INITIATIVE ON
Transforming Agrifood Systems in South Asia

Co-developing cropping scenarios for climate resilience and groundwater sustainability

A PARTICIPATORY SCENARIO DEVELOPMENT METHOD FOR NALANDA, BIHAR

Research note 16
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ABOUT THIS NOTE

The One CGIAR Initiative TAFSSA (Transforming Agrifood Systems of South Asia) prioritizes interdisciplinary farm and landscape level research including an assessment of groundwater availability and sustainable use under scenarios of climate change scenarios and crop diversification. To integrate groundwater and cropping system modelling participatory practices were used to identify potential cropping scenarios in Nalanda, Bihar, through bottom-up exercise in a one-day workshop. This brief presents the methods and findings of this scenario development workshop.

KEY STUDY FINDINGS

1. The research describes and uses a participatory qualitative method for developing and assessing future cropping scenarios
2. Eight cropping scenarios were developed with four types of stakeholders under different conditions of groundwater availability and climate risk
3. Potential trade-offs were identified between climate resilience, groundwater sustainability and feasibility (income and household food security) under alternative cropping patterns

INTRODUCTION

Work Package 2 of the One CGIAR Initiative TAFSSA partially focuses on assessing groundwater resources using numerical modeling to understand groundwater behavior in response to future climate and agronomic management scenarios, including the impact of crop diversification in Bihar, India (Mizan S et.al. 2023). To enhance the realism and potential effectiveness of computer simulations concerning climate change and crop modeling, it is advisable to collaborate with farmers and key stakeholders in the development of scenarios. This collaborative approach aims to incorporate an understanding of the potential constraints, risks, and opportunities that stakeholders may face into the simulations. This process may potentially improve the relevance and significance of the simulations, offering insights for future research efforts.

CIMMYT | IFPRI International Food Policy Research Institute | IRRI International Rice Research Institute | IWMI International Water Management Institute | CIP International Potato Center

We used a bottom-up, participatory scenario development exercise to identify likely cropping system scenarios to inform groundwater modelling and to ensure they are socially inclusive and nutritionally sensitive without over-exploiting nature groundwater resources in either current or future climates. A bottom-up approach was taken to ensure the scenarios identified are realistic and align realistically with the decision-making of farmers and other key stakeholders. TAFFSA operates in research 'learning locations' akin to living laboratories across South Asia and this modelling uses the Bihar state district of Nalanda as a case study.

METHODOLOGY

A structured multi-stakeholder workshop was conducted in Patna, Bihar (12th October 2013) to implement this participatory approach. The engagement was designed with a lean timeframe to ensure more inclusive access to the engagement for farmers (particularly for women farmers) and other governance stakeholders. Scenario planning was facilitated using the intuitive logic method (Wack, 1985) which uses qualitative narrative scenario techniques based on implicit knowledge, experience and insights of stakeholders participating in the process (Kosow & Gaßner, 2008), with a scenario analysis methodology modified from Keseru et al. (2021). The following stepwise logic was implemented:

1. **Scenario field identification**: The purpose of the scenarios, key issues being addressed, and the geographical scope of the scenarios emerged from core enquiries of associated modeling study with a focus on groundwater behaviour under likely future climate and groundwater scenarios and increased crop diversification in terms of the sustainable management of groundwater. The objectives and desired outcomes of the analysis were to identify potential alternative cropping patterns that are likely to increase resilience to climate risks while encouraging the sustainable use of groundwater resources, and also fulfilling farmer priorities of productivity, profitability and household food security.

2. **Identification of key factors**: This step involves gaining insight on the current situation and identifying the key driving forces influencing farmers' decision making, i.e. political, economic, social, technological, and ecological factors.

3. **Analysis of key factors for unpredictability**: Since changing climatic and groundwater resource patterns were the two key variables that are being targeted for study, current trends in these variables, as observed by stakeholders over the past ten years, were documented to frame potential future scenarios.

4. **Scenario framing with stakeholders**: Potential outcomes which were identified after considering the trends locally observed in climate and groundwater variables formed the basis of scenarios developed by groups of stakeholders.

5. **Evaluating the scenarios**: Criteria for evaluation were developed based on the desired outcomes of the study, the feasibility of key decision-making factors, and constraints identified in shifting from current farming systems to potential future farm management. The future scenarios were prioritized using qualitative criteria and will subsequently be used to evaluate their potential resilience and sustainability. In this analysis the focus was on stakeholder values and decision-making factors to assess the socioeconomic and institutional feasibility of proposed cropping system scenarios.

Stakeholder groups:
Workshop participants comprised four groups:

- Policymakers and senior national agricultural research system (NARS) managers – 6
- Relevant civil society members (e.g. progressive farmers, district officials, local governance, members of Krishi Vigyan Kendra - KVK (a government-backed farmer support network) – 10
- Scientists – 8
- Women farmers 7

Workshop sessions:
The workshop comprised three sessions of focussed group discussions with each of the four stakeholder groups separately. Women farmers were deliberately engaged with as a separate group to ensure their opinions were less influenced by perceptions of inequality from male farmers and/or local government officials. For the three sessions the following structure of engagement was adopted across all four groups to facilitate and guide discussions, which were otherwise unscripted. A detailed outline of the workshop protocol is shown in the annex.

1. Understanding current agricultural patterns and drivers (cropping and agronomic practices)

- What crops are currently grown/promoted/recommended in each of the cropping seasons in Nalanda, Bihar?
- What are the factors driving these cropping decisions (or the decision not to crop) – why were these crops preferred or chosen?
- Were there any challenges or constraints to growing the preferred crops in the current resource, climatic and economic environment? If so, what are these?

2. Perceived changes in key agricultural practices and climatic patterns

- Have there been any changes in common agricultural practices (irrigation, tillage, residue management) in the Nalanda District in the last ten years?
- Have there been any changes in weather patterns in the region in the last ten years?

3. Agricultural responses to future climatic and groundwater scenarios responded to by participants:

- If you could make ANY changes in crops and agricultural practices in response to changing climatic patterns, what would you change from the current cropping patterns or practices: a) with groundwater unlimited; b) with restricted use of groundwater?

