Estimation of Groundwater Storage Changes in Transboundary Cambodia-Mekong River Delta Aquifer using GRACE Satellite

Surabhi Upadhyay[1]; Sangam Shrestha[1]; Ho Huu Loc[1]; Santosh Dhungana[1]; Lim Sokneth[2]

[1] Asian Institute of Technology, Thailand
[2] ALLEZ Engineering and Technology, Cambodia

OUTLINE

- Introduction
- Study Area
- Data Used
- Methodology
- Results and Discussion
- Conclusion

INTRODUCTION

- **Groundwater** – a fundamental component of the global hydrological cycle
- Vital freshwater source – **agriculture, industry, public supply, and ecosystems** increasingly reliant on groundwater
- In **Lower Mekong Basin**, groundwater supplies water to approximately **60 million** people (MRC, 2010).

<u>Stressors</u> on groundwater in the **Cambodia-Mekong River Delta aquifer -** climate change and excessive abstraction (Lee et al., 2018) leading to land subsidence, water shortage, and saltwater intrusion (Chen et al., 2016).

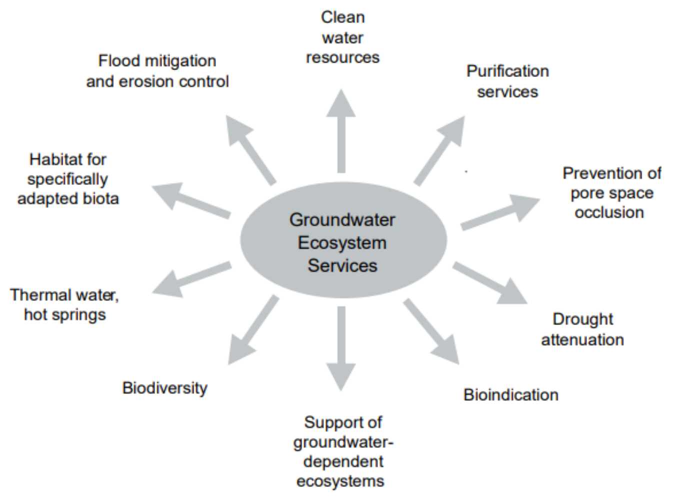


Fig: Importance of groundwater ecosystems (Avramov et al., 2010)

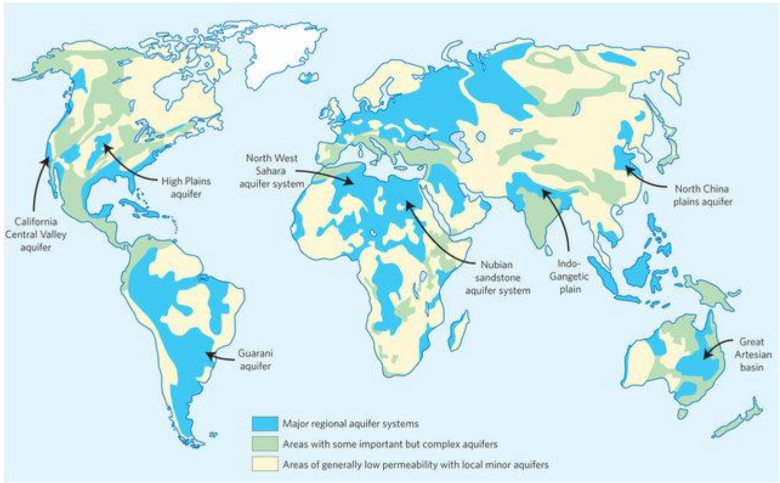


Fig: Major aquifers of the world (Lee et al., 2018)

INTRODUCTION

- Water security in **Vietnam** – proper understanding of the **regional groundwater flow regimes** – especially associated with the recharge within the **Cambodian territory**.
- Increase in **population** and **economic development** - stressed **shared aquifer resources** – in near future – might result in **conflicts.**

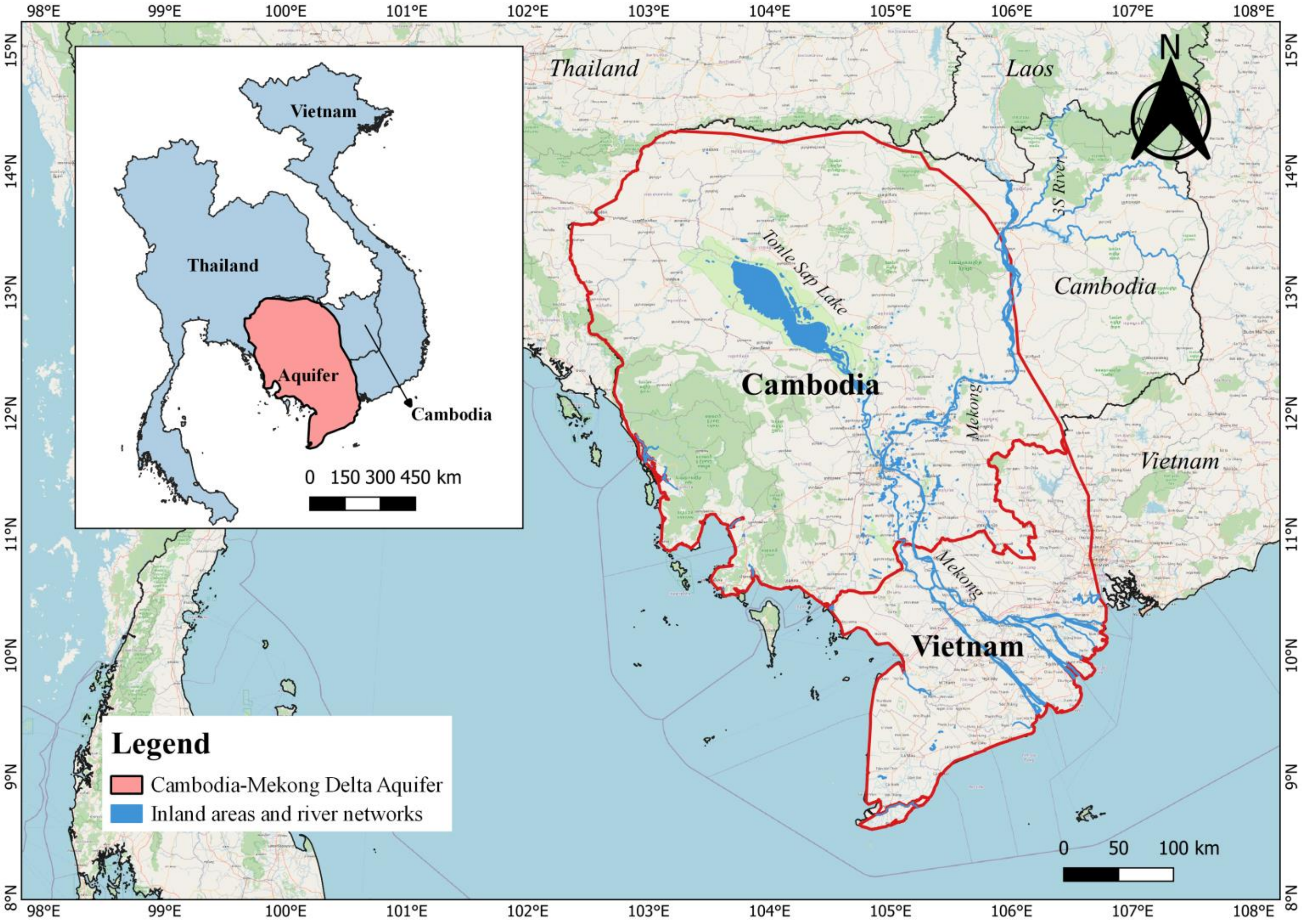
Figure 4: Rice fields in Mekong Delta, near Can Tho, Vietnam
Source: Circle of Blue

