

# SNOW COVER DYNAMICS ACROSS THE HINDU- KUSH HIMALAYAS

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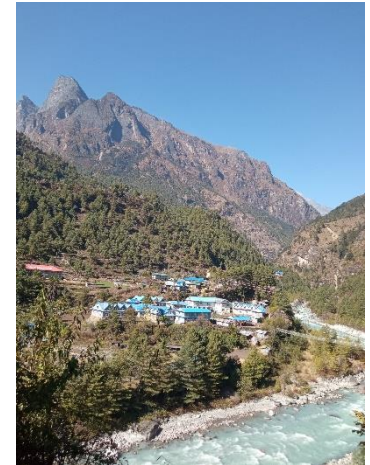
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# Introduction

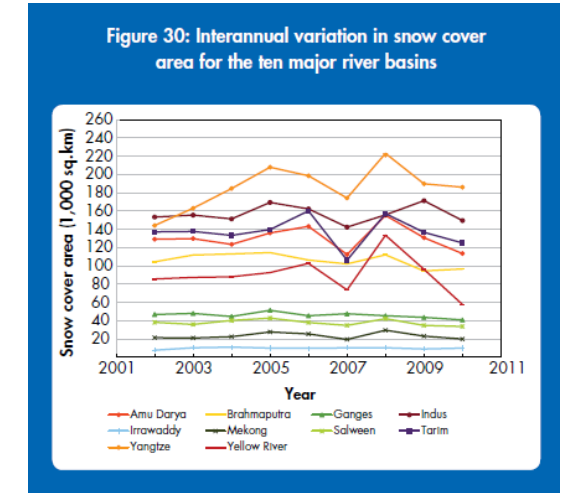
- More snow than anywhere else in the world outside the polar regions in HKH - (Panday et al. 2011), the third pole (Gurung et al. 2011),
- Snow fundamental source of discharge for 10 major Asian rivers (Immerzeel et al. 2010, Gurung et al. 2011), glacier and snow melt supports more than 1.3 billion people (Jianchu et al. 2007),
- HKH climatically sensitive (Beniston 2003, Bradley et al. 2006), increasing temperature trends (Gautam et al. 2009, Immerzeel 2008, Gusain et al. 2014) and decreasing precipitation trends (Bollasina et al. 2011, Palazzi et al. 2013),
- Strong correlation between snow cover and downstream discharge (Yang et al. 2009, Delbart et al. 2015), Negative correlation to atmospheric temperature (Barman et al. 2015, Bednorz 2004),



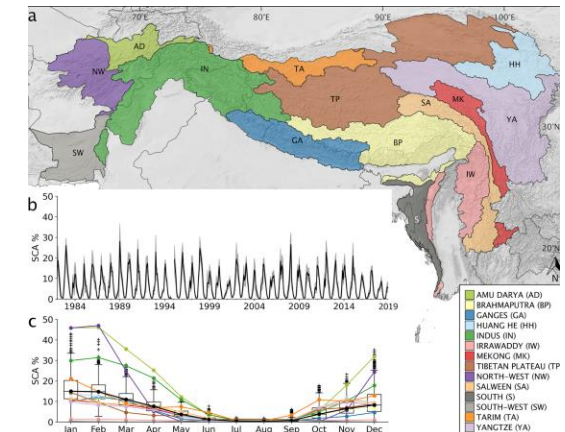
Pictures: Darwin Rana and Dibas Shrestha 2021



- Studies agree to a general decline in SCA across the HKH, results vary depending on regional scale, study period and data used (Hasson et al. 2014; Singh et al. 2018),
- For every °C increase in temperature, the snow line predicted to rise by about 150 m (Beniston 2003),
- Large variation in snow cover and increasing trend from west to east Himalaya's and the Tibetan plateau (Immerzel et al. 2008),
- Highest rate of declining SCA in Eastern HKH (Gusain et al. 2014, Singh et al. 2014, Gurung et al. 2017, Li et al. 2018),