- For each of these changes suggested, do you foresee any constraints or challenges in making these changes to shift to the new patterns: a) with groundwater unlimited; b) with restricted groundwater?

RESULTS:

Overview of observed engagement dynamic

Senior policy and management stakeholders: This group identified high-level challenges and solutions. They were very aware of the key issues facing farmers and their solutions incorporated both hydrologic and agronomic knowledge. They grasped the activities quickly and readily summarized solutions. There was strong agreement between group members.

Scientists: Much of their knowledge emerged from intensive experience with agronomic and hydrological data and experiments. There was general agreement on most issues.

Civil society: Having both scientific knowledge and field understanding, KVK scientists in this group suggested a highly diverse range of alternative cropping systems. Other civil society participants, such as those from the WASH (Water, Sanitation and Hygiene) sector, provided important insights on community level water-access and climate challenges. Progressive farmers in the group had a more practiced and grounded understanding of the on-ground consequences of drought, increasing climate variability and climate related risks, in contrast to the KVK scientists who were more theoretical.

Senior policy and management discussion group

Scientists' discussion group

Civil society discussion group

Women farmers discussion group

Photo credits: Aaroz Raza, IWMI

Women farmers: These farmers made cropping system decisions based on their practical knowledge and familiarity with certain crops for given seasons. Their knowledge of different innovative and improved agronomic management practices (e.g., using improved seed varieties) was limited. The group recognized the value of cultivating crops could be both consumed within the household and sold to generate income.

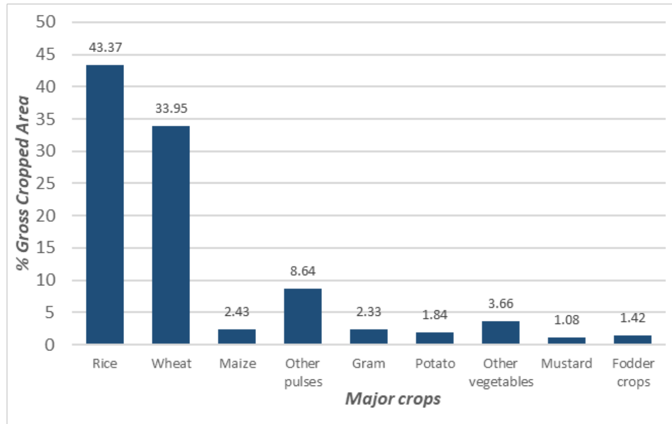

Figure 1. *Area under major crops in Nalanda district (2020-21). Source: calculated from Land Use Statistics of the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare (MoAFW 2020-21)*

Current cropping scenarios and constraints

To consider options for future cropping changes and be able to evaluate new patterns for feasibility, preference, and sustainability/resilience outcomes, we first sought to understand current cropping patterns in Nalanda District: why they were widespread and what the current challenges are in managing them. The first workshop session focussed on understanding status quo in Nalanda from the perspectives of the different stakeholder groups. Through this we sought to ensure a comprehensive understanding of common decision-making factors determining current cropping patterns.

To position workshop participants' responses more broadly we examined the latest available government data on major crops produced in Nalanda (MoAFW, 2020-21). The area under 'major crops' (i.e. those covering more than 1 % of the gross cropped area, or GCA, in Nalanda) is shown in Figure 1. The cultivation of major crops and specifically rice and wheat, accounts for over 95% of the total land area cropped in Nalanda.

Workshop participants' nominations of the major crops in Nalanda, as shown in Table 1, align well with Government of India data. Participants identified paddy rice and vegetables as the major crops in the summer *kharif* (wet) season, wheat, lentils and other pulses, maize, mustard and vegetables are the main *rabi* (dry) winter season crops, and in the summer *zaed* season maize, mungbean (gram), vegetables and fodder crops are largely grown. Fallow lands and tree-based produce (such as mango and other horticultural crops) are also common. Workshop respondents agreed that crop selection in each season was primarily a consequence of access (or not) to secure irrigation water access. Government of India data (MoAFW, 2020-21) indicates that 45.84% of the total arable area in Nalanda is cropped more than once each year, additionally indicating constraints in irrigation access, as well as potential risks to crops from adverse weather events (e.g. droughts, terminal heat stress, lodging) and/or biotic pests.

Table 1. *Drivers of crop choice and cropping challenges for major crops grown in Nalanda as identified by workshop participants*

Crops	DRIVERS OF CROP CHOICE											
	Cultural factors	Ecological suitability	Input availability						Cost/Profit	Policy/Market incentives	Risk	
Definition	*Staple food, traditional knowledge & familiarity*	*Soil type, local temperature and precipitation patterns*	*water*	*land*	*labour*	*seed*	*credit*	*mechanised equipment*	*input cost, profitability*	*Policy incentive, market demand/incentives*	*Pest*	*Climate*
Monsoon/Kharif												
Paddy	green	green		low land	green	orange	green	green		green		green
Vegetables:	green	orange		high land		orange			green		orange	orange
Winter/Rabi												
Boro Paddy	green		orange		orange	orange				green		
Wheat	green	green			orange	orange			orange	green	orange	orange
Lentils:	green	green							green		orange	orange
Mustard	green	green							green			orange
Maize	green	green	orange		orange			orange	green	green	orange	green
Vegetables:	green		orange		orange	orange			green		orange	orange
Millets	green		less water access									green
Summer/Zaed												
Maize	green	green	orange		orange					green	orange	orange
Mungbean		green										orange
Pigeon Pea									green		orange	
Vegetables	green		orange			orange			green			orange
Fallow lands			no water access						orange			
Agroforestry system			green						green	green		green
Fodder crops		green	green (less water access)							green		
Millets	green		green		orange				green	orange		green

green	Drivers of crop choice
orange	Challenges of cropping
	Indifferent/Not identified as a signicant factor in decision-making

Some of the key drivers identified for crop selection in any season are:

- Cultural factors including traditional knowledge and preferences to consume particular foods.
- Agroecological conditions.
- Likely profitability of crops sold.
- Input availability, especially water, labour and quality seeds.
- Risks from pests and biotic stressors.
- Climate variabilities, including ability to plan seasonal management.
- Labour availability, particularly after migrant labourers depart after the large-scale rice harvests at the end of the monsoon season.
- Water availability constrained due to falling groundwater levels especially during the dry seasons.
- Equitable and widespread access to irrigation water, as determined by the disaggregated nature of farm plots and the limited ownership of pumps and access to groundwater.
- Policy incentives (available for a limited variety of crops).
- Ease and availability of good markets and storage for produce (available for a limited variety of crops).

