73RD INTERNATIONAL EXECUTIVE COUNCIL MEETING

24th ICID INTERNATIONAL CONGRESS
73rd IEC MEETING
3RD OCT - 10TH OCT 2022
ADELAIDE | SOUTH AUSTRALIA

Theme: Innovation and research in agriculture water management to achieve sustainable development goals

INTERNATIONAL WORKSHOP ON
"THE WATER ENERGY FOOD NEXUS: IMPLEMENTATION AND EXAMPLES OF APPLICATIONS"

04 October 2022: 08:45-10:30 and 11:15 to 13:00 Hours
Adelaide, Australia

24th International Congress on Irrigation and Drainage & 73rd IEC Meeting
3-10 October 2022, Adelaide, Australia

Development of Water-Energy-Food Nexus Model for Basin-Scale Studies

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Outline

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- Background
- Objectives
- Methodology
  - Study area
  - Modelling Framework
  - Data
- Results
- Conclusions

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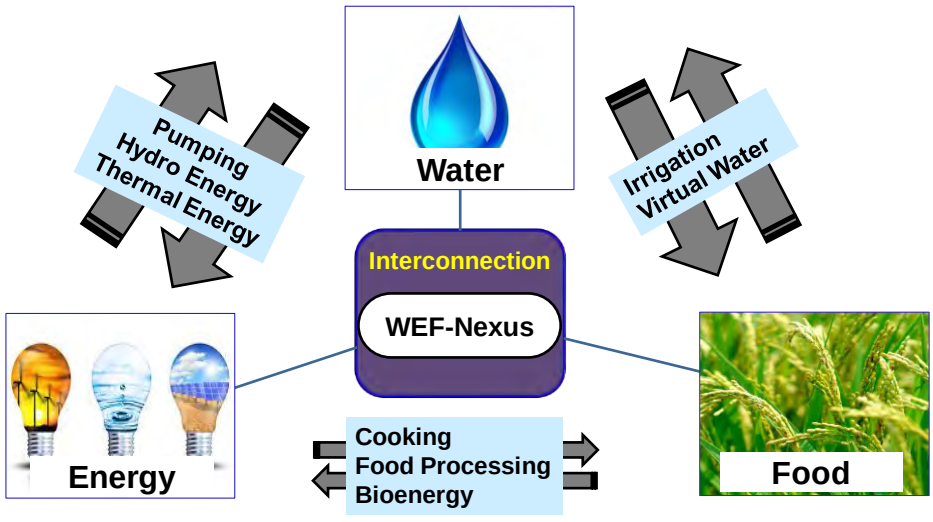
Background

Water-Energy-Food Nexus



Background

Current Challenges - India

Unmet Demand (India)

- 91 million people have no access to basic water supply
- 13% household have no access to electricity
- 189.2 million people are undernourished

(WHO & UNICEF, 2019; NITI Aayog, 2020)

Population Growth

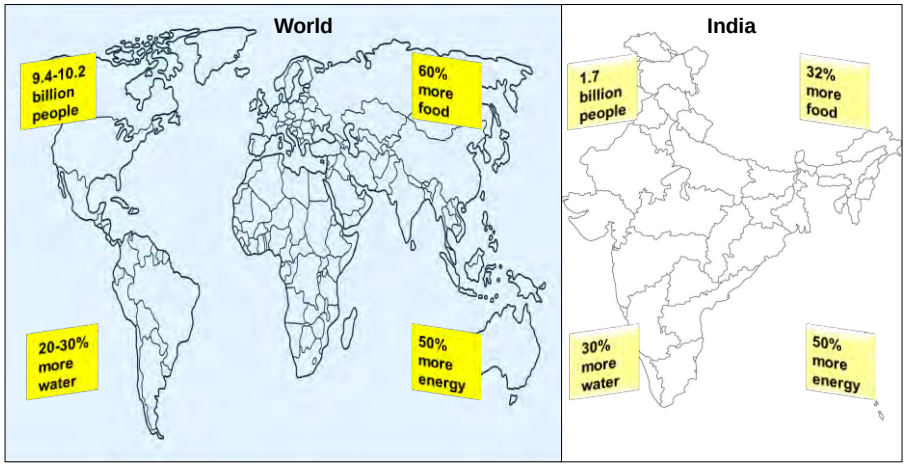
Increasing Demand

Changes in Consumption Pattern

Economic Development

Background

2050 Challenges



Need for a

SYSTEMETIC WEF-NEXUS APPROACH

(Boretti and Rosa, 2019; Newell et al., 2021)

