

The economic impact of the ground water irrigation in India is generally explored by using primary data collected from farm level or secondary data from sub-national level. While the farm level data helps to provide insights into the micro-level socio-economic implications, it often fails to account for the broader agro-ecologic differences. In addition recommendations based on such studies have a lacuna of lacking the necessary macro perspective needed to policy formulation. On the other hand, studies based on sub-national aggregation units (states, as far as India is concerned) conceals much larger variations due to the higher scale of aggregation. Moreover, the number of major states in India in which groundwater based irrigation is widespread is less than one and a half dozen; and therefore is not sufficient to provide a degree of freedom sufficient enough for econometric treatment using cross-sectional data. Therefore, a level of aggregation which falls in between would be more suitable to study the impacts with a sufficient level off aggregation and variation. Districts constitute the basic administrative units within the states, and most of the relevant secondary information regarding agriculture is collected at district level. On these premises district level data was used for the analysis.

Two separate regressions analyses have been used for estimating the relationship. The first regression was undertaken to examine the poverty implications of the groundwater based irrigation, using rural poverty as the dependent variable. Poverty estimates are the head-count ratio of number of people living below the poverty line arrived at based on the expenditure level for prescribed daily calorific food intake. The specific model used for the estimation is provided below:

Poverty = f(fertilizer usage, net irrigated area, share of groundwater irrigated area in net irrigated area, livestock density, average size of operational holding, population density, rural literacy rate, rural wage rate, dummy variable for agro-climate, interaction between total irrigation and the share of groundwater based irrigation in it) ... (1)

It is postulated that the factors that directly influence agricultural productivity like fertilizer usage, and irrigation would have negative influence on poverty through increased agricultural production (Fan *et al*., 2000; Bhattarai and Narayanamoorthy, 2003). It is well documented that agricultural production exerts significant influence on poverty reduction (Datt and Ravallion, 1998; Irz *et al*., 2002). Since the groundwater irrigation helps farmers to extract water subjected to the capital availability and stock of water at a particular point of time, it provides farmers larger control on water usage, and contributes to higher agricultural productivity, and thereby reducing poverty. The extent of groundwater based irrigation has been captured by the percentage share of groundwater irrigated area in net irrigated area. One of the important income sources for farmers in the rural areas is livestock farming. It is expected that larger holdings of livestock would have dampening effect on rural poverty. The stockings of livestock have been captured by livestock density measured as adult cattle units per net cropped area. The major institutional variables included in the model were rural literacy rate, agricultural wage rates (captured by mean agricultural wage for unskilled male labourers), and average size of operational holdings. Based on literature, all these variables were hypothesised to influence the rural poverty negatively (Bhattarai and Narayanamoorthy, 2003). The model also involves a variable denoting demography, represented by population density. However, the sign of this variable is ambiguous as high population density may influence the process of agricultural intensification (Binswanger and McIntire, 1987), thereby reducing rural poverty through increased farm income. On the otherhand, it may increase the rural poverty through increased competition for productive resources. Also included in the model were a variable for capturing the interaction effect of net irrigation and groundwater usage, and a dummy variable to account for agro-climates (0 for rainfed districts and 1 for irrigated districts).

The second regression analysis was undertaken to examine the sustainability implications of the groundwater based irrigation. The sustainability of groundwater was conceptualised to be captured through the availability of ground water for future irrigation normalised by the net cropped area. The Central Groundwater Board under the Ministry of Water Resources provides data regarding various aspects of groundwater including its potential availability, annual withdrawal, replenishment and future availability. The district level statistics regarding same is published by the board at certain interval. Availability of groundwater for irrigation purpose measured as hectare metre for one thousand hectare of net cropped area was considered as the indicator variable for capturing the sustainability. The specific model used in the analysis is provided below:

Groundwater sustainability = f (net irrigated area, share of groundwater irrigated area in net irrigated area, population density, rural literacy, agroclimate, average size of operational holding, rural poverty, rainfall, dummy variable for agro-climates) ...(2)