Paddy rice (grown in the *kharif* season), maize (in the *rabi* season), millets, and horticultural tree crops were considered by workshop participants to be relatively more resilient to climate risks and/or water scarcity. Paddy was considered a less risky crop in the face of untimely rainfall during much of the *kharif* season and although it is affected by prolonged drought conditions, it can be sustained using irrigation, which is generally easier to access in the wet season than at other times.

Paddy was also considered by many participants to be the only suitable crop for (relatively) low-lying fields.

In the *rabi* season wheat is highly vulnerable to terminal heat stress and thus is not suitable for late sowing which frequently occurs as a consequence of rice varieties being transplanted and harvested later in the year, being of long duration, and/or being dried *in situ* in fields. Maize is more heat tolerant than wheat, more water efficient, and higher yielding and is becoming a preferred cash crop across Bihar.

Vegetables are at risk of waterlogging in the *kharif* season, particularly the black clayey soils common in Nalanda district. *Kharif* season vegetables are primarily grown on higher land with good drainage. During the *rabi* season vegetables are at risk of terminal heat stress and again their timely sowing is impeded by the long rice cultivation window. Often winter vegetable plots are separate to those on which paddy is grown in the *kharif* season.

Other crops such as mustard and lentils are highly temperature- and water-sensitive. Climatic risks posed by delayed winter onset and early withdrawal, or untimely rabi season rainfall affect crop production and yield. Millets and horticultural tree crops are more resilient to adverse weather (especially dry conditions) and are grown with little or no access to irrigation water.

Changes in climatic patterns and agricultural practices

Sessions 2 and 3 of the workshop focused on understanding participants' observed changes in climate patterns and their preferences for key agricultural practices in Nalanda. Table 2 shows the observed changes reported by all stakeholder groups. During the kharif season the choice of crops are selected based on their resilience to both dry periods and high-intensity rainfall events, as erratic and extreme rainfall has become more common. During the *rabi* season participants' primary concern is selecting shorter-duration crops which can be sown after a late-harvested rice and harvested before temperatures rise. During the *zaed* season participants preferred those crops which tolerate high temperatures including extended periods of high temperatures.

Table 2. *Key climatic changes in Nalanda in the past ten years as reported by stakeholders*

KHARIF (MONSOON / LATE SUMMER)	Delayed monsoon onset
	Reducing number/duration of rainy days
	Increased intensity rainfall in shorter rainy duration/days
	Increased extreme precipitation events
	Untimely rainfall more frequent in towards end of the season
	Increased incidence of floods and droughts
	Not much change in temperature patterns
RABI (WINTER)	Delayed onset of winter/low temperatures
	Critical reduction in incidence of fog
	Early terminal heat stress/withdrawal of winter
	Shorter winter low temperature growing season
	Not much change in the rainfall pattern during this season
ZAED (EARLY SUMMER)	Early onset - increased duration of high temperatures
	Hotter temperatures

Stakeholders also identified the following changing trends in irrigation water supply and access over the in last ten years:

- Increasing intensity of groundwater extraction and use.

- Groundwater decline: participants identified consistent decline, particularly during low rainfall years (anecdotally tubewell depth has increased from 18.3m (60 feet) to 45.7m (150 feet) in some areas.
- Increased ownership of private tubewells and pumps.
- Declining availability of traditional surface water irrigation sources, largely due to declines in infrastructure and rainfall.
- Irrigation shifting from diesel to electric sources because of increasing electricity subsidies and the availability of separate electric feeders for agriculture pumps: increasing the erratic nature of water supply.
- New technologies, including solar pumps, pipeline-based groundwater irrigation delivery

Participants' observations were again well correlated to data from the Government of India (Figure 2): groundwater is the main source of irrigation in the region (MoAFW 2020-21). With increasing intensity of water use and extraction through private tubewell ownership, declining groundwater levels are expected to continue. Electricity subsidies also incentivize greater groundwater extraction, while electricity rationing and erratic electricity supply (often a consequence of black- or brown-outs) will result in increasing inequity of access to groundwater. Due to declining rainfall and lack of infrastructural upkeep, traditional surface water irrigation and floodwater harvesting systems (*Ahar pynes*) were considered to be less efficient and harvest less water for irrigation. Together these factors indicate the likelihood of increasing irrigation water insecurity and challenges to access in future scenarios, especially under current systems of water management.

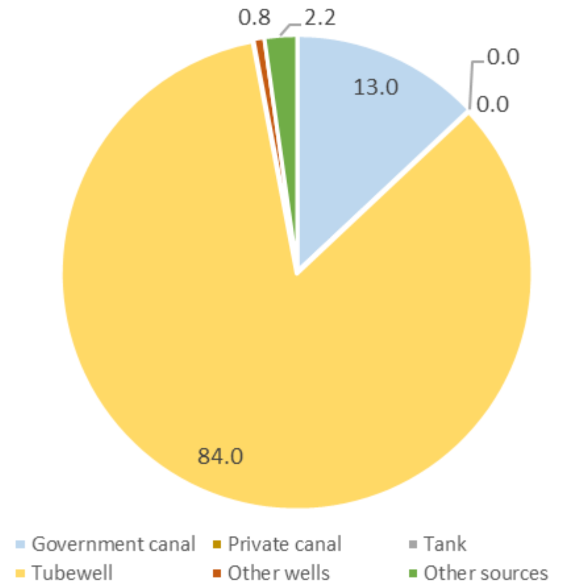

Figure 2. *Percentage of gross irrigated area by different sources of irrigation 2020-21. Source: calculated from Land Use Statistics, Ministry of Agriculture*

Additional insights on irrigation access constraints emerged from the women farmers group:

"As groundwater levels are consistently falling and especially over last two years there has been a severe decline, the demand for submersibles [pumps] has increased in this season to access irrigation for paddy. For those who need to buy water, prices have increased. Since land parcels are scattered even those who own sources of irrigation need to buy water. Many of women farmers [face constraints since they] are tenant farmers with lower decision-making ability about mechanisation and irrigation ownership."