Motivation

WEF Nexus Tools/Models

- **46 WEF Nexus Tools/Models (Taguta et al., 2022)**
  - Developed between 2009-2021
  - 61% Unreachable to the intended users
  - 70% Lack key capabilities like GIS integration and scale transferability
  - Only 28% have been applied by multiple-users

MuSIASEM (Giampietro et al., 2009)

WEAP-LEAP (SEI, 2012)

WEF Nexus tool 2.0 (Daher and Mohtar, 2015)

Pardee RAND WEF Security Index (Willis et al., 2016)

Q-Nexus (Karnib, 2017)

SIM4NEXUS (Susnik et al., 2018)

WEF Nexus Index (Simpson et al., 2020)

NeFEW (Sadegh et al., 2020)

WEF Nexus Discovery Map (Arenas et al., 2021)

Only Country/National Scale | No GIS Interface | Water & Energy Centric | Food Centric

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Motivation

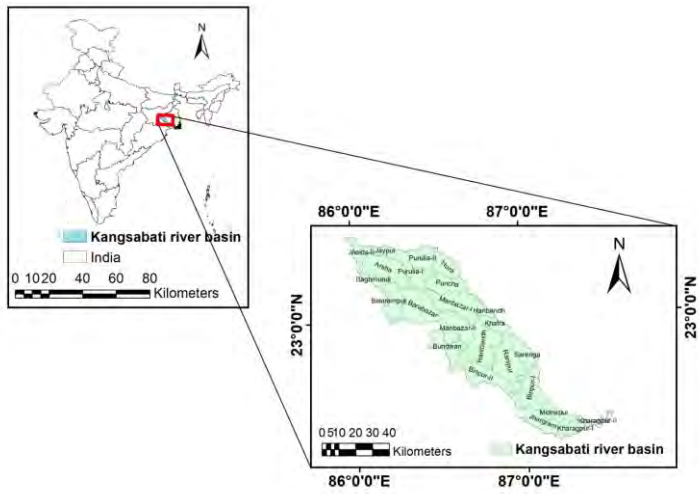
WEF Nexus Tools/Models

- **Scope to develop a Robust WEF-NexusTool/Model**
  - Multi-Scale Flexibility/Transferability
  - GIS Interface
  - Adaptability across Users and Uses

- **Objectives**
  - To develop a distributed water-energy-food nexus model for analysing WEF security at the basin (or any chosen) scale
  - To test the performance of the developed model in the Kangsabati river basin, India

Methodology

Study area



Location:

87°32´ E and 85°57´ E;

22°18´ N and 23°28´ N

Area: 5796 km^2

Annual mean rainfall: 1400mm

Min temperature: 13.5℃

Max temperature: 43.2℃

Districts: 3 (Purulia, Bankura, West Midnapore)