Figure: Increased groundwater use in Cambodia
Source: The Phnom Penh Post

Objective

To **evaluate** the viability of remote sensing data to accurately estimate **changes in groundwater storage (GWS)** and **assess** the **spatio-temporal trend in GWS change**

STUDY AREA: Cambodia-Mekong River Delta Aquifer



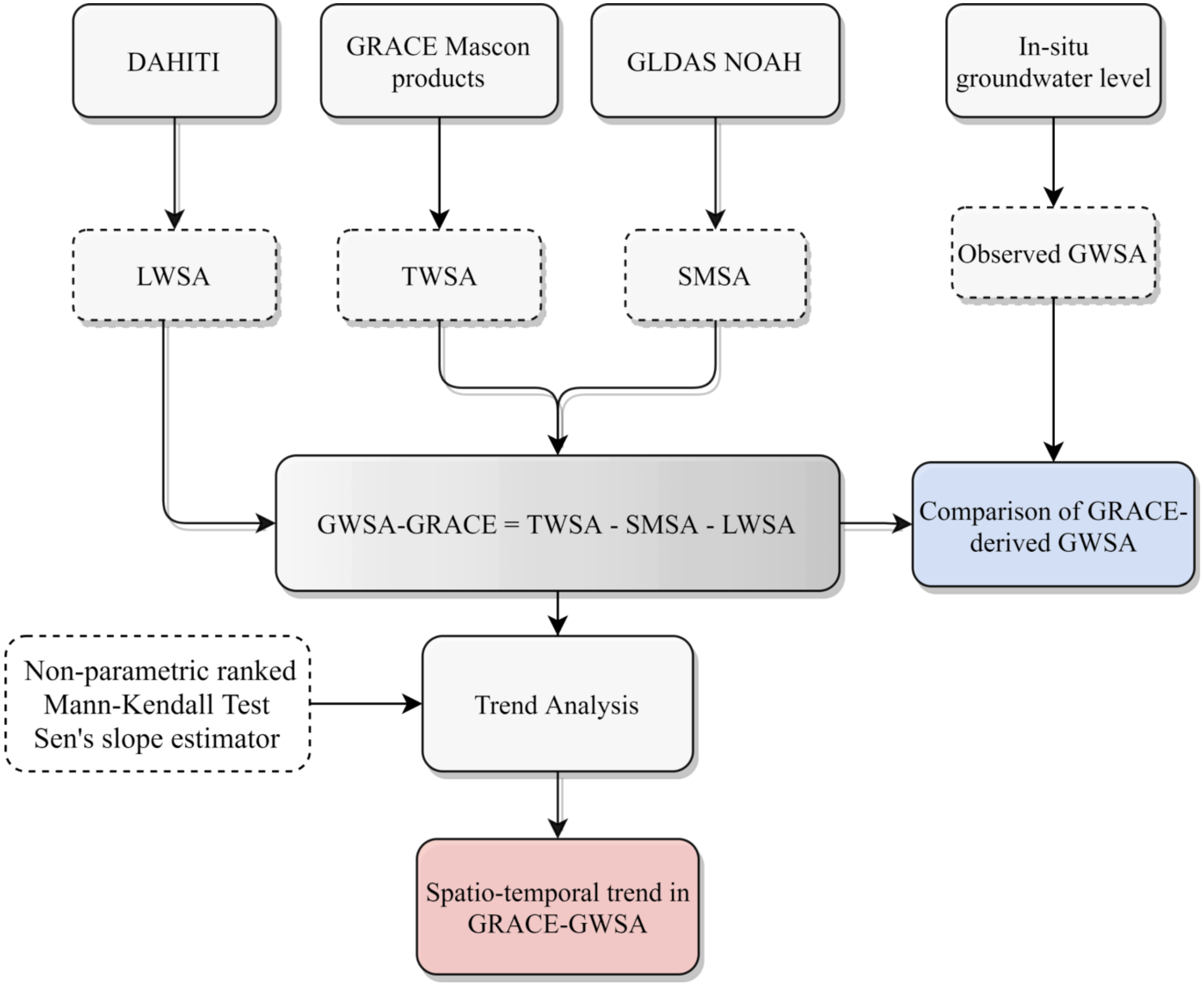
Study area map: The Cambodia-Mekong River Delta aquifer