Cropping Scenarios

Environmental conditions in Nalanda, in particular its clay soils, and alluvial aquifer, high groundwater levels, and proximity to surface water streams and waterbodies mean the district is naturally well-endowed with conditions conducive to water storage and management. In suggesting future cropping system scenarios we asked participants to consider scenarios under both plentiful and restricted access to groundwater. These cropping system scenarios are shown in Table 3.

Table 3: *Cropping scenarios under plentiful and limited groundwater (GW) as determined by stakeholders*

Current crops	WITH GW AVAILABILITY				WITHOUT GW AVAILABILITY			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Monsoon/Kharif	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4
Paddy	low duration variety, late sowing/late harvesting	Directly seeded rice, Double transplanted Increased seedlings	Directly seeded rice	early planting with irrigation			Short duration varieties Sowing with monsoon	Short duration / Drought-tolerant / Multi-stress tolerant varieties Sowing late with rainfall
Vegetables:	raised beds and drainage systems along plots	Okra, Ridge Gourd				Okra		
		Maize					Maize	
		Millet				Millet	Millet	
		Blackgram				Blackgram		
						Soyabean		
						Mungbean		
								Fallow
	deepen TW farm ponds (flood management/GW recharge)	Raised Bed Planting			farm ponds for recharge and fishing	line sowing Increased seedlings	Water Harvesting structures Better Irrigation planning	Small water storage Increase irrigation efficiency
	alternate livelihood: fishing in farm ponds						More focus on non-farming incomes	Non-farm income Migration Increased govt support
Winter/Rabi								
Boro Paddy								
Wheat	early wheat	short duration						
Lentils:	masoor				masoor	pulses	pulses	pulses
Mustard		Oilseeds	Oilseeds, mustard	Oilseeds			oilseeds	oilseeds
Maize								
Vegetables:	raised beds	potato and onion raised bed planting				okra, beans		
Millets						barley		
			High remuneration fruits (dragonfruit)					
			Agroforestry/trees	Agroforestry/trees				Agroforestry/trees
								Fodder
		line sowing KNO_3, Boron spray				line sowing Increased Seedligs		
							More focus on non-farming incomes	More focus on non-farming incomes (eg. livestock)
Summer/Zaed								
Maize	heat resistant variety mulching							
Mungbean/Green gram			Pulses	Pulses	More N fertiliser needed to compensate			
Pigeon Pea			Pulses	Pulses				
Vegetables		Japanese Mint Raised Bed Planting						
Fallow lands								
Agroforestry							Integrated farming system	
Fodder crops								
Millets								

	Increased area under
	Reduced (partially or completely) area under
	No change in area mentioned/implied
	Implied reduction

Note: Scenario 1 – Women Farmers, 2 – Local governance, 3 – Scientist, 4- Senior Policy and Management

Under plentiful groundwater conditions there was less diversity in the cropping patterns nominated by stakeholders. These cropping patterns were centered around more water-intensive, high-value crops such as paddy rice, wheat and maize. Where groundwater availability was restricted cropping patterns are more diversified and water-efficient, with larger areas under vegetables, pulses, oilseeds, tree crops and fallowed: here there is a focus on groundwater recharge and management, and a broader diversification of household income which is less reliant on agriculture. However, many of these crops were nominated as being less water intensive are also less resilient to increasing climate variability and production uncertainty. For instance, wheat, mustard, and lentil crops were considered by participants to be sensitive temperature and have a limited (and reducing) growing window in the *rabi* season. Crops such as maize, millets, and pulses were also identified by participants as being less tolerant under intensive rainfall events. Also, as paddy rice is the major staple crop for household food security in Nalanda, diversifying away from paddy is very challenging for rural households.

Arriving at optimal scenarios of cropping systems is a complex and imperfect process as climatic, resource and market uncertainties engender constraints which may be of simultaneously opposing nature; therefore, trade-offs and compromises are required. For instance, increasing incidences of extreme precipitation require crops that can withstand both short-term droughts and high intensity precipitation events. Or cropping systems which reduce groundwater depletion may have lower productivity or incomes for rural households. Table 4 shows the strengths and trade-offs identified by stakeholders for potential cropping system scenarios.

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Table 4: *Strengths and trade-offs of change in cropping and practices proposed in scenarios*

