Mapping Inter-State Rice Virtual Water Trade in India Using Complex Network Analysis

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Abstract

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

Background

- Inter-state agricultural trade redistributes water through **virtual water flows** (Chapagain & Hoekstra, 2008), particularly for water-intensive crops such as rice.
- In India, analyses have largely focused on **commodity trade and water use in isolation**, with limited assessment of **inter-state dependencies arising from trade-mediated water transfers** (Katyaini et al., 2017).
- This study addresses this gap by applying a **network-based framework** to analyse the structure and implications of inter-state rice virtual water trade.

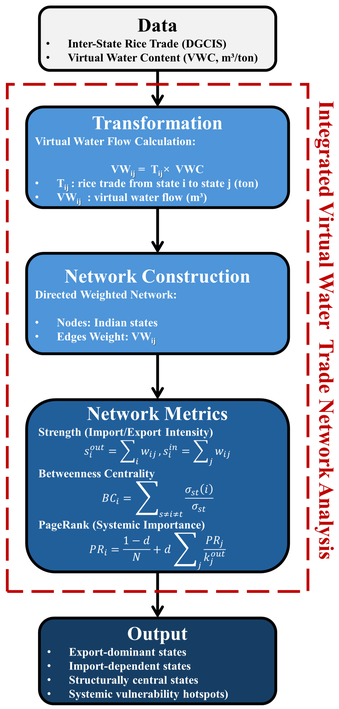
Methodology

Data Inputs

- DGCIS inter-state rice trade dataset for the year 2017
- State-to-state trade volumes (ton)
- Crop-specific virtual water (VW) content (m^3/ton) (Hoekstra et al., 2011)
- Assumption of spatially uniform VWC

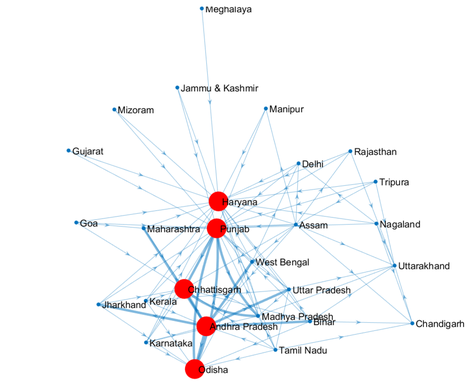
VW-Network Analysis

- Transformation of trade volumes into virtual water flows
- Directed, weighted network representation of inter-state flows
- Edge weights defined by virtual water transfer volumes
- Centrality analysis: Node strength, Betweenness, PageRank
- Identification of dominant exporters and structurally central states



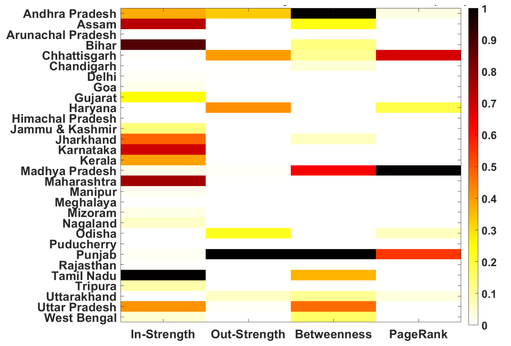
Results

Dominant Exporters in VW-Trade



- Top 5 states account for **~96% of total virtual water exports**
- Punjab and Haryana act as primary suppliers
- Export structure is **extremely concentrated**
- Suggests high dependence on limited source regions

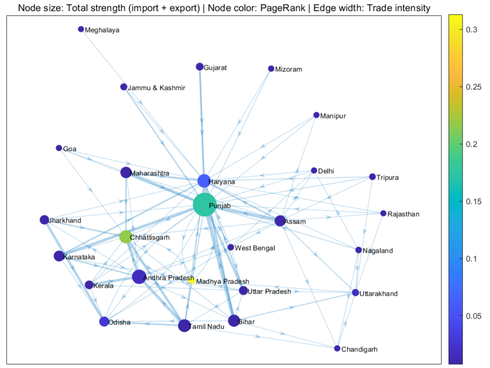
Centrality and Functional Roles



- Punjab exhibits highest export intensity and systemic importance (PageRank ≈ 0.31)
- Madhya Pradesh functions as the primary intermediary (Betweenness Centrality ≈ 47)
- Uttar Pradesh shows secondary mediation capacity (Betweenness Centrality ≈ 22)
- **Flow mediation is concentrated in non-dominant exporters, indicating indirect dependency pathways**

Network Topology and Systemic Importance

- Node size ∝ total strength; color ∝ PageRank and edge-width ∝ trade intensity
- Network exhibits a core periphery structure with dense central connectivity
- Peripheral states connect primarily through a limited set of core nodes
- Flow pathways are highly centralized, indicating constrained routing
- Low redundancy in connections suggests limited alternative trade pathways
- Strong asymmetry in connectivity between core and peripheral states
- **Topology indicates system-level dependence on a few critical nodes**



Summary and Discussion

- Inter-state rice trade redistributes water through a **highly centralized network**
- Export supply is concentrated in a few states, creating **structural dependencies**
- Network pathways are mediated by intermediary states, not only dominant exporters
- Core–periphery topology indicates **limited redundancy in trade connections**
- Current structure suggests **potential vulnerability under water stress in key regions**

Key Takeaways

- Limited system-level understanding of **inter-state virtual water dependencies** in India
- Network-based framework enables **quantitative characterization of trade-mediated water flows**
- Virtual water exports are **highly concentrated (~96%) among a few states**
- Trade structure exhibits **dependence on dominant exporters and key intermediary states**
- Results indicate **potential vulnerability under water stress in major producing regions**

References

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