- **Area:** 180,000 square kilometers
- **Aquifer type and deposits:** Alluvial type with complex unconsolidated to semi-consolidated alluvial sediments
- **Shared countries:** Cambodia (80%) and Vietnam (20%)
- **Climate:** Tropical dry
  - **Wet season:** May to October
  - **Dry season:** November to April
- **Major water bodies:** Tonle Sap lake in Cambodia and Mekong River in Vietnam

DATA USED

Components	Data Description	Spatial and Temporal Resolution	Time span	Units	Sources
Satellite Remote Sensing					
Terrestrial Water Storage Anomaly (TWSA)	GRACE mascon solutions a. CSR-M b. JPL-M c. GSFC-M	0.5°× 0.5°, Monthly	2002-2017	cm	CSR-M JPL-M GSFC-M
Lake Water Level and Area	Tonle Sap Lake	Monthly	2002-2017	m	DAHITI
Land Surface Model					
Soil Moisture Storage, Evapotranspiration	GLDAS v.2.1 (NOAH)	0.25°× 0.25°, Monthly	2002-2017	cm	GLDAS
Ground-based observations					
Groundwater Level	**Cambodia** Kampong Speu Prey Veng Siem Reap	Monthly	2014-2017 2006-2008 2006-2008	m	NexView Project
	Vietnam Mekong Delta	Monthly	2002-2015	m	Division for Water Resources Planning and Investigation for the South of Vietnam (DWRPIS)

METHODOLOGY: Overall framework



GRACE: Gravity Recovery and Climate Experiment
GLDAS: Global Land Data Assimilation System
DAHITI: Database for Hydrological Time Series of Inland Waters
TWSA- Terrestrial Water Storage (TWS) Anomaly
SMSA - Soil Moisture Storage (SMS) Anomaly
LWSA - Lake Water Storage Anomaly
GWSA - Groundwater Storage Anomaly

METHODOLOGY: Satellites overview

GRACE

Satellite mission - launched to measure the time-varying component of Earth's gravity field and **track the mass change** in the hydrosphere, cryosphere, and oceans with high accuracy at ~**30-day intervals**. Integrate water storage changes from the **land surface** to the **deepest aquifers.**

GLDAS

Integrates **satellite**-and **ground-based** monitoring data and aims to produce **optimal land surface and flux variables.** Gives an **independent** estimation of **soil moisture**, **canopy water storage**, and **snow water equivalen**t.

DAHITI

Database for hydrological time series of inland waters estimates the **water level time-series** for lakes from **multi-mission satellite altimetry** and **surface area** using optical imagery like **Landsat and Sentinel-2**.

RESULTS and DISCUSSION

- Cambodia – **old and young alluvium deposits**
- **Old deposits** – thick pile of coarser textured sediments
- **Young alluvium** – finer grained -silts and clays