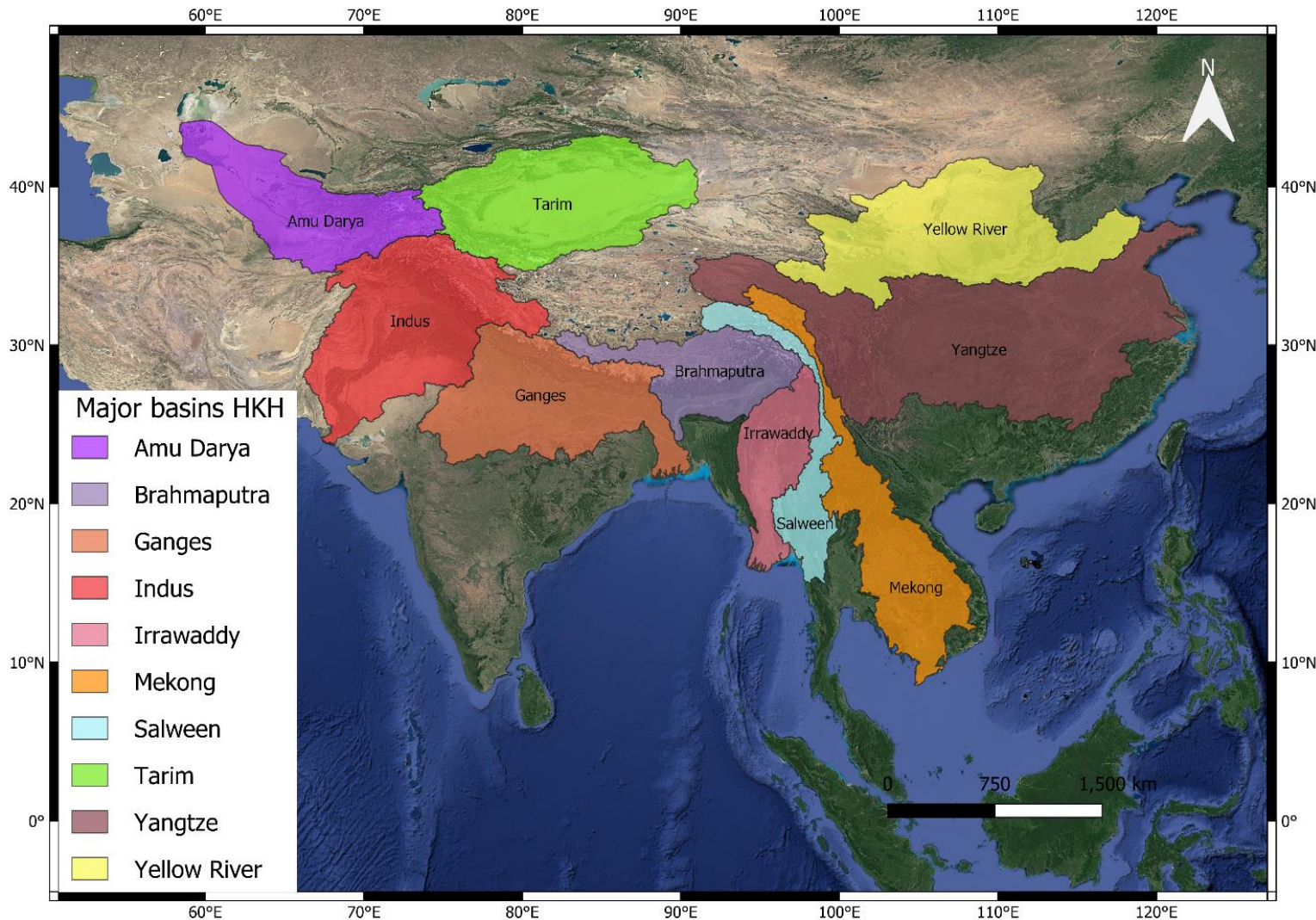


Gurung, DR; Amarnath, G; Khun, SA; Shrestha, B; Kulkarni, AV (eds) (2011) Snow-cover mapping and monitoring in the Hindu Kush-Himalayas. Kathmandu: ICIMOD



Naegeli, K., Franke, J., Neuhaus, C. et al. Revealing four decades of snow cover dynamics in the Hindu Kush Himalaya. *Sci Rep* **12**, 13443 (2022). <https://doi.org/10.1038/s41598-022-17575-4>

# Study Area



- South-east monsoon brings heavy rainfall in the eastern part during summer (JJAS), Westerly winds cause winter precipitation (DJFM) mostly in the form of snow in western part (Rees & Collins 2006),
- Westerly-influenced basins have longer periods of snow cover (Singh et. al 2014, Immerzeel et. al 2009, Gurung et. al 2017),

# Research Question

- What are the trends of SCA in the major basins of HKH?
- Is the SLE shifting upwards?

## Research Objectives

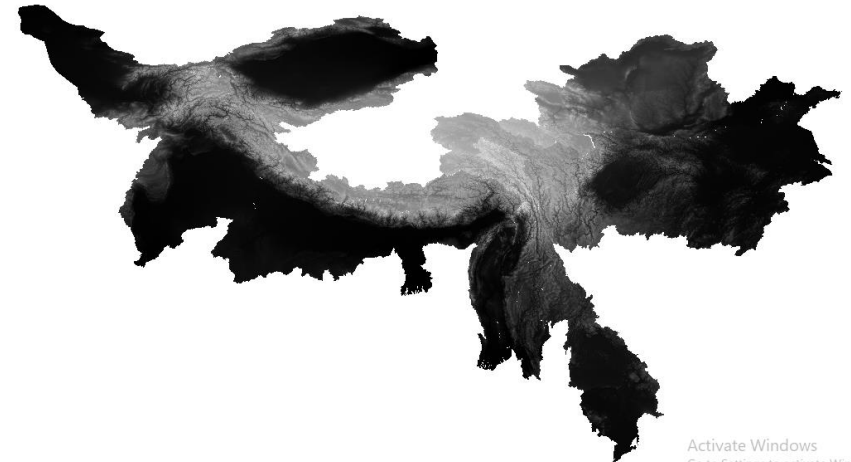
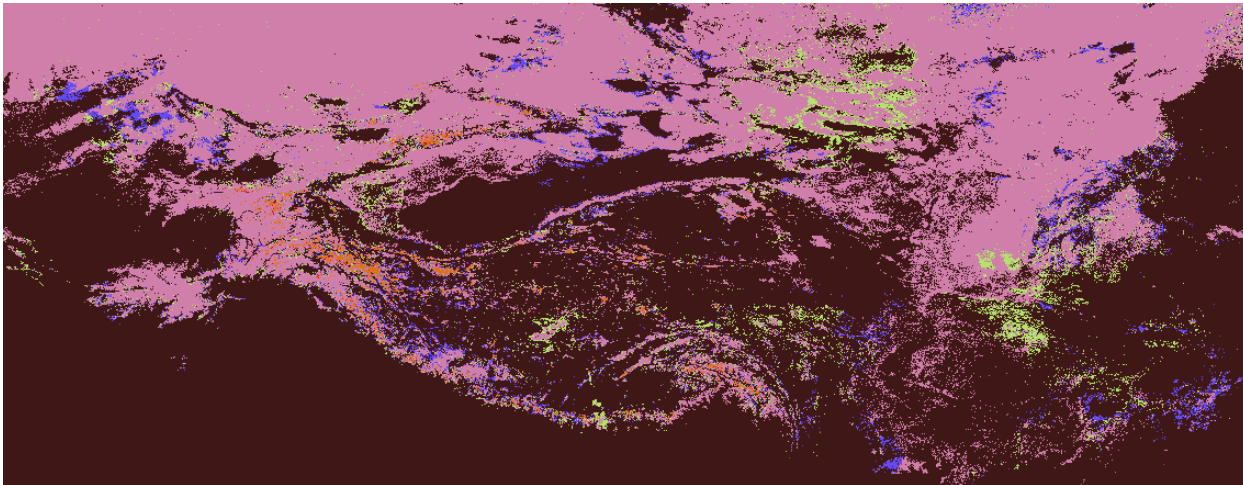
The main objective of the study is to evaluate Snow cover dynamics across the HKH through:

- Snow Cover Area and Snow Line Elevation



# Data

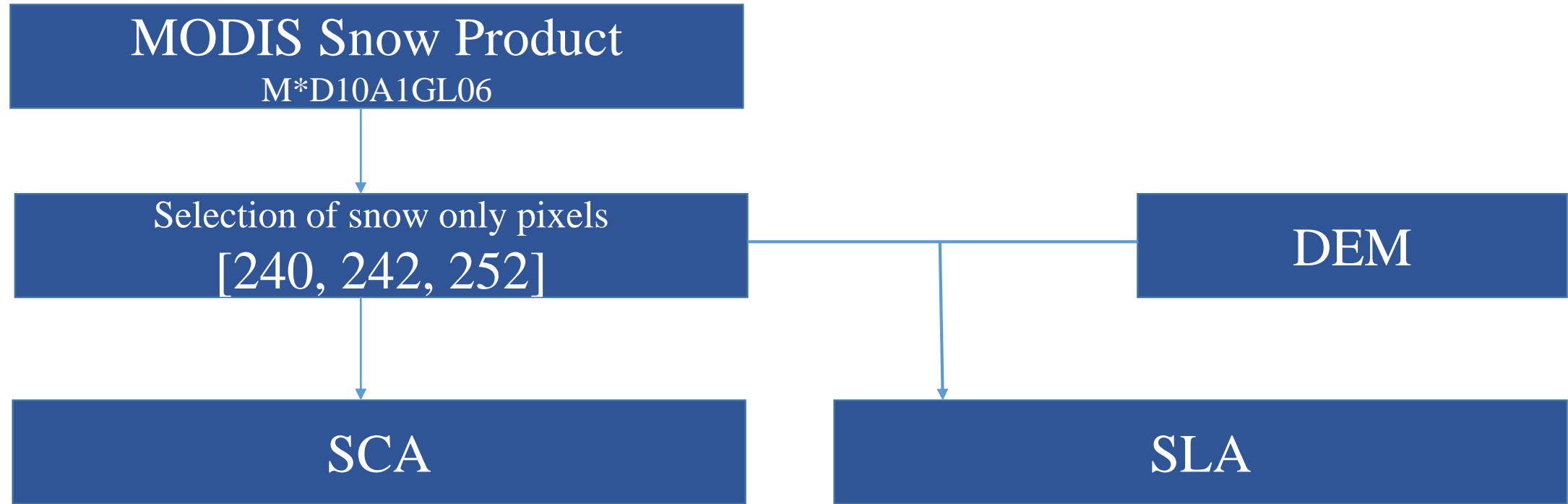
- Improved Terra–Aqua MODIS daily cloud-free snow and Randolph Glacier Inventory 6.0 combined product, named M\*D10A1GL06 for 2002 to 2019 covering the high mountain Asia (Muhammed and Thapa 2020) <https://doi.org/10.1594/PANGAEA.918198>,
- Original daily Terra and Aqua images cloud cover significantly removed with remaining clouds of 0.001%, average snow of 5.56% increased to 16.95%,
- Digital Elevation Model (DEM): SRTM 90m <http://srtm.csi.cgiar.org/>,



## Improved product described by thirteen classes:

- 25: No Snow
- 50: Cloud
- 198: Snow only in Terra
- 199: Snow only in Aqua
- **200: Snow in both Terra and Aqua**
- 238: Debris-covered ice with Terra Snow
- 239: Debris-covered ice with Aqua Snow
- 240: Exposed debris-covered ice
- **242: Debris-covered ice with Snow in both Terra and Aqua**
- 248: Debris-free ice with Terra Snow
- 249: Debris-free ice with Aqua Snow
- 250: Exposed debris-free ice
- **252: Debris-free ice with snow in both Terra and Aqua**