Blocks (micro administrative units)**:** 24

Cities/Towns: Purulia, Mukutmanipur, Raipur, Midnapore, Kharagpur

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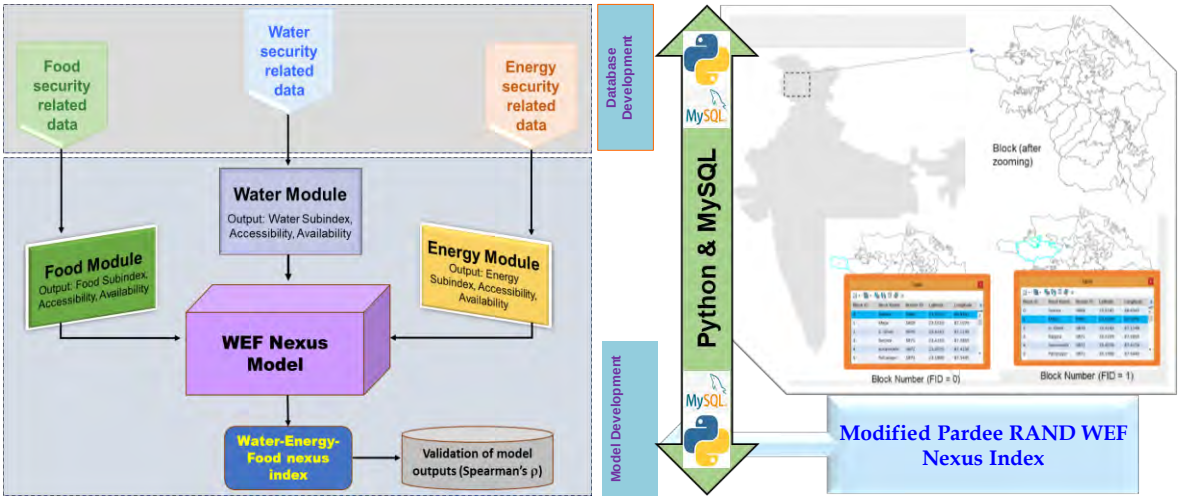
Methodology

Model Framework

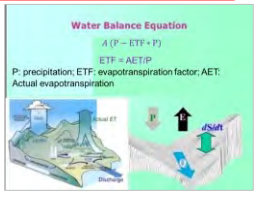


RSGISLib (Python Module) for RS and GIS

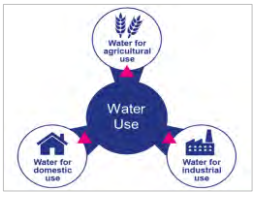
Methodology

Modifications in Pardee RAND approach

Model Development

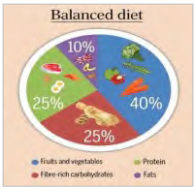


Water balance equation to calculate total water availability

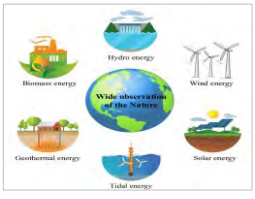


Sector-wise water requirement and use

Major types of food production



Dietary requirement for different age groups



Renewal energy sources

Solar lift irrigation

Farmers having access to modern farm equipment

Hunger Index

Methodology

Modified Pardee RAND WEF Nexus Index

Model Development

Sector	Security Indicators	Equation	Variable definition (unit)
Water	Water Availability (WAv)	$(WAv) = \frac{w_{avi}}{w_{req}} = \frac{A\,(P-ETF*P)}{WR_d+WR_{cp}+WR_{ch}+WR_m+WR_{ml}+WR_e}$ ETF = ET/P, ET is calculated using the Hargreaves equation	w_{avi}: water available (m^3) w_{req}: water requirement (m^3) A: geographical area (ha) P: precipitation (mm) ETF: evapotranspiration factor $WR_d, WR_{cp}, WR_{ch}, WR_m, WR_{ml}, WR_e$: water required for domestic purposes, crop production, chicken production, meat production, milk production, egg production, respectively (m^3)
	Water Accessibility (WAc)	$WAc = \sqrt[2]{PDS * FSW_i}$	PDS: % population having access to sufficient water for drinking and sanitation FSW_i: % farmer having access to sufficient water for irrigation
	Water Sub-index (WSI)	$WSI = \sqrt[2]{WAv * WAc}$	WAv : water availability (ratio) WAc: water accessibility (ratio)
Energy	Energy Availability (EAv)	$\frac{E_{avi}}{E_{req}} = \frac{TES + 0.28\,(ME + HLE)}{ER_d+ER_{cp}+ER_{ch}+ER_m+ER_{ml}+ER_e}$ TES = TE+SE+HE+WE	E_{avi}: energy available (kwh) E_{req}: energy requirement (kwh) TES: total electricity supply (kwh) TE, SE, HE, WE: thermal, solar, hydropower, wind energy, respectively (kwh) ME: machinery energy (MJ) HLE: human labour energy (MJ) $ER_d, ER_{cp}, ER_{ch}, ER_m, ER_{ml}, ER_e$: energy required for domestic purpose, crop production, chicken production, meat production, milk production, egg production, respectively (kwh)