TYPES OF CHANGES	STRENGTHS	TRADEOFFS
Shifting to different varieties *Eg. Short duration, drought-tolerant, heat-resistant, multi-stress tolerant varieties*	Allows for improving climate resilience of existing cropping pattern *(retaining their advantages as staple food crops such as paddy/maize)*	- Availability, access to, and cost of new varieties - Lack of knowledge and awareness of varieties or optimum management strategies and subsequent impacts on yields of new varieties
Shifting to less water intensive crops *Eg. Shifting to vegetables, millets, gram, pulses, oilseeds*	Reduced pressure on groundwater resources – resource sustainability Income benefits from some of these which are high remuneration cash crops	- While being less water-intensive and therefore suitable for low water availability conditions, many of these are less resilient to climatic uncertainties such as sudden intensive precipitation spells/waterlogging, late onset of low temperatures/winters, or early withdrawal of winters. - Market linkages are not yet strong for these crops and may be affected by price fluctuations and supply chain issues
Shifting to less climate sensitive crops *Eg. Shifting to more paddy in wet season , shifting away from wheat, masoor (lentil), mustard*	Reduced risk to climate shocks	- Reducing remunerative crops such as masoor (lentil) and mustard lead to income trade-offs - Increased paddy rice and maize require higher groundwater resource extraction than other crops in the same season (paddy: kharif, maize: rabi and zaed) - Increasing vegetable production can lead to increased market risk as farmers do not have procurement safety nets, lack access to cold storage facilities, value-addition and processing alternatives, leading to intense price fluctuations in local markets
Shifting crop calendars *(early or late sowing/harvesting)*	Allow for improving climate resilience of existing cropping pattern *(retaining their advantages as staple food crops such as paddy/wheat/maize)*	- Late harvesting of paddy rice leads to late sowing of wheat/maize/pulses in subsequent season (rabi) which leads to greater risk of high temperature stress for winter crops during their flowering and harvest periods and therefore reduced yield. Early clearing of paddy fields may affect the quality of rice produced. - Particularly late harvest of crops in one season may mean the field is fallowed in the next season - Early sowing of paddy rice leads to higher reliance on and extraction of groundwater and electricity supply for irrigation if early-season rains are delayed or insufficient
Complementing with sustainable agricultural practices *Eg. Direct seeding, raised beds, water harvesting and management, mulching, no-till*	Improves climate resilience and reduces pressure on water resources	- Requires more awareness and training in practices and technologies - Timely, reliable and affordable access to necessary machinery - Requires policy incentives and subsidies to promote - May have productivity and yield implications
Enhancing input supply and application *eg. Irrigation and fertiliser application*	- Improves productivity. - Can offer climate resilience. - Retention of existing water-demanding staple crops	- Increases pollution and stress on water resources - Decreases soil health - Encourages soil mining and over-extraction of natural resources (eg. removing mungbean from rotation reduces nitrogen fixing potential and needs more N fertiliser to offset crop shift)
Farm and livelihood diversification *eg. agroforestry (horticulture tree crops), livestock, fisheries, migration, non-farm*	Offsets risks in agricultural income from climate, resource and market uncertainties	- Requires policy support, availability of alternate non-farm jobs, development of non-farm sector in the region - May reduce labour required, or require differently skilled labour

Evaluating potential cropping system scenarios

Based on the strengths and trade-offs of different cropping systems and the climate changes reported and discussed in the stakeholder workshop, the cropping system scenarios identified have been examined considering both their feasibility (supportive decision drivers) and impact (climate resilience and resource sustainability). Criteria based on the following information and assumptions were used to evaluate and prioritise the scenarios.

Feasibility criteria: For evaluating feasibility we used the TELOS framework that assesses feasibility on the following areas – Technical, Economic, Legal, Operational, Schedule – which is a method used in project feasibility assessments (Wetherbe, 1984; Mukherjee, 2017). The TELOS-CB framework adds cultural and behavioural aspects to the feasibility criteria (Rashidi et.al. 2022) . Here we consider feasibility in terms of farmers' willingness or interest in shifting to new cropping systems. The stakeholder-identified drivers of crop and cropping system selection (except climatic risk drivers since the scenarios have been developed to respond to this) were aligned with the feasibility criteria as shown in Table 5. We then used the responses in Table 1 to prioritise feasibility criteria based on participants' most important values using the following logic for interpretation of stakeholders' responses. For example, as Table 1 shows current cropping patterns, we assume that the drivers which have been identified as challenges are of lesser value to farmers as cropping decisions have been made despite these challenges. Following the same logic, we rank the positive drivers according to their prevalence in decision-making across the different crops (i.e. the number of crops where a particular driver was explicitly identified as a decision-factor). We also group these stakeholder values into fundamental objectives and means objectives (Keeney 1996) . Fundamental objectives are those where the desired end outcomes are pursued for their own sake while means objectives contribute to the attainment of the fundamental objectives. In Figure 3 we developed a means-ends diagram based on the major drivers of crop choice presented in Table 1 draws out a logical hierarchy of these drivers identifying some as constituent-goals needed for achieving other end-goals (Van der Lei et al. 2011).

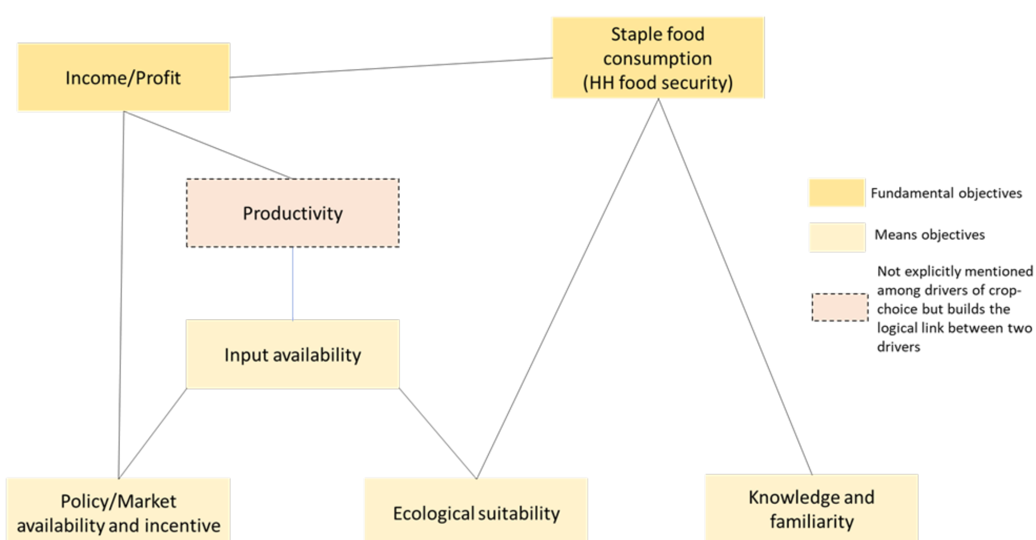

Figure 3. *Means-Ends Diagram adapted and based on Van der Lei et al. (2011)*

We prioritise fundamental objectives over means objectives in narrowing down the key feasibility evaluation criteria. In particular, we consider the means objectives as potential areas which deliberate interventions can affect and therefore offer important recommendations for policy to support appropriate cropping scenarios. Ecological suitability factors are external drivers that cannot be easily modified within the system but can be partially overcome through suitable agricultural practices and inputs. Policy/market factors and input availability may be affected through policy interventions.