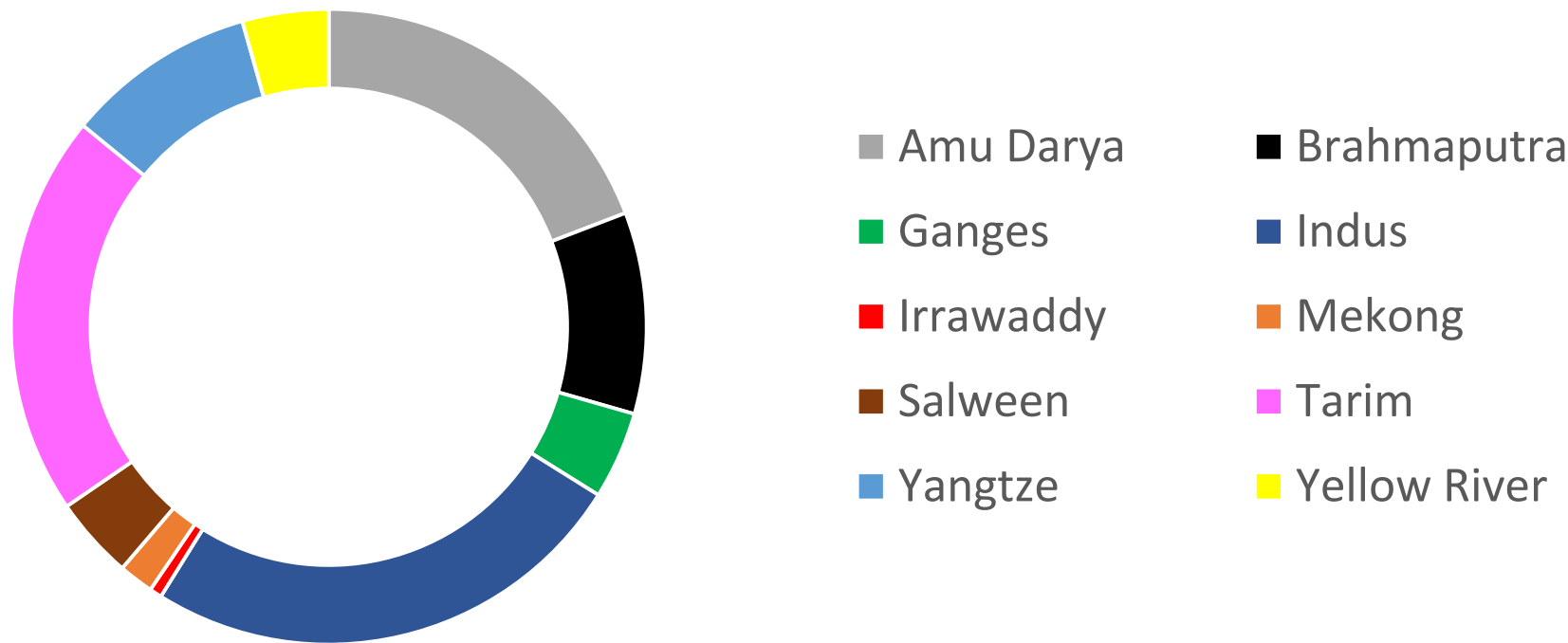
# Methodology



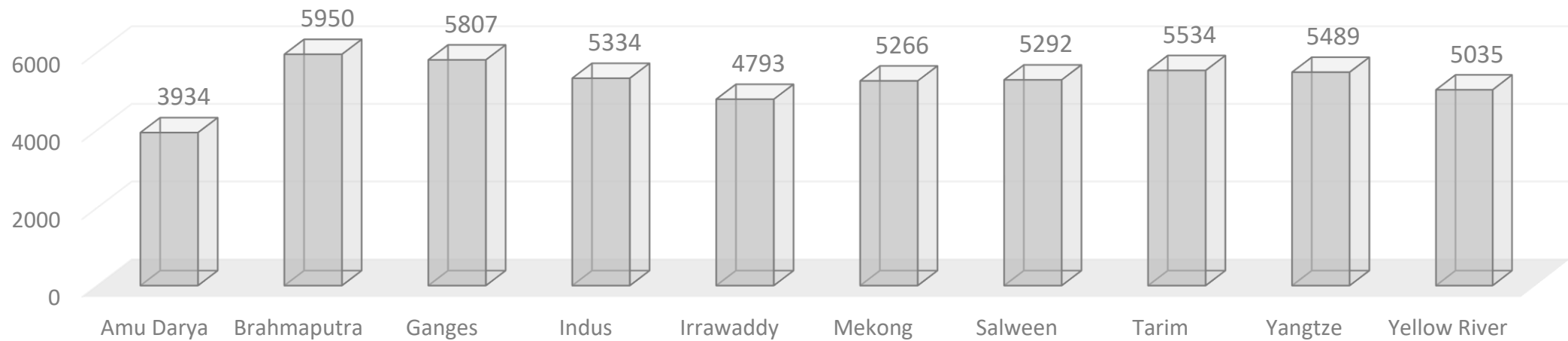
- Pixels with high presence of snow only selected for the analysis (probability 100%),
- Change in snow cover analyzed based on median snow cover,
- Krajčů et. al 2014 Method for estimation of snowline elevation (SLE),
- Applied the Mann-Kendall test to determine inter-annual trends (Mann 1945; Kendall 1975),