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It was anticipated that the net irrigated area would have a negative impact on the sustainability of groundwater for future irrigation; the share of groundwater irrigated area in net irrigated area would strengthen this negative relation. This expectation was based on several factors such as land and water degradation as in many irrigated regions in India (Singh, 2000). The population density was expected to have a negative sign on sustainability as higher population density would entail extraction of more water for irrigation as well as for domestic purpose (Sharma *et al*., 2006). In case of size of average operational holding for the district, it is implied that levels of holding would serve as an indicator of capital availability with the farmers. In the Indian rural settings, size of holding is the indicator of the asset base and therefore capital status. Higher level of capital ownership enables them to acquire groundwater based irrigation structures. Therefore negative sign was expected for the variable towards the sustainability. It is logical to expect that higher level of rainfall would facilitate recharge of ground water and thereby larger quantity of ground water for future irrigation. The signs of two variables, viz. rural literacy and poverty are ambiguous. As far as poverty is concerned, it is both a determinant of ground water based irrigation development as well as its outcome. Poverty excludes many farmers from accessing groundwater, as installation of tube wells is capital intensive. On the other hand, groundwater based irrigation helps to reduce the level of poverty. In case of literacy, it would have positive influence on the adoption of efficient water management practices and thereby contributing towards the sustainability of the system. On the contrary, by being a major determinant of adoption of modern agricultural practices, higher level of literacy would lead to greater extraction of groundwater, thereby affecting the sustainability negatively.

The data on the variables were collected from various secondary sources, broadly corresponding to the year 2004-05. Indian Council of Agricultural Research has identified five broad agro-ecosystems over entire India, viz. arid, coastal, hill and mountainous, irrigated, and rainfed systems, and have classified districts accordingly. For analytical purposes, only those districts falling under the arid, rainfed and irrigated systems were considered. The districts falling under the coastal and hill and mountainous region were not included in the analysis as the agricultural practices in these regions are unique in their own terms. Moreover, for these regions a sharp differentiation with respect to water as in the case of irrigated and rainfed system is not relevant. Since the arid and rainfed agro-ecosystems share some common features as far as the water availability is concerned, the districts falling under both of them are grouped into a single category (and named as rainfed systems). The multiple linear regression was selected based on the best fit estimated by using alternate models including semi-log and double log models.

Results and Discussion

Table 3 provides the means of different variables in rainfed and irrigated agro-ecosystem. The irrigated system depicted significantly higher fertilizer usage, net irrigated area, share of groundwater irrigated area in net irrigated area, livestock density, and wage rates; whereas, the rainfed system possessed significantly higher level of average size of holding and groundwater availability for future irrigation. Interestingly, the level of poverty, though was marginally higher in case of the rainfed regions, did not turn out to be statistically significant. This could be due to the fact that though the poverty in absolute number might be larger in case of the rainfed regions, some of the dominantly irrigated regions of India have large concentrations of rural poverty.

Before attempting the regression analyses, the correlations of poverty and availability of groundwater for irrigation with other socio-economic and institutional variables were estimated (Table 4). It indicated that the rural poverty was negatively and significantly correlated with fertilizer usage, irrigation, livestock density, average size of operational holding, groundwater usage and wage rate. On the other hand, the availability of groundwater for future irrigation was positively correlated with the rainfall and rural poverty, and negatively with fertilizer usage, net irrigated area, current usage of groundwater, literacy and average size of operational holding.