We prioritized factors in our feasibility assessment using the logic shown in Table 5. The different decision-making drivers were first aligned with the TELOS-CB feasibility criteria and then in accordance with the means-ends framework presented in Figure 3, they were identified as fundamental and means objectives. A ranking was then assigned based on the prevalence (number of crop types) of each driver in stakeholder responses in decision-making in the current cropping pattern (i.e. in Table 1). Based on these multiple valuations of the drivers we prioritised two drivers – Income (cost/profit) and HH Food security (Staple food for household consumption) – as the feasibility indicators given their higher ranks in terms of prevalence across crop decision-making for most crops and their location in the means-ends framework as fundamental objectives. While Traditional knowledge & familiarity would also ideally score a rank of 1 in terms of a recurring prevalent driver of crop-choice, we rank it lower here given its location in the means-ends framework as a factor (knowledge and familiarity) that can be affected through improved training and policy support.

Table 5. *Designing feasibility evaluation criteria for cropping system scenarios*

Criteria	Explanation	Alignment with drivers	Objective structure	Assigned ranking
Technical	Buildability, Functionality/performance, reliability/availability	Input availability	Means	6
Economic	Benefits versus cost relationship	Cost/Profit	Fundamental	2
Legal	Align with regulatory requirements and institutional support	Policy/Market incentives	Means	5
Operational	Project's synergetic environmental or system suitability	Ecological suitability (soil/water/land feasibility)	Means	4
Schedule	Within desirable or mandatory timelines	Ecological suitability (climatic/seasonal feasibility)	Means	4
Cultural	Acceptance in cultural milieu	Cultural factors (Traditional knowledge & familiarity)	Means	3
Behavioural	Meets behavioural patterns and mandates	Cultural factors (Staple food for household consumption)	Fundamental	1

Impact criteria: The impact criteria for the scenario evaluation emerged from the discussion in Section 3 that identified changes in climate and groundwater resource. Assuming current directions of changes in climatic patterns and groundwater use (summarised in Table 6 below based on the detailed responses presented in Table 2 earlier) continue in Nalanda, we prioritised these directions as conditions to which the scenarios will need to respond in order to contribute to climate resilience and sustainable groundwater use. Here we have used only the qualitative considerations of sensitivity to climatic fluctuation and the water requirements of different types of crops to shortlist high priority cropping scenarios for further integration into the quantitative groundwater-climate-crop modelling analysis.

Table 6. *Designing impact evaluation criterion for scenarios*

Impact criteria		Conditions
Climate resilience	Kharif/monsoon	Erratic and extreme precipitation conditions
	Rabi/winter	Shorter duration of low temperature conditions
	Zaed/summer	Longer duration and hotter temperatures
Groundwater	Sustainability	Reduce demand / Increase recharge under two conditions: • Increased groundwater access and intensified extraction and use • Depleting groundwater and reduced groundwater availability

Scoring scenarios:
Based on the two criteria (feasibility and impact) we used a qualitative scoring for each of the scenarios to score them (ranked 0-2) across four indicators, as shown in Table 7.

Table 7. *Scoring parameters for feasibility-impact matrix*

FEASIBILITY	SCORES	SCORING DEFINITIONS
Income *(cost/profit)*	2 – Improved 1 – No change/ maintained 0 - Reduced	Increase in area under cash crops
HH food security *(staple food for HH consumption)*	1 – No change/ maintained 0 - Reduced	Reduction/no change in area under crops contributing to staple diet of household
IMPACT		
Climate resilience *(specific risk factors in kharif/rabi/zaed)*	2 – Improved 1 – No change/ maintained 0 - Reduced	Reduced area under climate sensitive crops Practices to improve climate resilience
Groundwater sustainability	2 – Improved 1 – No change/ maintained 0 - Reduced	Reduced area under water intensive crops Increased area under less water intensive crops Groundwater recharge/manageme nt practices

We scored the change in crop selection and management practice in each cropping system scenario identified in Table 3 against the criteria of income, household food security, climate resilience and groundwater sustainability. We further gave paddy and wheat a greater weighting (of x2) given their very high coverage in cropping area of Nalanda District (Figure 1). These scores were then summed as for the feasibility criteria and impact criteria separately and mapped to compare the scenarios on a matrix (Figure 4). A detailed scoring is shown in the annex. The scores are based on stakeholder responses of constraints in shifting to new cropping scenarios (workshop session 3) as well as from an understanding of the pros and cons of different crops on these criteria we gained from stakeholder responses for drivers and challenges for different crops (session 1, Table 1).

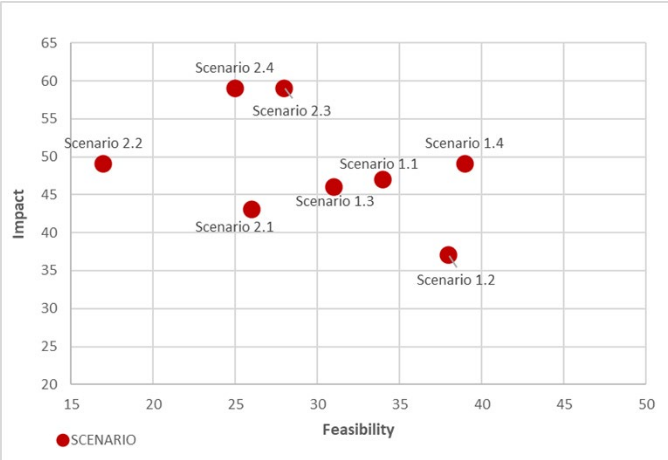

Figure 4. *Feasibility-Impact matrix evaluation of scenarios*

Based on this qualitative assessment of the scenarios on a feasibility-impact matrix, it is evident that cropping patterns that are favourable for climate resilience and groundwater sustainability do not necessarily align with feasibility factors valued by farmers; there are tradeoffs involved. Therefore, scenarios which balance both may constitute ideal future scenarios.

This evaluation may not constitute an entirely accurate quantification of the feasibility and impact of the cropping system scenarios identified by participants in the workshop as it only allows for a qualitative scoring based on several broad assumptions. This evaluation has nevertheless provided an important visualisation of the trade-offs between resilience-groundwater sustainability and economic-behavioural feasibility and is thus a valuable tool for identifying those cropping system scenarios which should be prioritized in subsequent cropping and groundwater system modelling and analysis, which will enable mor accurate quantification and analysis of the resilience and sustainability of the cropping system scenarios.