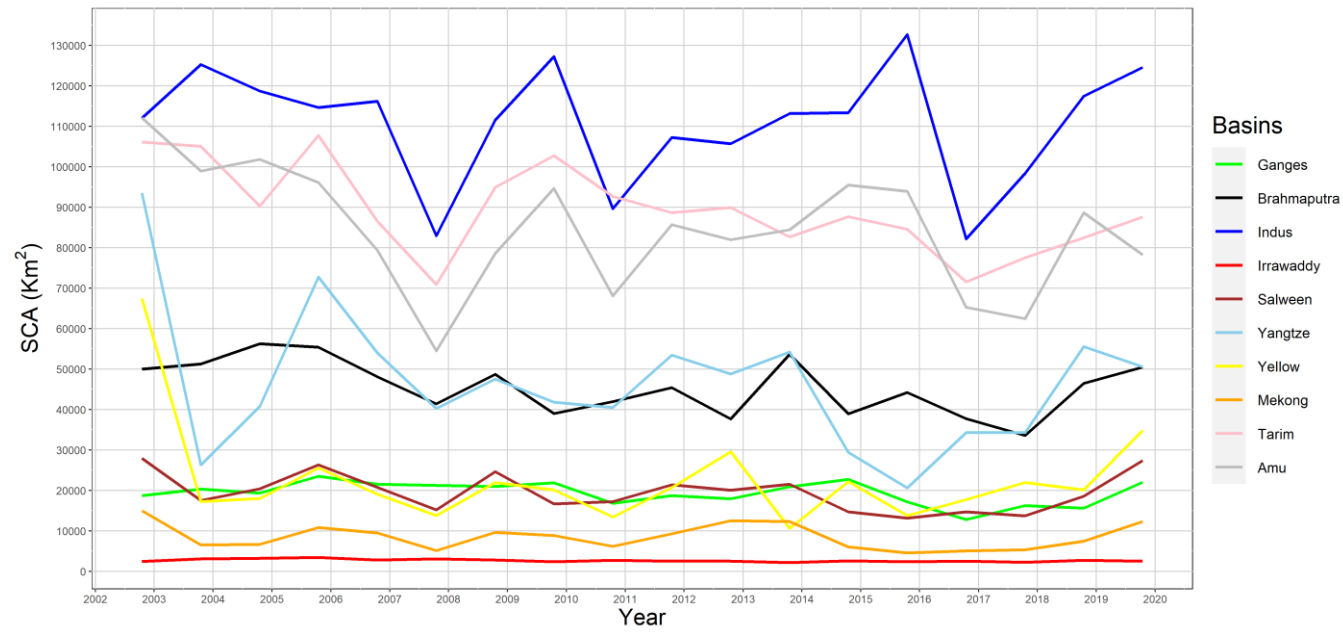
Snow Cover in the HKH



Snow Line in the HKH

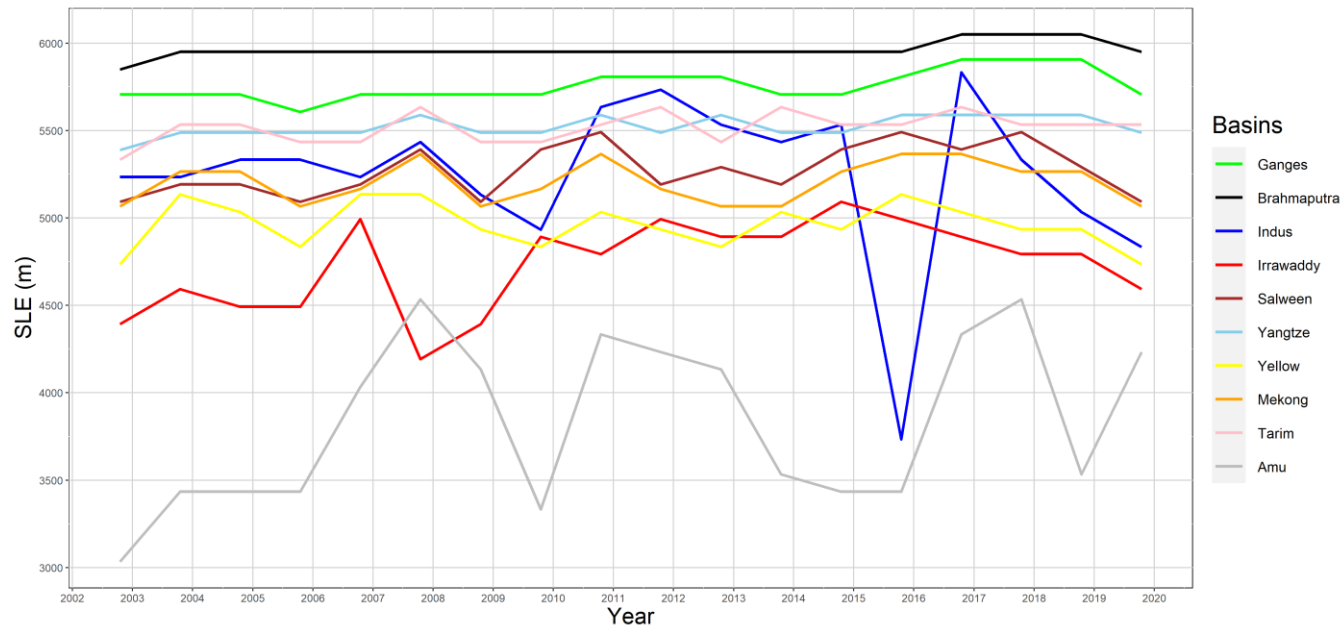


### Median Snow Cover Area in HKH



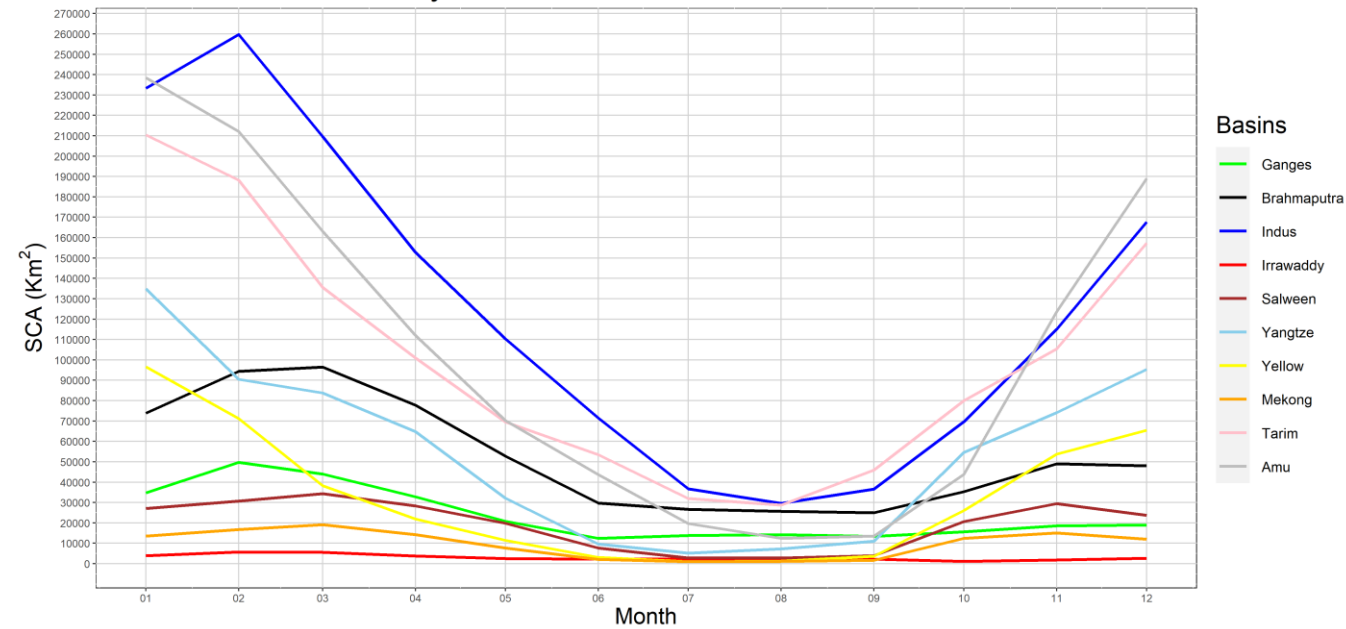
P-Value	
Yangtze	0.49537
Indus	0.82022
Irrawaddy	0.02803
Ganges	0.17269
Salween	0.12975
Brahmaputra	0.04888