Table 3: Comparison of means of the selected variables across rainfed and irrigated regions

Variable	Rainfed system	Irrigated system	t value
Fertilizer usage (kg/ha)	89.9	234.6	-14.9**
Net irrigated area (%)	33.3	78.5	-22.0**
Rural poverty (%)	31.5	29.3	1.1
Livestock density (no/ km^2)	132.1	180.0	-4.9**
Operational size of holding (ha)	1.9	1.6	1.9*
Share of groundwater irrigated area in net irrigated area (%)	29.8	71.6	-13.7**
Groundwater availability for future irrigation (ha m/ 000 ha/ year)	169.1	91.5	3.4**
Wage rate (Rs/ day)	54.5	85.5	-10.0**
Population Density (No/ km^2)	461.4	400.6	1.1
Rural literacy rate (%)	49.5	46.0	2.7**

** and * indicates statistical significance at 1 and 5 %, levels.
Source: Computed by the authors

Table 4: Bivariate correlation between the different variables over the entire sample

Variables	Rural poverty	Ground water availability for future irrigation
Fertilizer usage (kg/ha)	-0.30**	-0.28**
Net irrigated area (%)	-0.24**	-0.18**
Rainfall (mm/ year)	0.36**	0.62**
Rural poverty (%)	1.00	0.36**
Livestock density (no/ km^2)	0.18**	0.10
Average size of operation holding (ha)	-0.15**	-0.30**
Share of groundwater in net irrigated area (%)	-0.16**	-0.16**
Groundwater availability for future irrigation (ha m/ 000 ha/ year)	0.36**	1.00
Wage rate (Rs/day)	-0.46**	-0.60**
Population density (no/km^2)	0.10*	-0.04
Rural literacy rate (%)	-0.39**	-0.17**

**, and * indicate the statistical significance at 1 and 10 per cent levels, respectively
Source: Calculated by the authors

The regression analyses revealed that, as expected, the percentage area under irrigation had significant negative effect on the rural poverty; and, the share of groundwater based irrigation in total irrigation strengthened the poverty reduction effects of irrigation (Table 5). This strengthening role of groundwater

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based irrigation needs to be tapped judiciously so as to achieve the maximum level of social outcome on a sustainable basis. This strengthening role of groundwater based irrigation might be due to many factors including the better management and timeliness associated with the groundwater based irrigation systems. While the effectiveness of irrigation in reducing the rural poverty has already been established; the strengthening role of the groundwater irrigation warrants greater attention. Thus, there could be an interaction effect between the net irrigated area and the share of groundwater based irrigation in it. As expected, the variable used to capture this interaction effect turned out to be significantly positive. The level of fertilizer usage, as expected, had a negative influence on poverty reduction, probably through its positive role in boosting agricultural productivity. The rural literacy, wage rate and livestock density had significant negative influence on poverty reduction. It is strikingly noticeable that the dummy variable for agro-climates did not turn out to be significant, highlighting the fact that irrespective of the agro-climates, it is the socio-economic and institutional settings that influence the poverty levels. These points to the fact that the poverty reduction warrants targeted approach.

Table 5: Regression estimates of the determinants of the rural poverty and sustainability of groundwater irrigation

Variables	Dependent variable: Rural Poverty(%)		Dependent variable: Future water availability (ha m/ 000 ha/ year)	
	Coefficient	Standard error	Coefficient	Standard error
Constant	105.1***	11.42	132.16**	55.19
Fertilizer usage (kg/ ha)	-0.16***	0.045	-	-
Net irrigated area (%)	-0.33**	0.12	-0.03	0.48
Share of groundwater irrigated area in net irrigated area (%)	-0.12**	0.06	-0.97***	0.34
Interaction effect (net irrigated area and groundwater share)	0.002***	0.001	-	-
Rainfall (mm)	-	-	0.10***	0.03
Rural poverty (%)	-	-	2.24***	0.54
Livestock density (ACU/ km^2)	-0.06**	0.03	-	-
Holding size (ha)	-3.07*	1.744	-25.45***	6.22
Population density (No/ km^2)	0.004	0.004	-0.05**	0.02
Rural literacy (%)	-0.40***	0.15	-1.76**	0.77
Dummy variable (0 for rainfed, 1 otherwise)	13.6	10.61	-30.41	32.96
Rural wage rate (Rs/ day)	-0.37***	0.098	-	-
R^2	0.51		0.42	
N	112		248	
F	10.82***		21.26***	

