

Research Gaps and Innovative Ideas for Inter-basin Water Transfer (IBWT)

1. Identified Research Gaps

Based on a comprehensive review of all documents in the repository, the following research gaps related to Inter-basin Water Transfer (IBWT) have been identified:

1. **Socio-Hydrological “Rebound Effect” and Agricultural Intensification:** While IBWT is designed to alleviate water scarcity, evidence from regions like the North China Plain (NCP) and Xinjiang suggests that the increased water security often triggers unintended agricultural expansion or intensification (increased Leaf Area Index and crop density). This “rebound effect” can partially or completely offset the hydrological gains achieved by the transfer. There is a lack of integrated satellite-based studies that quantify this human-behavioral feedback loop in near-real-time.
2. **High-Resolution Monitoring of Ecological Costs in Donor Basins (WSA):** The majority of current research focuses on the benefits received by destination basins. However, donor basins (Water Source Areas) often suffer from reduced surface water availability, vegetation loss (e.g., Konqi and Han Rivers), and degraded ecosystem services. High-resolution, multi-decadal satellite assessments of these “ecological costs” in the donor regions are insufficient.
3. **Route-wide Satellite-Based Water Quality Monitoring:** Hydrological models (e.g., SWAT) predict significant shifts in Nutrient loads (Nitrogen and Phosphorus) and Water Environmental Capacity (WEC) following IBWT. However, there is a lack of continuous, integrated satellite-based monitoring of water quality parameters (turbidity, Chlorophyll-a, CDOM) across the thousands of kilometers of transfer canals and within the receiving reservoirs.
4. **Invasive Species Spread along IBWT Corridors:** Global reviews have long identified the risk of spreading invasive aquatic and riparian species by connecting previously disconnected river basins. Despite this, modern remote sensing techniques (using high-resolution data like Sentinel-2) have not been fully utilized to track and model the spread patterns of these species along IBWT infrastructure.
5. **Unintended Flooding and Geomorphological Changes in Recipient Basins:** Increased discharge in recipient river channels (e.g., the Gadar River/Lake Urmia case) can lead to unexpected flood inundation in formerly low-flow areas and alter downstream morphology. Quantitative, GIS-based analysis of these physical transformations using multi-sensor satellite data remains a gap.

6. **Coarse-Resolution Limitation in TWS vs. Localized Subsidence:** While GRACE provides valuable regional Terrestrial Water Storage (TWS) trends, its 0.25-degree resolution is too coarse to evaluate localized groundwater recharge effectiveness at the city or district scale. Integrating coarse GRACE data with high-resolution Sentinel-1 InSAR for land subsidence monitoring is a promising but under-explored area.

2. Innovative Research Ideas

Research Idea 1: Assessing the Socio-Hydrological “Rebound Effect” of IBWT on Agricultural Intensification using Multi-Sensor Satellite Data

Background and Justification: Based on repository findings (e.g., Dong et al., 2023; Ma & Wang, 2024), IBWT projects like the SNWTP effectively stabilize regional water storage. However, the increased water supply often encourages farmers to increase crop density or expand irrigated areas. This phenomenon, known as the “rebound effect,” can diminish the project’s ability to restore groundwater levels. Quantifying this feedback is essential for sustainable water management and agricultural policy.

Research Objectives: - To quantify the spatiotemporal changes in agricultural land extent and crop density (LAI) following IBWT implementation. - To determine the correlation between water transfer volumes and the “rebound” in agricultural water consumption. - To assess the net impact of agricultural intensification on regional Terrestrial Water Storage (TWS) recovery.

Proposed Methodology: - **Satellite Datasets:** Use **GRACE/GRACE-FO** for regional TWS trends, **MODIS (MOD15A2H)** for 8-day Leaf Area Index (LAI) time-series, and **Sentinel-2** for high-resolution crop type mapping. - **GIS Analysis:** Perform spatial correlation analysis between IBWT canal routes, transfer volumes (from bulletins), and pixel-level LAI increases. - **Modeling:** Apply a Water Balance framework (similar to Dong et al., 2023) to disentangle climate-driven vs. IBWT-induced agricultural changes.

Expected Scientific Contribution: This research will provide a new quantitative framework for assessing human-behavioral feedbacks in water transfer systems. It will contribute to the field of socio-hydrology by providing satellite-based evidence of the “rebound effect,” assisting policymakers in setting agricultural limits alongside IBWT projects.

Potential Study Regions: - North China Plain (NCP) - specifically Hebei and Henan provinces. - Tarim River Basin, Xinjiang, China.

Research Idea 2: High-Resolution Satellite-Based Evaluation of the “Ecological Cost” in IBWT Donor Basins (Water Source Areas)

Background and Justification: Existing documents (e.g., Cui et al., 2025; Zhuang et al., 2025) indicate that while receiving areas benefit from greening,

donor basins like the Han River Basin may experience reduced vegetation activity and increased ecological vulnerability. There is a critical need to use high-resolution remote sensing to identify specific ecosystem services and vegetation types most at risk in the source regions to inform ecological compensation strategies.

Research Objectives: - To identify high-risk ecological zones in the donor basin based on long-term vegetation health trends. - To quantify the loss of specific ecosystem services (e.g., NPP, water retention) in the source region. - To develop a satellite-based “Ecological Cost Index” for IBWT donor areas.

Proposed Methodology: - **Satellite Datasets:** **Sentinel-2** and **Landsat-8/9** for high-resolution NDVI, EVI, and Net Primary Productivity (NPP). **MODIS (MOD11A2)** for Land Surface Temperature (LST) as a proxy for moisture stress. - **GIS Analysis:** Use Geographically Weighted Regression (GWR) to attribute vegetation declines to reduced surface water levels in source reservoirs vs. climate variability. - **Spatial Analysis:** Hotspot analysis (Getis-Ord G_i^*) to locate areas of significant ecological degradation.