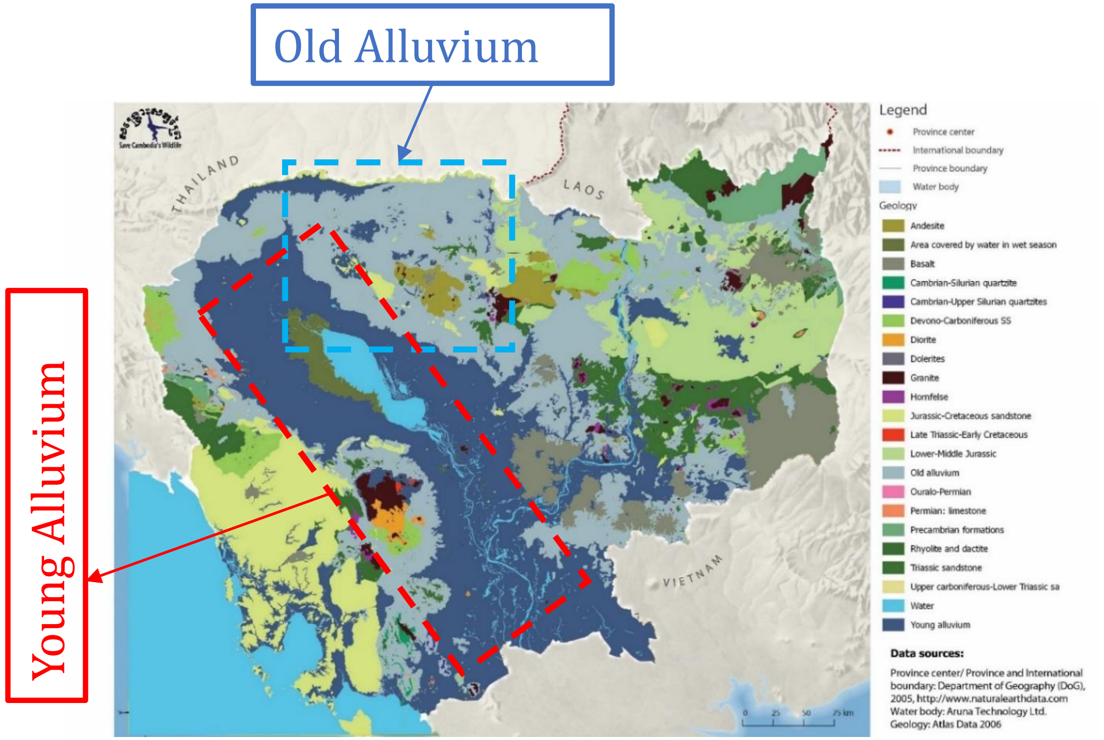


Fig: Geology of Cambodia

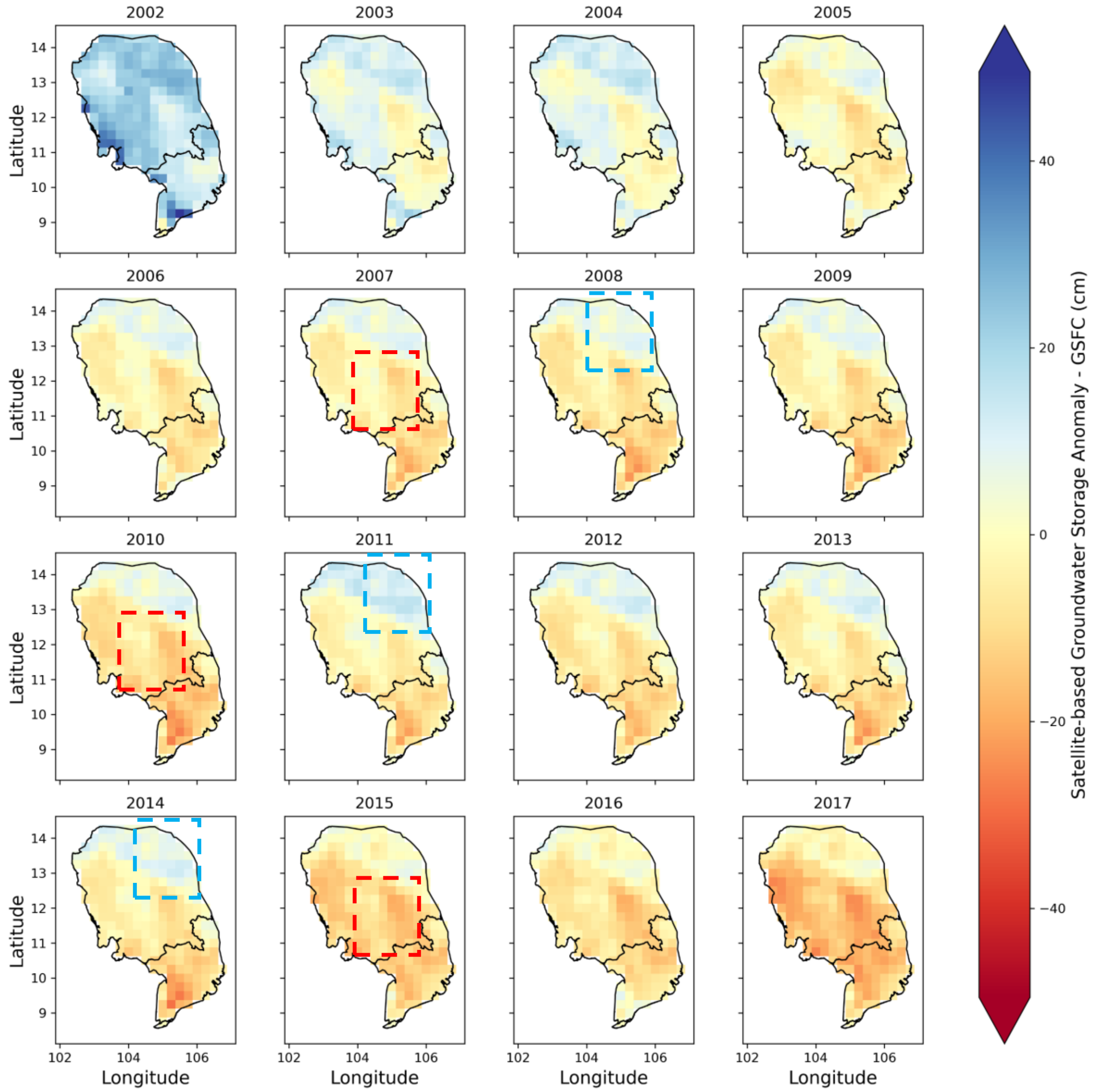


Fig: Yearly variation in groundwater storage anomalies

RESULTS and DISCUSSION

- **Eight alluvium aquifers** in Mekong Delta Vietnam (Vuong et al., 2016).
- **Holocene aquifer –** poor water quality - less yield and high susceptibility to pollution.
- Aquitard and aquicludes **limit recharge** to deeper aquifers (Pleistocene and Miocene) (Vuong et al., 2016).