Methodology

Modified Pardee RAND WEF Nexus Index

Model Development

Sector	Security Indicators	Equation	Variable definition (unit)
Energy	Energy Accessibility (EAc)	$EAc = \sqrt[4]{P_e + H_{mf} + F_{fe} + F_{sei}}$	P_e: % population having access to electricity for household H_{mf}: % household having access to modern fuel F_{fe}: % farmers having access to modern farm equipment F_{sei}: % farmer having access to sufficient electricity for irrigation
	Energy Sub-index (ESI)	$ESI = \sqrt[2]{EAv * EAc}$	EAv: energy availability (ratio) EAc: energy accessibility (ratio)
Food	Food Availability (FAv)	$\frac{F_{avi}}{F_{req}} = \frac{C_p+F_p+Ch_p+M_p+Ml_p+E_p}{\sum_i DR_i * Pop_i}$	F_{avi}: food availability (ton) F_{req}: food requirement (ton) $C_p, F_p, Ch_p, M_p, Ml_p, E_p$: crop production, fish production, chicken production, meat production, egg production, respectively (ton) DR: dietary requirement (kg/year) Pop: population i: different age group
	Food Accessibility (FAc)	$FAc = \sqrt[2]{(1/FPLI) * (1-HI)}$	FPLI: Food price level index (ratio) HI: Hunger index (ratio)
	Food Sub-index (FSI)	$FSI = \sqrt[2]{FAv * FAc}$	FAv: food availability (ratio) FAc: food accessibility (ratio)
WEF	Water-Energy-Food Nexus Index	$WEFNI = \sqrt[3]{WSI * ESI * FSI}$	WSI: Water Sub-index ESI: Energy Sub-index FSI: Food Sub-index

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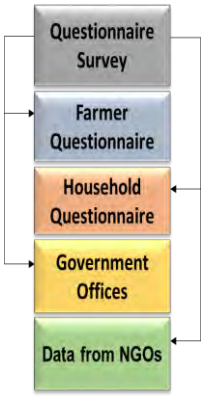
Methodology

Data

Data used for WEF Nexus model simulation (2011)

Data sets	Data information	Sources
Energy Security	o Population having access to electricity connection in their house o Total number of households; Households that have LPG connection o Total electricity supply (thermal, solar, bio and hydro) (kwh) o Number of solar and lift irrigation pumps, number of tractors, agriculture worker o Energy requirement for per unit crop, chicken or meat, egg, milk, electricity production (kwh/ton)	West Bengal (WB) Census report 2011; Government of WB 2011
Food Security	o Agriculture area, aquaculture area (ha) o Total number of farmers, number of farmers having access to modern farm equipment o Number of farmers who benefited per solar and lift irrigation pump o Cropping intensity, crop productivity (ton/ha) of different crops (paddy, wheat, maize, potato) o Dietary requirement/per capita of different age groups (kg/year) o Total chicken, meat, egg, and milk production (ton/year) o Fish production per unit aquaculture area (kg/ha) o Number of the population under different age groups o Hunger index, food price level index	Government of WB 2011b, WB Census report 2011, Global Hunger Index 2011, CEIC India data
Water Security	o Crop water productivity (kg/m^3) of different crops (paddy, wheat, maize, potato) o Water requirement/capita for domestic purposes (lit/day) o Water requirement for per unit production of chicken or meat, egg, milk, electricity (m^3/ton) o Population having access to sufficient water for domestic purposes o Annual groundwater storage and draft (m^3) o Geographical area (ha), rainfall and evapotranspiration (mm)	WHO 2003, Government of WB 2011c, WB Census report 2011, India WRIS, NABARD 2018, CAG, 2020