Expected Scientific Contribution: The study will advance the understanding of environmental trade-offs in IBWT systems. It will provide a standardized methodology for monitoring the “silent” ecological costs in source regions, which is vital for equitable inter-basin management and UNESCO criteria compliance.

Potential Study Regions: - Han River Basin / Danjiangkou Reservoir (WSA for MR-SNWTP). - Konqi River Basin, China.

Research Idea 3: Spatiotemporal Modeling of Invasive Riparian Species Spread along Inter-basin Transfer Corridors using Sentinel-2 and GIS

Background and Justification: Global overviews in the repository (e.g., Snaddon et al., 1999) highlight the significant risk of biological invasions associated with IBWT. The connection of hydrologically separate basins facilitates the movement of alien species. Modern satellite data, particularly the high spectral and spatial resolution of Sentinel-2, offers an innovative way to detect and track the spread of these invasive species along the thousands of kilometers of transfer canals.

Research Objectives: - To map the distribution of invasive riparian species along IBWT canals. - To model the rate of spread and identify “invasion hotspots” where ecological integrity is most threatened. - To assess the impact of invasive species on local biodiversity and canal maintenance.

Proposed Methodology: - **Satellite Datasets:** **Sentinel-2 (10m)** using its Red-Edge bands for improved species-level classification. Multi-temporal imagery to capture phenological differences of invasive vs. native species. - **GIS Analysis:** Buffer analysis along transfer canals to track longitudinal spread patterns. - **Machine Learning:** Random Forest or Support Vector Machine

(SVM) classifiers for high-accuracy species identification in Google Earth Engine (GEE).

Expected Scientific Contribution: This research will integrate high-resolution remote sensing with biological invasion theory. It will provide a scalable tool for water managers to monitor invasive species spread in near-real-time, potentially saving costs in canal maintenance and biodiversity conservation.

Potential Study Regions: - The Middle Route of the South-to-North Water Diversion (MR-SNWDP) canal system. - Pennar to Cauvery Link Canal, India.

Research Idea 4: Integrated Satellite Monitoring of Water Quality and Environmental Capacity (WEC) in Mega-Scale Transfer Systems

Background and Justification: While many studies focus on water quantity, documents such as Jiao et al. (2021) emphasize that IBWT also transfers pollution loads and affects the Water Environmental Capacity (WEC). There is a research gap in using satellite remote sensing to continuously monitor water quality parameters (e.g., Turbidity, Chlorophyll-a) along the entire transfer route and in the recipient reservoirs, ensuring that transferred water meets municipal and ecological standards.

Research Objectives: - To retrieve water quality parameters (Turbidity, Chl-a, CDOM) along IBWT routes using satellite imagery. - To analyze the longitudinal changes in water quality from donor reservoir to recipient outlets. - To evaluate the impact of IBWT volume fluctuations on the WEC of destination river channels.

Proposed Methodology: - **Satellite Datasets:** **Sentinel-2 (MSI)** and **Landsat-8/9 (OLI)**. Use **Sentinel-3 (OLCI)** for larger reservoirs due to high spectral resolution. - **Remote Sensing Models:** Semi-analytical bio-optical models (e.g., C2RCC or Case-2 Regional Coast Colour) for water quality parameter retrieval. - **GIS Analysis:** Longitudinal profiling of water quality along the canal path using GIS-based network analysis.

Expected Scientific Contribution: The study will demonstrate the feasibility of route-wide water quality monitoring from space. It will provide a framework for integrating remote sensing into Water Environmental Capacity (WEC) management, moving beyond point-source measurements to continuous spatial monitoring.

Potential Study Regions: - The Middle Route of the SNWDP from Danjiangkou to Beijing. - The Sao Francisco River Transbasin Diversion, Brazil.

Research Idea 5: Assessing the Hydrological and Geomorphological Impacts of Increased Discharge on Recipient River Channels: A Multi-Sensor Approach

Background and Justification: As shown in the Lake Urmia case (Bui et al., 2020), IBWT can dramatically increase the discharge of destination rivers (sometimes tripling it), leading to unintended flood inundation and morphological changes. This research idea emphasizes using GIS and multi-sensor satellite data (e.g., SAR and Optical) to quantify these physical transformations and their impacts on local land cover and infrastructure in receiving basins.

Research Objectives: - To map the changes in surface water area and flood inundation extent in recipient river channels post-IBWT. - To quantify riverbank erosion and geomorphological shifts caused by sustained high-discharge events. - To assess the risk to human infrastructure and agricultural land adjacent to recipient channels.

Proposed Methodology: - **Satellite Datasets:** **Sentinel-1 (SAR)** for monitoring inundation during cloudy periods and detecting subtle surface changes. **Landsat-8/9** and **Sentinel-2** for multi-temporal surface water area (SWA) extraction. - **GIS Analysis:** Digital Elevation Model (DEM) analysis (using **SRTM** or **Copernicus DEM**) to model potential flood zones at different discharge levels. - **Change Detection:** Land use/land cover (LULC) change detection to quantify the loss of riparian land to expanded river channels.

Expected Scientific Contribution: This research will provide critical insights into the “downstream hydraulic risks” of IBWT, which are often overlooked in the planning phase. It will offer a robust, multi-sensor methodology for monitoring geomorphological stability in artificial hydrological systems.

Potential Study Regions: - Gadar River and Lake Urmia, Iran. - Fenhe River Basin, China.