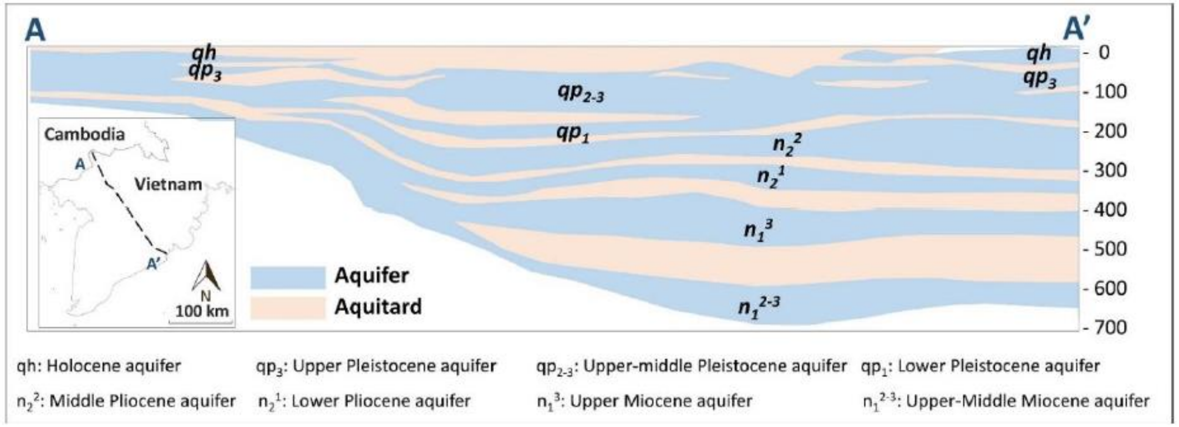


Fig: Hydrogeology of Mekong Delta, Vietnam

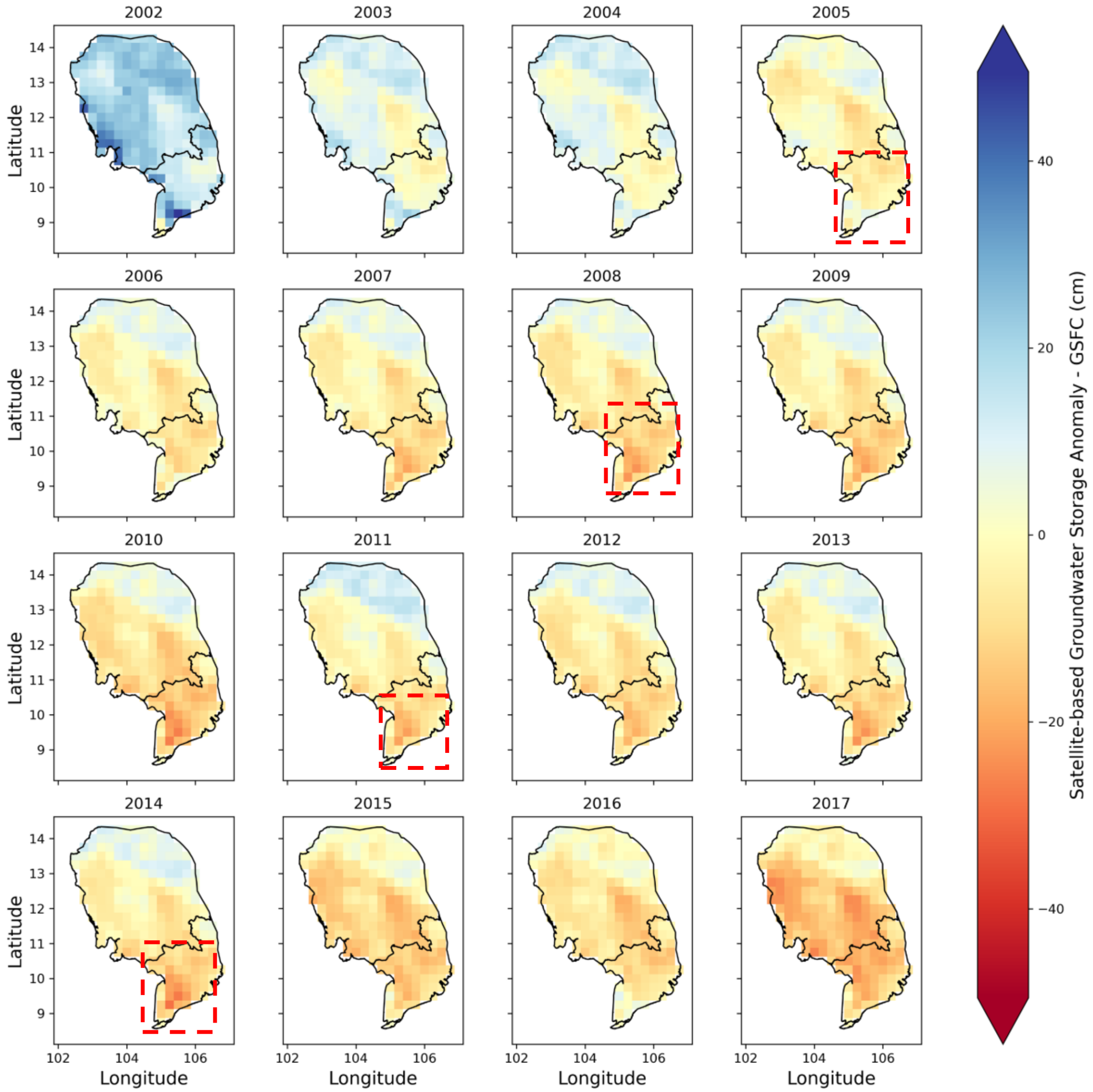


Fig: Yearly variation in groundwater storage anomalies

RESULTS and DISCUSSION

Comparison between GRACE-satellite and observed data in grid scale

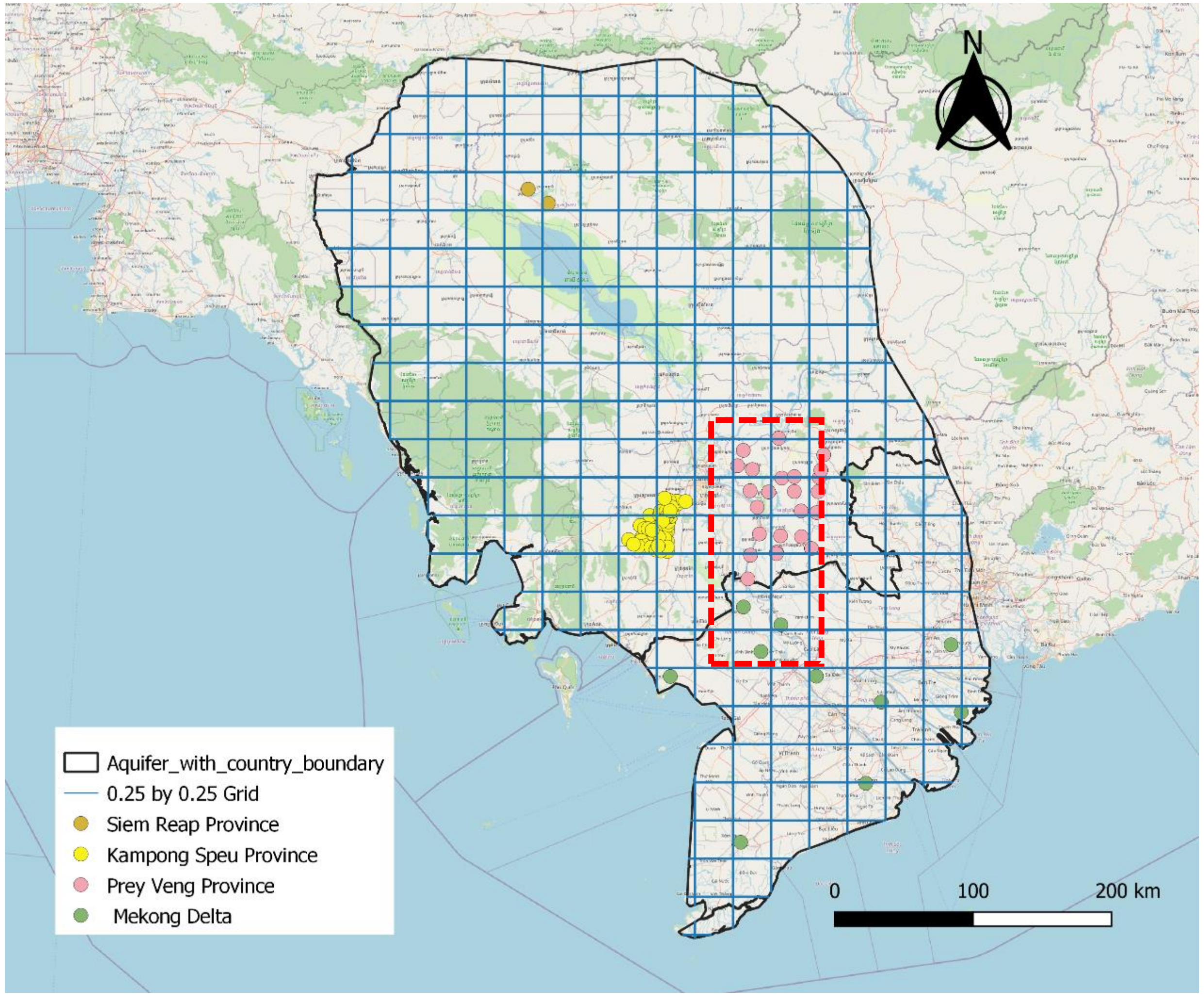


Fig: Location of monitoring wells

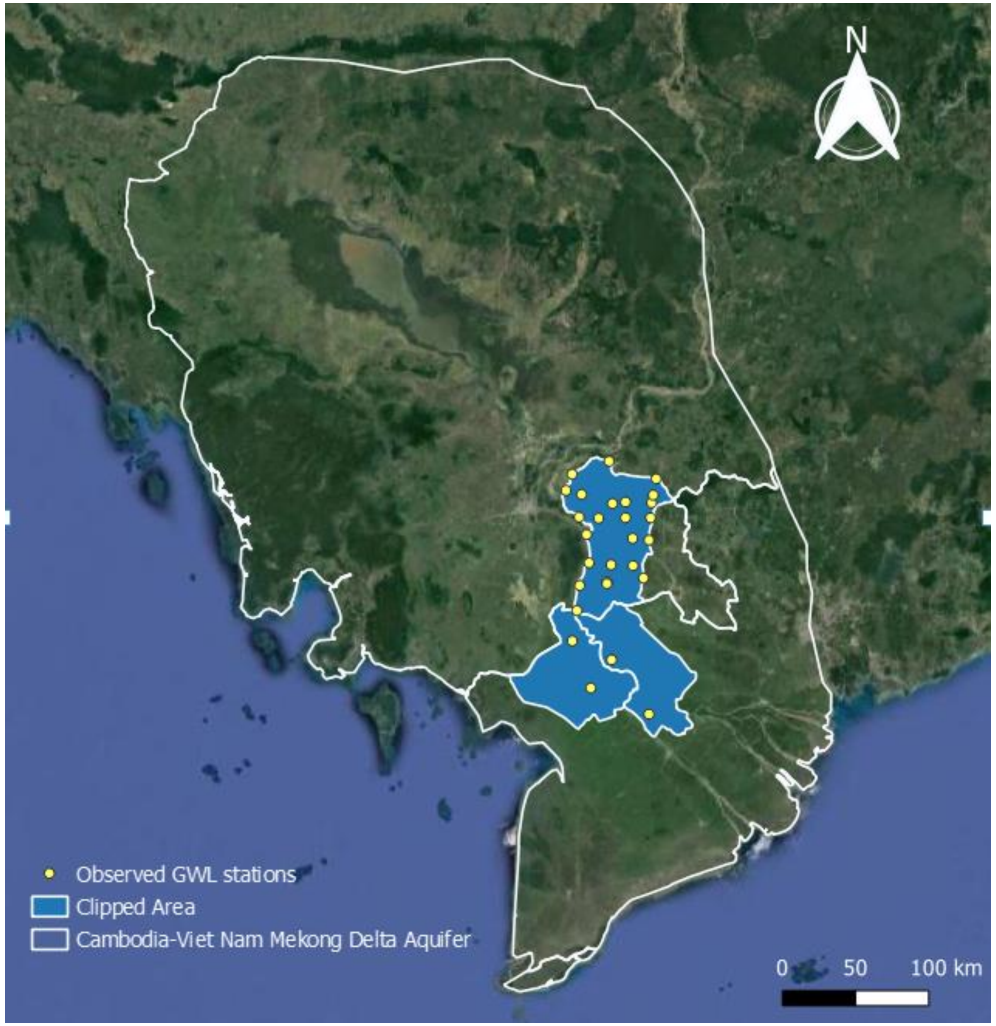


Fig: Grid to grid comparison

RESULTS and DISCUSSION