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ANNEXURES

ANNEXURE 1 - Concept and Agenda

CGIAR TAFSSA STAKEHOLDER WORKSHOP ON AGRICULTURAL FUTURES UNDER GROUNDWATER AND CLIMATIC UNCERTAINTIES

Date and Time: 12 October 2023, 9:30am – 3:30pm IST
Venue: Hotel Maurya, Patna

CGIAR Transforming Agrifood Systems in South Asia

Background

CGIAR's Transforming Agri-Food Systems in South Asia (TAFSSA) Initiative is delivering a coordinated program of research and engagement across the food-production-to-consumption continuum throughout South Asia to support equitable access to sustainable healthy diets, improve farmer livelihoods and resilience, and conserve land, air and groundwater resources.
Under the Initiative, International Water Management Institute (IWMI) is conducting modelling of groundwater resources in Nalanda District in Bihar to simulate likely groundwater usage under current and future climates. We now seek to understand which agronomic management scenarios will be most relevant and feasible for smallholder farmers under changing climate and economic conditions.

Workshop Objective

To co-design scenarios of future groundwater use in Nalanda, Bihar, to ensure they are feasible, plausible and attractive to farmers and other key stakeholders as well as being socially inclusive and nutritionally sensitive while maintaining groundwater resources under current and future climates.

AGENDA

Timing	Activity
9:30 – 10:00	Registration and Tea
10:00 - 10:10	Opening and Introduction
10:10 - 10:25	Keynote and context setting
10:25 - 10:45	Explanation of Ground Water modelling and introduction to test-case scenarios
10:45 - 11:30	Participatory Session 1
11:30 - 11:45	Tea Break
11:45 - 12:30	Participatory Session 2
12:30 – 12:45	Report Back from Session 1 and 2
12:45 – 13:30	Participatory Session 3
13:30-14:30	Lunch
14:30 -15:00	Participatory Session 4:
15:00 – 15:15	Review and Finalize scenarios
15:15 – 15:25	Next steps and how we will update participants (if they want)
15:25 -15:30	Vote of Thanks

Workshop Outcomes

At the workshop a series of scenarios of future agronomic practices will be identified for Nalanda district in Bihar. These scenarios will use groundwater differently, and thus have different implications for aquifer drawdown and recharge. The scenarios will be ranked by workshop participants in order of most to least attractive. Following the workshop scenarios will inform groundwater modelling and thus inform a policy brief and a journal paper. Ultimate outputs from the workshop will be circulated to participants if desired.

ANNEXURE 2 –

SESSION PROTOCOL FOR PARTICIPATORY SCENARIO DEVELOPMENT

SESSION 1: Understanding current agricultural patterns (cropping and agronomic practices)

1. What crops are currently grown/promoted/recommended in different seasons?

2. What are the factors driving these cropping decisions (or not cropping) – why do you prefer or choose these crops? (15mins)
(Examples: climatic and precipitation conditions, soil conditions, input availability, input cost, labour requirement and availability, familiarity with crop practices, subsidy support, high productivity, high profit margins, market availability and access, extension support, self-sustenance etc.)

3. Do you face any challenges or constraints do these crops face in the current resource, climatic and economic environment? If so, what are these? (15mins)

Crops	**Drivers (why?)**	**Any Challenges?**
Kharif (monsoon)		
Rabi (winter)		
Zaed (Summer)		

SESSION 2: Perceived changes in climatic patterns

4. Have you seen/analysed any changes in the following agricultural practices in the region in the last 10 years: (5mins)

	Irrigation	Tillage	Residue management
Summer			
Monsoon			
Winter			

5. What changing climatic patterns that have been observed in your perception: (5mins)

(add to the list if any observations reported by stakeholders is not in the list)		
Summer: Increasing maximum temperatures (heat waves)		
Monsoon: Delayed onset		
Monsoon: Untimely high intensity rainfall		
Monsoon: Drought		
Winter: Reducing winter rainfall		
Winter: Early onset of heat stress		

Report Back from group facilitators: (5mins x 3)

SESSION 3: Responses to climatic and groundwater scenarios

6. If you could make ANY changes in crops and agricultural practices, what would you change from the current pattern under each condition? (20 mins)

- What crops would you introduce which are not being currently grown?
- What practices would you introduce which are not being currently used?
- What existing crops would you grow more of?
- What existing practices would you need to use more intensively?
- What crops would you stop growing?
- What existing practices would you stop using?

(Practices could refer to –
Land preparation methods
Crop establishment and seed application methods
Green houses
Intercropping, crop rotation, etc.
Furrows, terraces, ridge construction etc
Irrigation technologies and methods
Water augmentation methods
Water management methods
Nutrient use and application methods
Pesticide use and application methods
Weeding methods
Residue management
Harvesting time and methods
Etc.)

7. For each of these changes suggested, do you foresee any constraints or challenges in making these changes? (10 mins)
(Example:
No markets
Not able to access required technology or equipment or other inputs
High-cost requirements/affordability
No capacity or knowledge
Not enough labour availability
Lack of government support for these (subsidy, procurement etc)
Not profitable
Too much effort for little gain
Better opportunities in other occupations – will leave agriculture)

Report back (5mins x 3)

8. Based on these cropping conditions and decisions by the three groups we will now jointly develop three cropping pattern scenarios for the case region:
Each stakeholder will now walk up to the 3 boards/charts and rank the 3 cropping scenarios using sticky notes based on feasibility/ease of adoption and potential to provide longer-term climate resilience and resource sustainability (Impact-Feasibility Matrix).
Local stakeholders will require support for this from facilitators.