Notes: ***, ** and * indicates statistical significance at 1, 5 and 10 % levels, respectively.
Source: Estimated by the authors

In the second regression, the sustainability of the groundwater based irrigation was examined. One of the major determinants of groundwater availability for future could be the hydrological aspects. Due to the obvious limitations, this variable was not considered in the analysis. It was observed that given the hydrological aspects, level of current usage of the groundwater and other socio-economic factors exerted significant role in determining future availability of groundwater. The results indicated that the current level of irrigation *per-se* was not a determinant of availability of groundwater for future irrigation; rather, it is negatively influenced by the extent of groundwater based irrigation in the total irrigation. As expected, rainfall had a significant positive effect. The results revealed a positive role of poverty in groundwater sustainability. However, this positive impact needs to be interpreted with care, as it points to the exclusion of the relatively less endowed farmers from accessing ground water. This was a direct effect of the high level of capital expenditure required for installing groundwater extracting units. Average size of holding, by being proxy to the capital assets of the rural households, exerted a significant negative influence on the future availability of groundwater. Population density had a significant negative influence on groundwater sustainability.

Conclusion and implications

The study provides some important conclusions and policy implications. It has turned out that the fertilizer usage per hectare of net cropped area, rural wage rate, livestock density, and share of groundwater in total irrigated area are significantly higher in the case of irrigated agro-ecosystem compared to rainfed system. On the other hand, the rainfed agro-ecosystem possesses larger size of operational holding and groundwater availability for future irrigation. In the case of rural literacy, the rainfed regions are marginally better than the irrigated regions. Also, in case of rural poverty, there was no statistically significant difference between rainfed and irrigated regions, pointing to the significance of the underlying social, economic and institutional factors responsible for poverty.

Rural poverty is significantly negatively correlated with fertilizer usage, net irrigated area, share of groundwater irrigated area in net irrigated area, average size of operational holding, wage rate and literacy rate. As far as the sustainability of the ground water usage is concerned, it is negatively correlated with the current level of irrigation and the share of groundwater irrigation in it; fertilizer usage; size of operational holding; wage rate and rural literacy.

It has turned out that the higher share of groundwater based irrigation in net irrigation strengthens the poverty reduction effects of irrigation. This has facilitated large scale extraction of groundwater resources even in hard-rock peninsular regions of India. The resultant increase in agricultural production and farm income has helped reduction of rural poverty. However, over extraction of groundwater dampens the sustainability of the very production system itself. And, this may further accentuate in the time to come due to the climate change (Kalra *et al*., 2007). Therefore, escaping poverty through unrestricted access to groundwater is not sustainable and may lead to poverty trap through competitive deepening and increased well failures, as has already been noted in some localities. The technology policy for rainfed lands needs to consider the location feature in terms of comparative advantage of natural resource base, and strongly discourage groundwater extraction over and above the recharge (World Bank, 2010). Rather than the strategy of yield enhancement through high input agriculture, the rainfed system needs to focus on yield enhancement though natural resource conservation, notably land and water. Since the property rights in case of groundwater favours unlimited access to groundwater, regulations emerge as the prominent alternative instrument in managing groundwater. Location specific regulations need to be devised towards this end. Groundwater recharge through rainwater harvesting and improvement in the water use efficiency through micro irrigation systems like drip and sprinkler irrigation needs further attention in the rainfed regions. In this context watershed based agricultural development has been proved to be beneficial in raising rural livelihood while ensuring the sustainability of the production system (Kerr, 2000). Rainwater harvesting needs to be an essential component of the approach to augment water availability and crop productivity (Liu *et al*., 2005). Another option for

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limiting the unsustainable extraction is to incentivise rainfed agriculture through price policies and market opportunities.

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