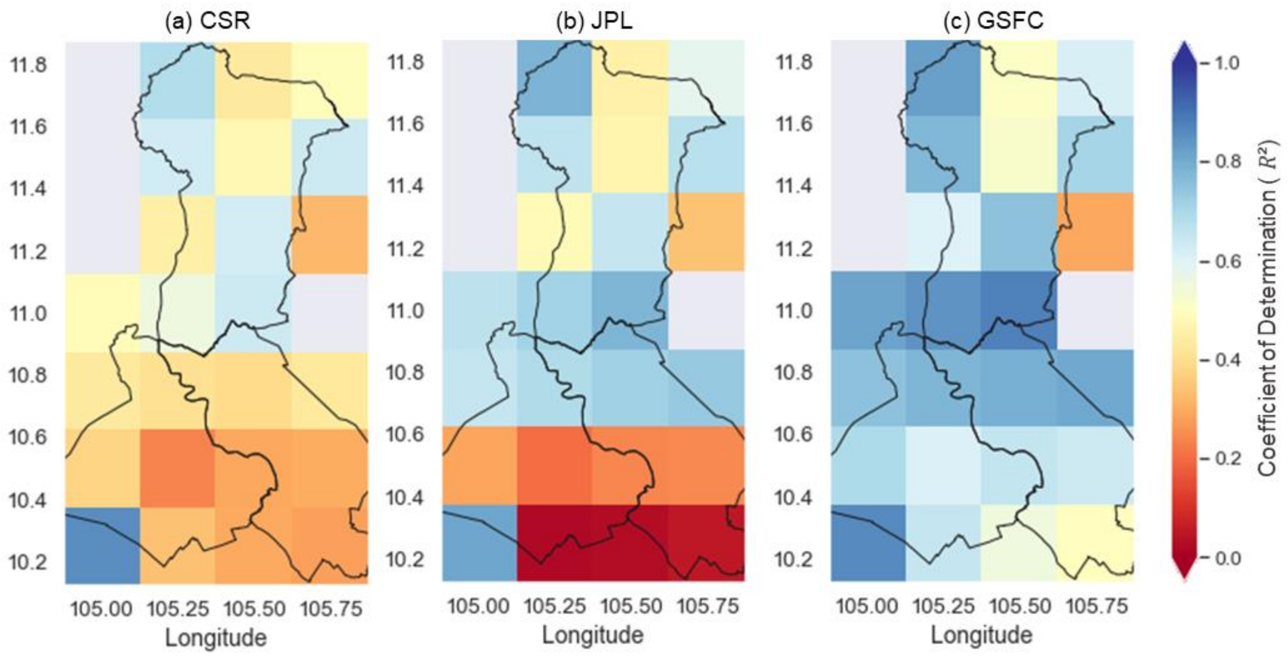


Fig: Correlation between GRACE-GWSA and observed-GWSA for
(a) CSR, (b) JPL, and (c) GSFC satellite

GWSA= groundwater storage anomaly
r = Pearson correlation coefficient
R^2 = Coefficient of determination,
RMSE = Root mean square error
MAE =Mean absolute error

Components	GRACE satellites	r	R^2	RMSE (cm)	MAE (cm)
GWSA (2006-2008)	CSR	0.78	0.61	11.97	10.55
	JPL	0.81	0.66	10.76	9.32
	GSFC	0.91	0.82	10.10	8.90