Mekong	0.36332
Yellow	0.82022
Amu	0.04082
Tarim	0.00313

### Median Annual Snow Line Elevation in HKH

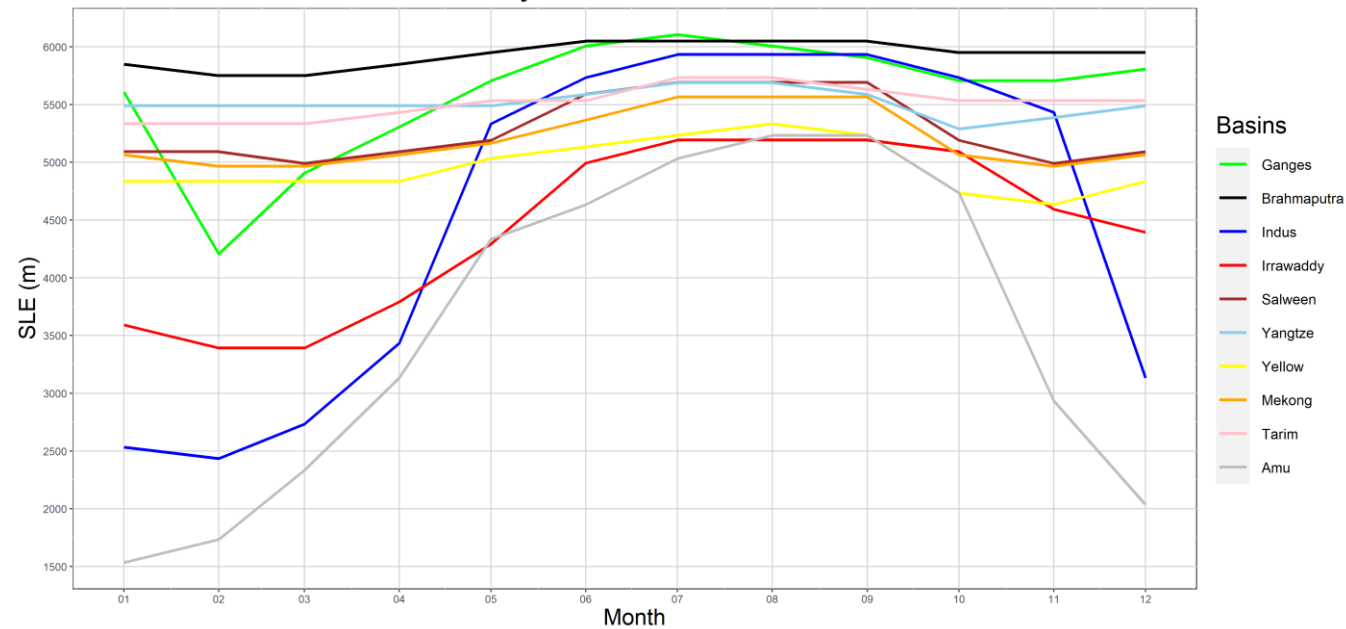


P-Value	
Yangtze	3.901E-22
Indus	2.243E-12
Irrawaddy	4.228E-34
Ganges	2.545E-36
Salween	4.687E-24
Brahmaputra	2.291E-39
Mekong	4.019E-06
Yellow	0.51802
Amu	2.342E-12
Tarim	3.043E-23