(add to the list if any observations reported by stakeholders is not in the list)	Groundwater readily available for irrigation		Potential constraints	Groundwater depleted – low irrigation availability		Potential constraints
	Crops	Practices		Crops	Practices	
	Do less of or not do / Do more of / Introduce new			Do less of or not do / Do more of / Introduce new		
Summer: Increasing max. temperatures (heat waves)						
Monsoon: Delayed onset						
Monsoon: Untimely high intensity rainfall						
Monsoon: Drought						
Winter: Reducing winter rainfall						
Winter: Early onset of heat stress						

ANNEXURE 3 - SCENARIO SCORING

Current crops	Scenario 1.1					Scenario 1.2					Scenario 1.3					Scenario 1.4				
	CROPS	EVALUATION				CROPS	EVALUATION				CROPS	EVALUATION				CROPS	EVALUATION			
Monsoon/Kharif		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW
Paddy	low duration variety, late sowing/late harvesting	2	2	4	4	Directly seeded rice, Double transplanted Increased seedlings	2	0	0	4	Directly seeded rice	2	2	2	4	early planting with irrigation	2	2	4	0
Vegetables:	raised beds and drainage systems along plots	1	1	2	1	Okra, Ridge Gourd - Raised Bed Planting	2	1	2	2		1	1	1	1		1	1	1	1
	deepen TW farm ponds (flood management/GW recharge)			2	2															
	alternate livelhood: fishing in farm ponds			2																
Winter/Rabi																				
Boro Paddy		0	0	1	2		0	0	1	2		0	0	1	2		0	0	1	2
Wheat	early wheat	4	2	0	0	short duration	4	2	4	0		0	0	4	4		0	0	4	4
Lentils:	masoor	0	0	2	0		2	1	0	2		2	1	0	2		2	1	0	2
Mustard		0	0	2	0	Oilseeds	2	1	0	2	Oilseeds, mustard	2	1	0	2	Oilseeds	2	1	0	2
Maize		2	1	2	0		0	0	2	2		2	1	2	0		2	1	2	0
Vegetables:	raised beds	2	1	2	2	potato and onion raised bed planting	2	1	2	2		0	0	1	0		2	2	2	2
Millets		1	1	1	1		1	1	1	1		1	1	1	1		1	1	1	1
Summer/Zaed																				
Maize	heat resistant variety mulching	1	1	2	1		2	1	0	0		0	0	2	2		0	0	2	2
Legume (mungbean/pigeon pea)		1	1	1	1		0	0	0	0	Pulses	2	1	2	2	Pulses	2	1	2	2
Vegetables		1	1	1	1	Japanese Mint Raised Bed Planting	2	1	0	2		0	0	2	0		2	1	0	2
Fallow lands		1	1	1	1		2	2	0	0		2	2	0	0		2	2	0	0
Agroforestry		1	1	1	1		1	1	1	1		2	1	2	2		2	1	2	2
Fodder crops		1	1	1	1		1	1	1	1		1	1	1	1		2	1	2	2
Millets		1	1	1	1		1	1	1	1		1	1	1	1		1	1	1	1

Current crops	Scenario 2.1					Scenario 2.2					Scenario 2.3					Scenario 2.4				
	CROPS	EVALUATION				CROPS	EVALUATION				CROPS	EVALUATION				CROPS	EVALUATION			
Monsoon/Kharif		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW		Income	HH Food security	Climate	GW
Paddy		0	0	0	4		0	0	0	4	Short duration varieties Sowing with monsoon	0	0	4	4	Short duration / Drought-tolerant / Multi-stress tolerant varieties Sowing late with rainfall	0	0	4	4
Vegetables:		2	1	2	2	Okra line sowing Increased seedlings	2	1	2	2		1	1	1	1		1	1	1	1
	farm ponds for recharge and fishing			2	2						Water Harvesting structures Better irrigation planning			2	2	Small water storage Increase irrigation efficiency			2	2
											More focus on non-farming incomes			2		Non-farm income Migration Increased govt support			2	
Winter/Rabi																				
Boro Paddy		0	0	1	2		0	0	1	2		0	0	1	2		0	0	1	2
Wheat		4	2	0	0		0	0	4	4		0	0	4	4		0	0	4	4
Lentils:	masoor	2	1	0	2	pulses	2	1	0	2	pulses	2	1	0	2	pulses	2	1	0	2
Mustard		0	0	2	0		0	0	2	0	oilseeds	2	2	0	2	oilseeds	2	2	0	2
Maize		0	0	0	2		0	0	0	2		0	0	0	2		0	0	0	2
Vegetables:		2	1	2	2	okra, beans	2	1	2	2		2	1	2	2		2	1	2	2
Millets		1	1	1	1	barley	1	1	2	2		1	1	1	1		1	1	1	1
Summer/Zaed																				
Maize		0	0	2	2		0	0	2	2		1	1	1	1		0	0	2	2
Legume (mungbean/pigeon pea)	More N fertiliser needed to compensate	0	0	0	0		0	0	0	0		1	1	1	1		0	0	0	0
Vegetables		2	1	0	2		0	0	2	0		1	1	1	1		2	1	0	2
Fallow lands		0	0	2	2		0	0	2	2		0	0	2	2		0	0	2	2
Agroforestry		1	1	1	1		1	1	1	1	Integrated farming system	2	1	2	2		2	1	2	2
Fodder crops		1	1	1	1		1	1	1	1		2	1	2	2		2	1	2	2
Millets		1	1	1	1		1	1	1	1		1	1	1	1		1	1	1	1

INITIATIVE ON
Transforming Agrifood Systems in South Asia

AUTHORS

Shreya Chakraborty, Researcher, IWMI
Alison Laing, Agroecology Specialist, CIMMYT
Syed Adil Mizan, Researcher, IWMI
Anurag Kumar, Senior Research Associate, CIMMYT
Alok Sikka, Country Representative, IWMI India
Anton Urfels, Senior Water Scientist, IRRI
Timothy J. Krupnik, Regional Director, Sustainable Agrifood Systems Program, Asia, Country Representative for Bangladesh, CIMMYT and CGIAR Country Convener for Bangladesh

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To learn more about TAFSSA, please contact:
t.krupnik@cgiar.org; p.menon@cgiar.org

ABOUT TAFSSA

TAFSSA (Transforming Agrifood Systems in South Asia) is a CGIAR Regional Integrated Initiative that supports actions improving equitable access to sustainable healthy diets, that boosts farmers' livelihoods and resilience, and that conserves land, air, and water resources in a climate crisis.

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