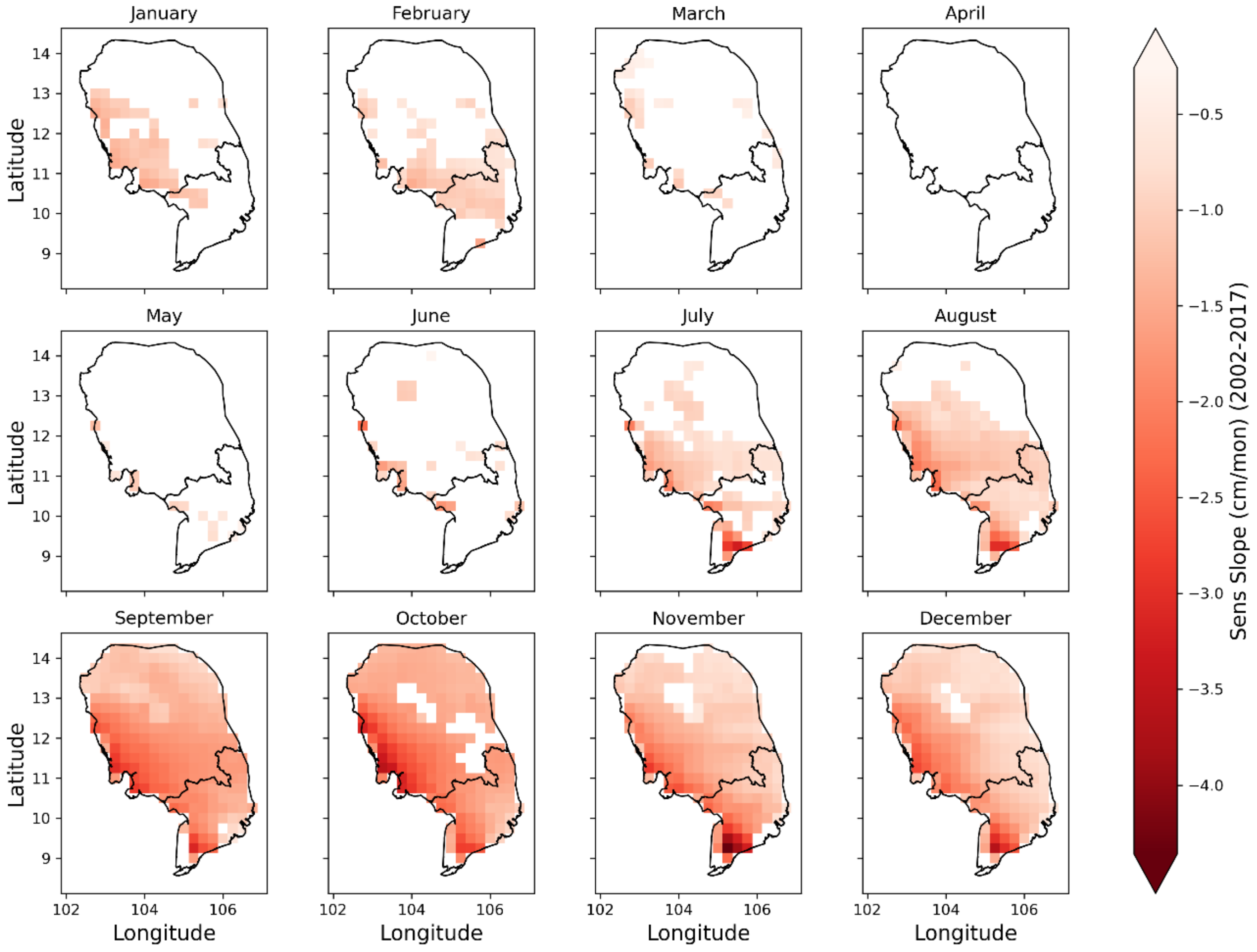
Reasons for discrepancies

- GRACE GWSA is available in grid-cell and cannot capture **local signals** (Tangdamrongsub & Šprlák, 2021)
- Ground-based observations – captures the change in groundwater level in a **certain aquifer**, GRACE captures for **all aquifers** (Guo et al., 2022).
- **Specific yield** and **specific storage** in this study were derived from past literature (Rateb et al., 2020)