Data collection for Kharif 2022 and Rabi 2022-2023



Results

GUI of Developed WEF Nexus model

Start Window

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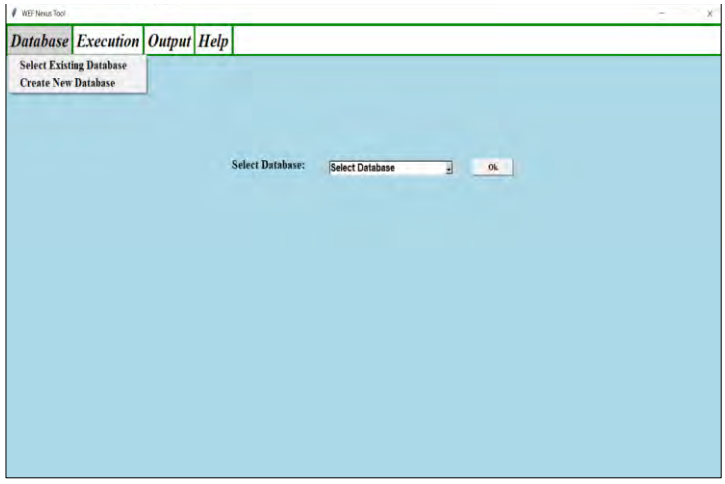
Results

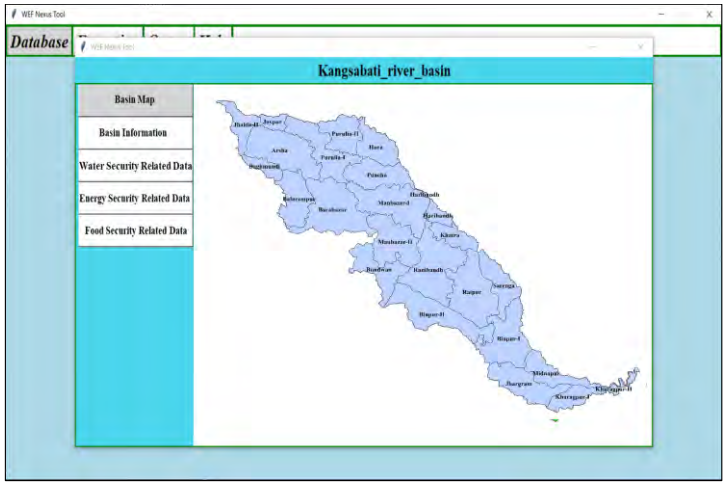
GUI of Developed WEF Nexus model



Database Window

Results

GUI of Developed WEF Nexus model



Existing Database

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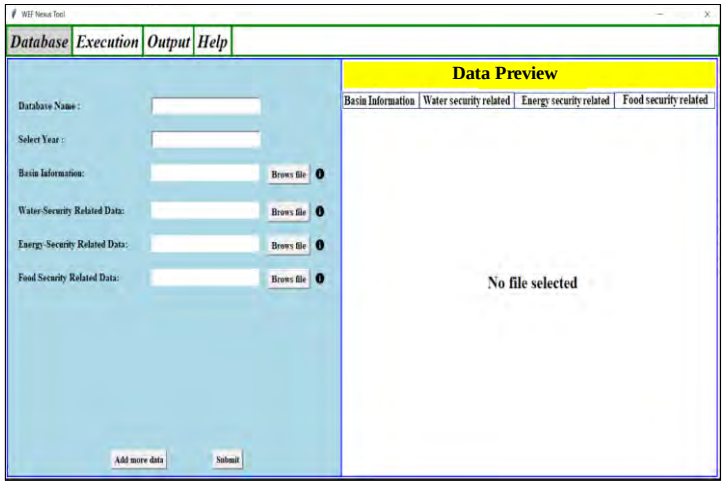
Results