### Monthly Median Snow Cover Area in HKH

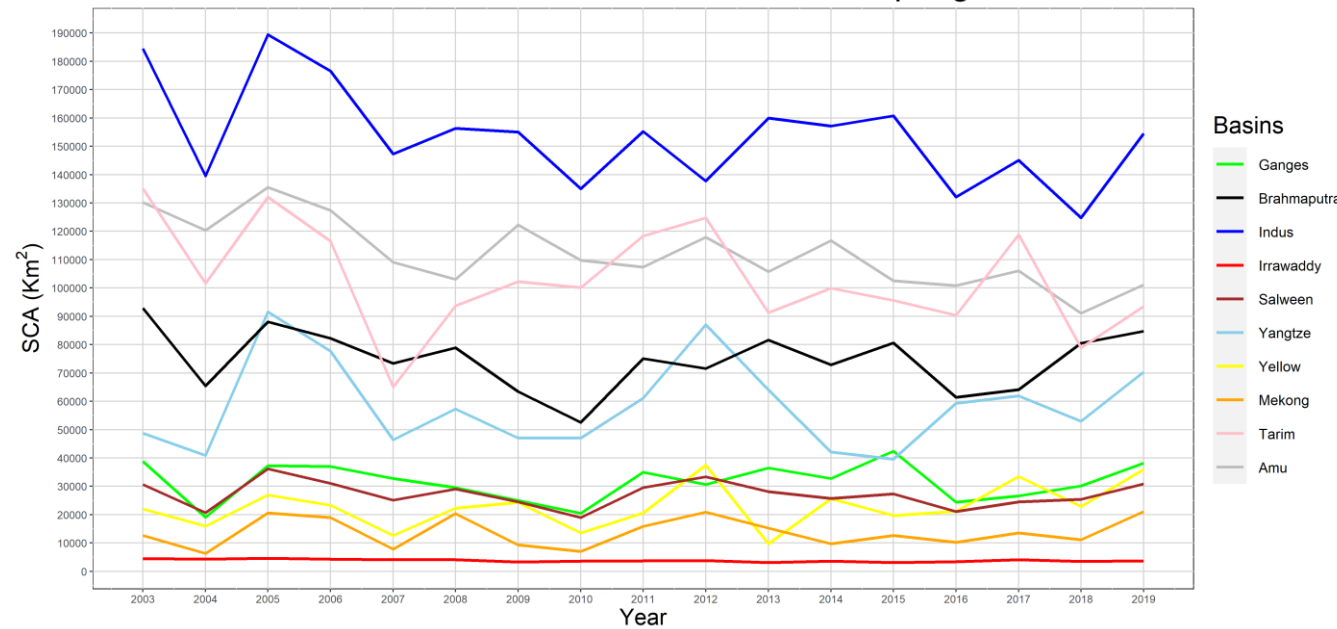


### Median Monthly Snow Line Elevation in HKH



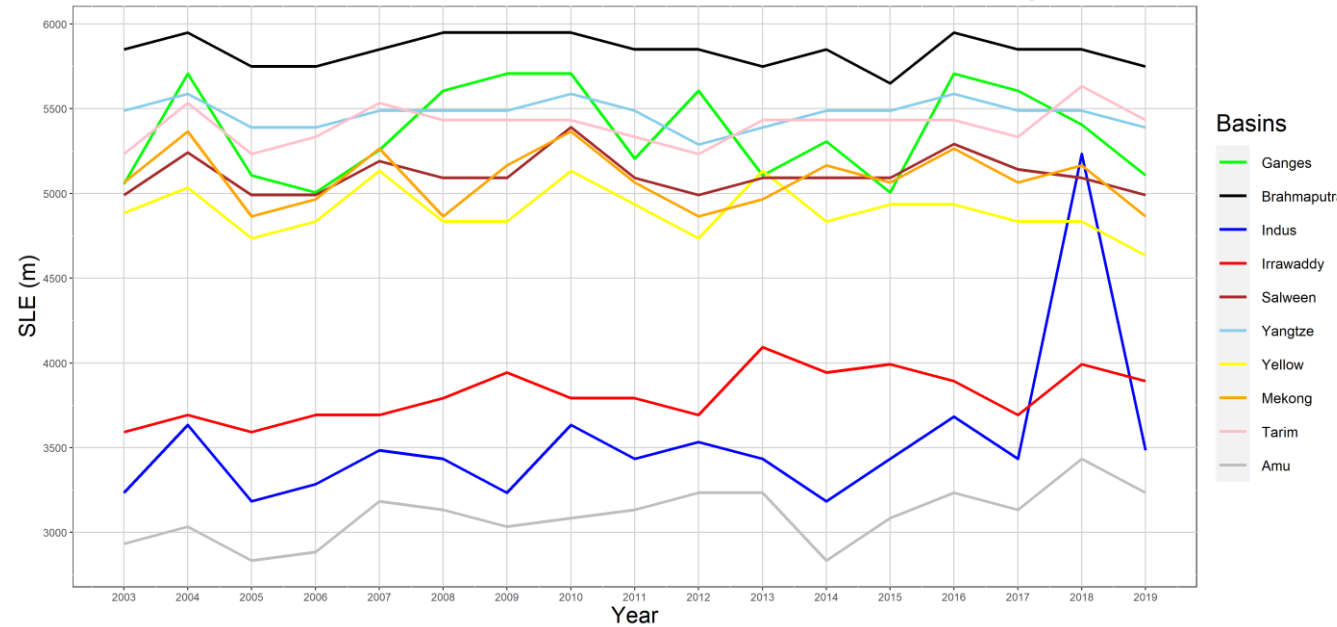


### Median Snow Cover Area in HKH in Spring



P-Value	
Yangtze	0.7108
Indus	0.0912
Irrawaddy	0.0058
Ganges	0.8368
Salween	0.4338
Brahmaputra	0.4838
Mekong	0.5923
Yellow	0.3031
Amu	0.0005
Tarim	0.0638