RESULTS and DISCUSSION

Month	Significant trend	Z-value	Rate of Depletion (cm/yr)	Total loss (km^3)
Jan		-1.48	-0.35	-10.85
Feb		-0.30	-0.13	-4.05
March		-1.39	-0.31	-9.57
April		-0.59	-0.11	-3.36
May		-0.10	-0.03	-0.93
June		-1.67	-0.19	-5.76
July		-1.09	-0.30	-9.14
Aug		-1.48	-0.60	-18.40
Sept	*	-2.97	**-1.05**	**-31.98**
Oct	*	-2.67	**-1.17**	**-35.86**
Nov	*	-2.57	**-0.87**	**-26.47**
Dec	*	-2.67	**-0.84**	**-25.72**
Wet season	*	-2.93	**-0.85**	**-26.09**
Dry season	*	-2.21	**-0.54**	**-16.53**
Annual	*	-2.84	**-0.68**	**-18.28**

**Note: Red highlights show declining groundwater storage anomaly at a confidence interval of 95% trends in the study area*



Sen's slope GRACE-GWSA (cm/year) (p<0.05)

RESULTS and DISCUSSION

- Rapid rise in the use of groundwater for **irrigating rice** in both **Cambodia and Mekong Delta - declining** groundwater storage anomalies
  - **20%** of groundwater is used for irrigation in the Mekong Delta and some parts of Cambodia.
- **Climatic variability** and **cropping pattern -** significant impact on groundwater level, **continuous pumping** through groundwater are responsible for negative trend (Chatterjee et al. 2020, Bera et al. 2021).
- Control mechanisms in terms of **groundwater abstraction** through some **effective laws and policies** needed in reducing depletion rate (Thomas & Famiglietti, 2019).

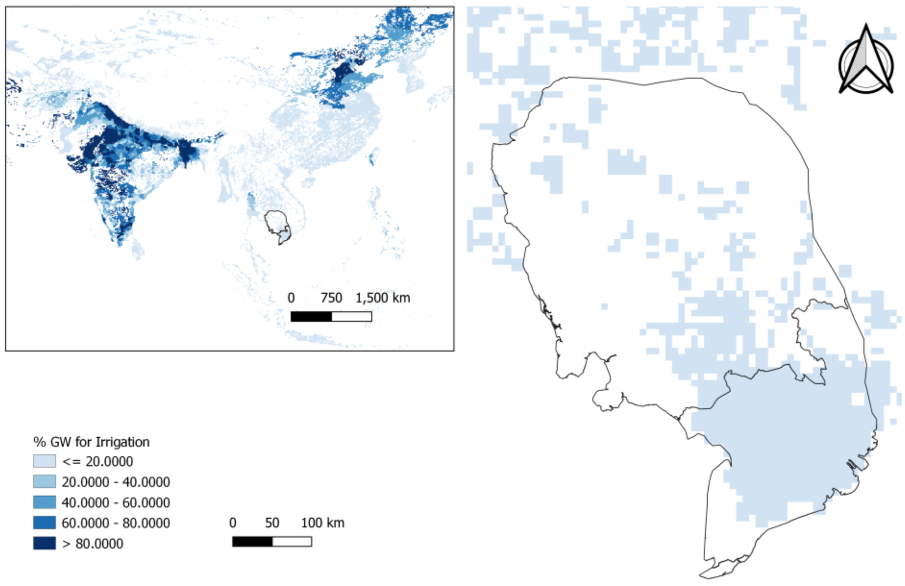


Fig: Percent of groundwater used for irrigation (extracted from FAO AQUASTAT)

RESULTS and DISCUSSION: Transboundary aquifer management

- Negative trend in GWSA –effective techniques for **science-based transboundary aquifer management** required
- In **Vietnam Mekong Delta**, groundwater resources monitoring, availability, and usage are limited, no proper legal framework is identified, very less involvement of local stakeholders in formulating and implementing policies, and governance was found to be centralized (Hamer et al., 2020)
- In **Cambodia**, proposed groundwater management strategies by (UNDP, 2020), strengthening institutional framework and law enforcement, capacity building of human resources in groundwater, groundwater inventory, enhancing coordination mechanisms and cooperation strategies, ***but not yet implemented***
- Two countries have **differences** in terms of laws and policies, levels of understanding of the groundwater system, complex hydrogeology, type of aquifers present, sectoral usage of groundwater, management priorities, etc.

CONCLUSION

- Two major components determining terrestrial water storage anomaly: **soil moisture storage anomaly** and **groundwater storage anomaly**.
- Correlation coefficient between GWSA obtained from GRACE and **PCR-GLOBWB greater than 0.7** with **observed GWSA greater than 0.8**.
- Long-term change in GWS showed a **declining trend** of **0.68 cm/year** and if it persists in the upcoming years, might have consequences for the domestic and agricultural sectors in the aquifer.
- **Potential** of **GRACE and GLDAS** in capturing the groundwater storage change in **data-scarce regions**.
- Basis for future research and in preparing policy briefs and groundwater management strategies for sustainable management of the **transboundary aquifer**

ACKNOWLEDGEMENT

Supported by **‘Ecosystem-based Adaptations for Sustainable Groundwater Resources Management in the Transboundary Cambodia-Viet Nam Mekong Delta Aquifer, Lower Mekong Region (GEBA)’** project

funded by **Sustainable Mekong Research Network (SUMERNET) 4 All** programme under **Stockholm Environment Institute (SEI)**


Thank You!