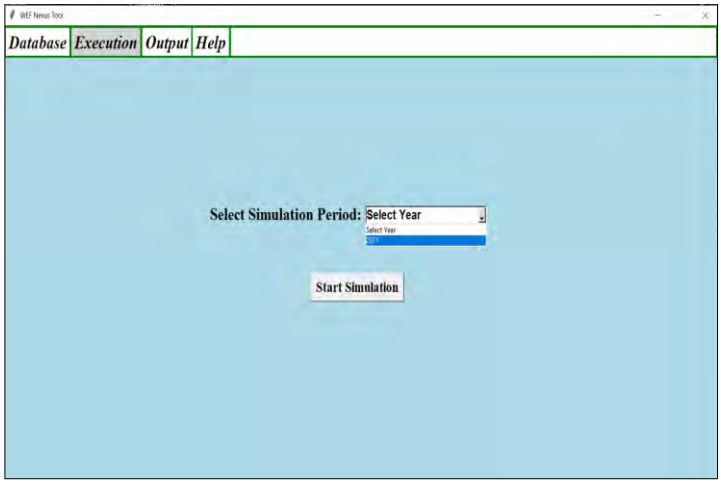
GUI of Developed WEF Nexus model



Create new database

Results

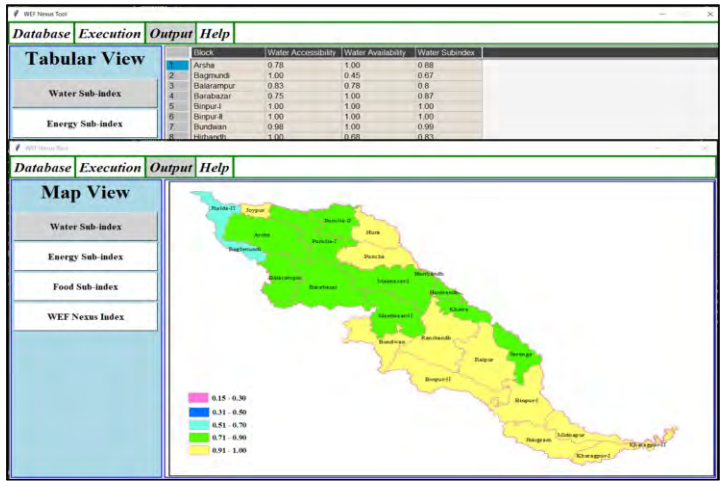
GUI of Developed WEF Nexus model



Execution Window

Results

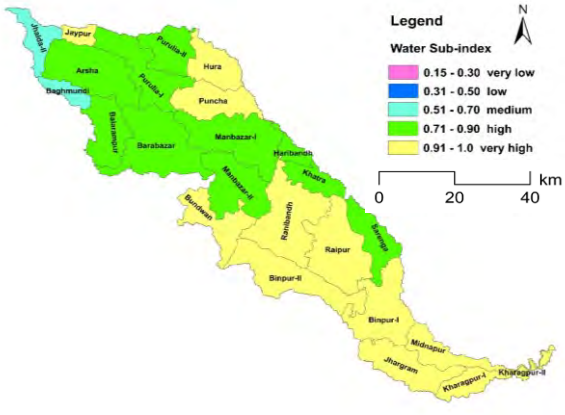
GUI of Developed WEF Nexus model



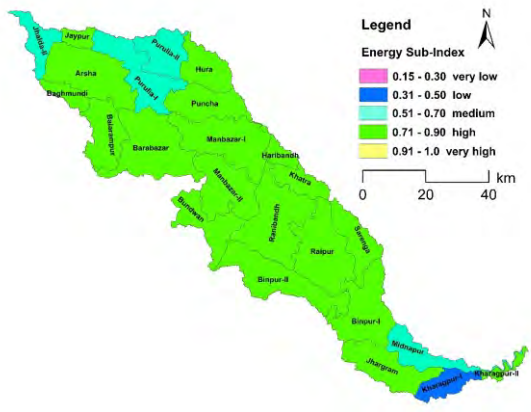
Output Window

Results

WEF Nexus Indices in Kangsabati River Basin



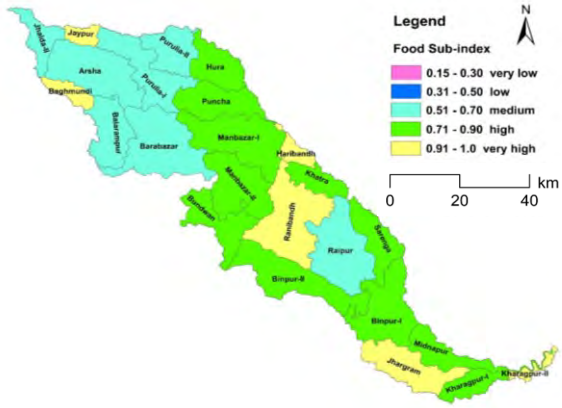
- Water Sub-index varies from medium to very high
- 92% blocks have a high to very high WSI

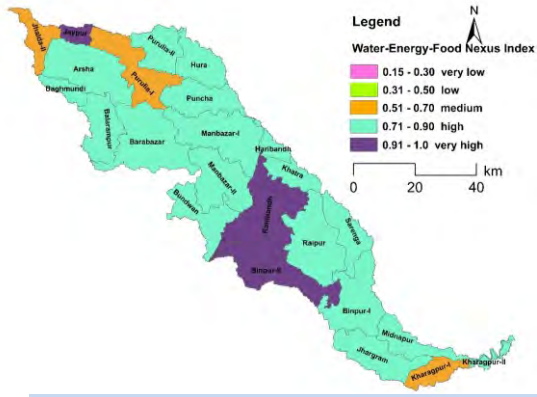


- Energy sub-index varies from low to high
- 79% blocks have a high ESI

Results

WEF Nexus Indices in Kangsabati River Basin





- Food Sub-index also varies from medium to very high
- 70% blocks have a high to very high FSI

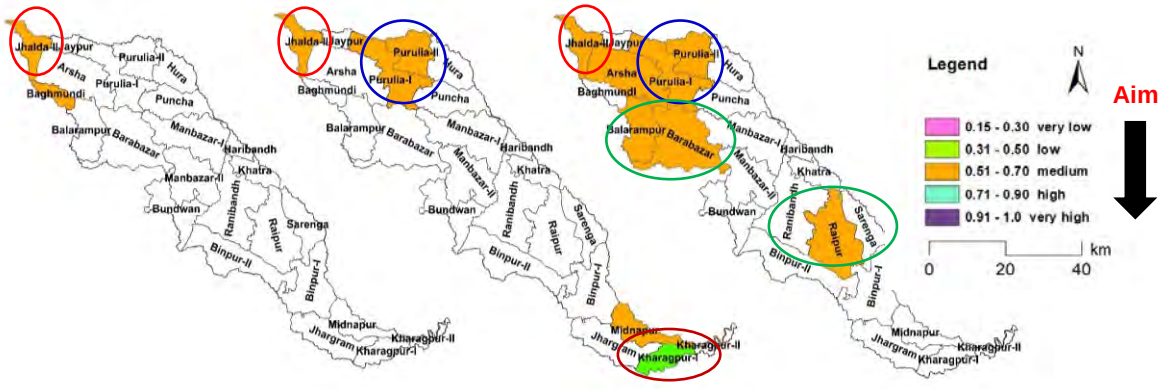
- 75% blocks have a high to very high WEFNI
- Since all blocks have water, energy and food sub-indices greater than 0.50, it shows that the blocks are on the path to achieving WEF security

(Nkiaka et al., 2021)

Results

Policy Intervention Needs

Water Sub-index | Energy Sub-index | Food Sub-index

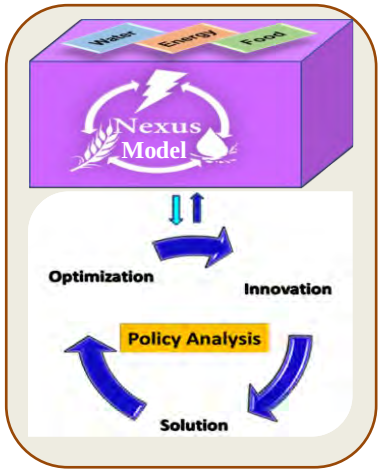


Water-Energy-Food | Energy-Food | Energy | Food

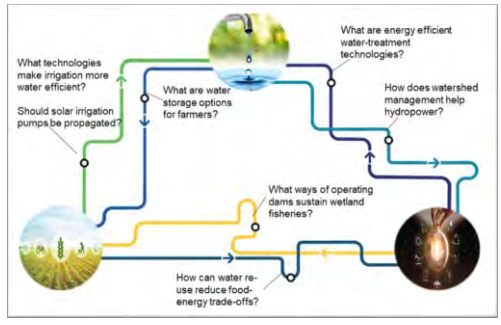
Proposed Module

Policy Analysis Module

- To analyse the impact of policy changes on the WEF sufficiency in a basin



➡ **Scenario Development**



Module will seek answers to these and many such questions

Conclusions

Conclusions

- The developed model analyses water, energy and food security by generating WEF sub-indices and nexus index
- The water, energy and food sub-indices, and WEF nexus index show that the Kangsabati basin is on the path to achieve WEF security

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Thank You

Thanks for your attention

Questions Please!