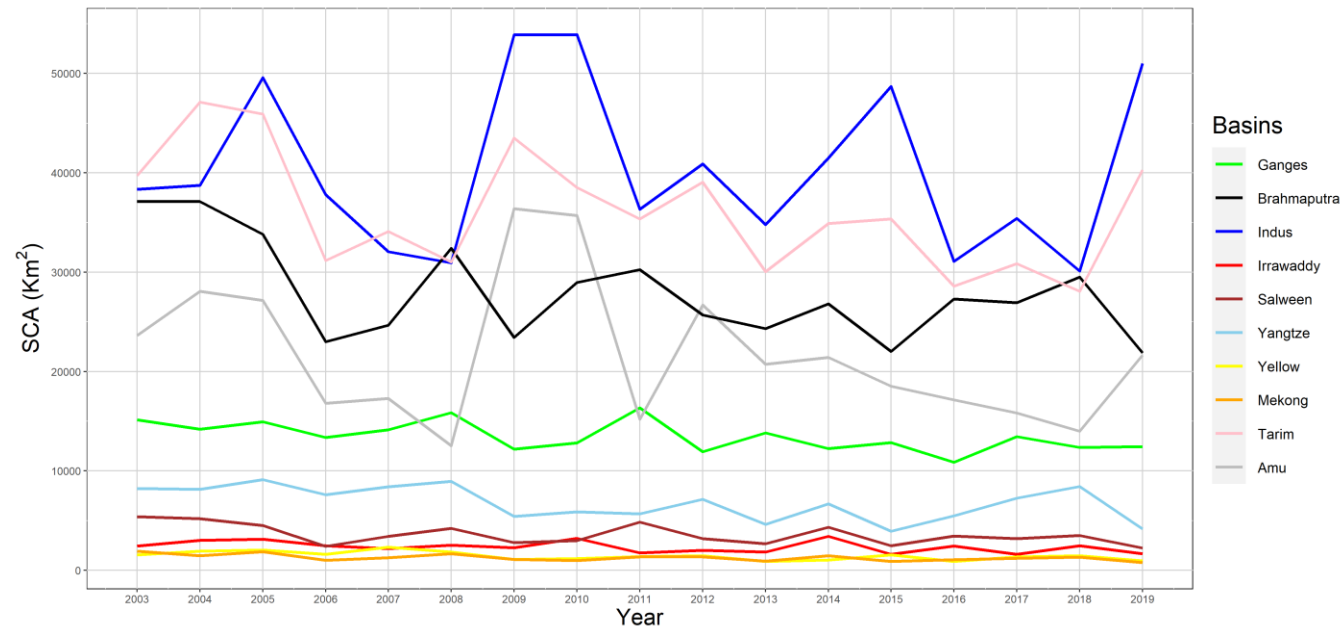
### Median Annual Snow Line Elevation in HKH in Spring



P-Value	
Yangtze	0.9276
Indus	0.1422
Irrawaddy	0.0071
Ganges	0.8672
Salween	0.6635
Brahmaputra	0.4298
Mekong	0.8996
Yellow	0.419
Amu	0.0085
Tarim	0.3785

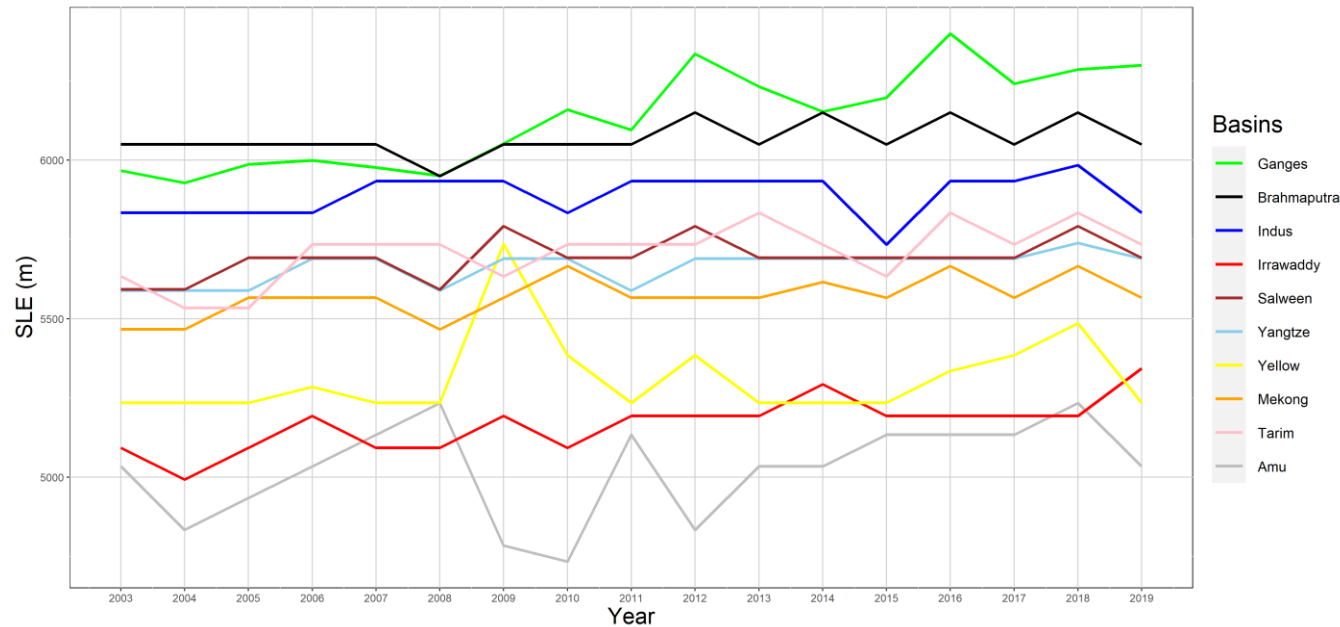


### Median Snow Cover Area in HKH in Summer



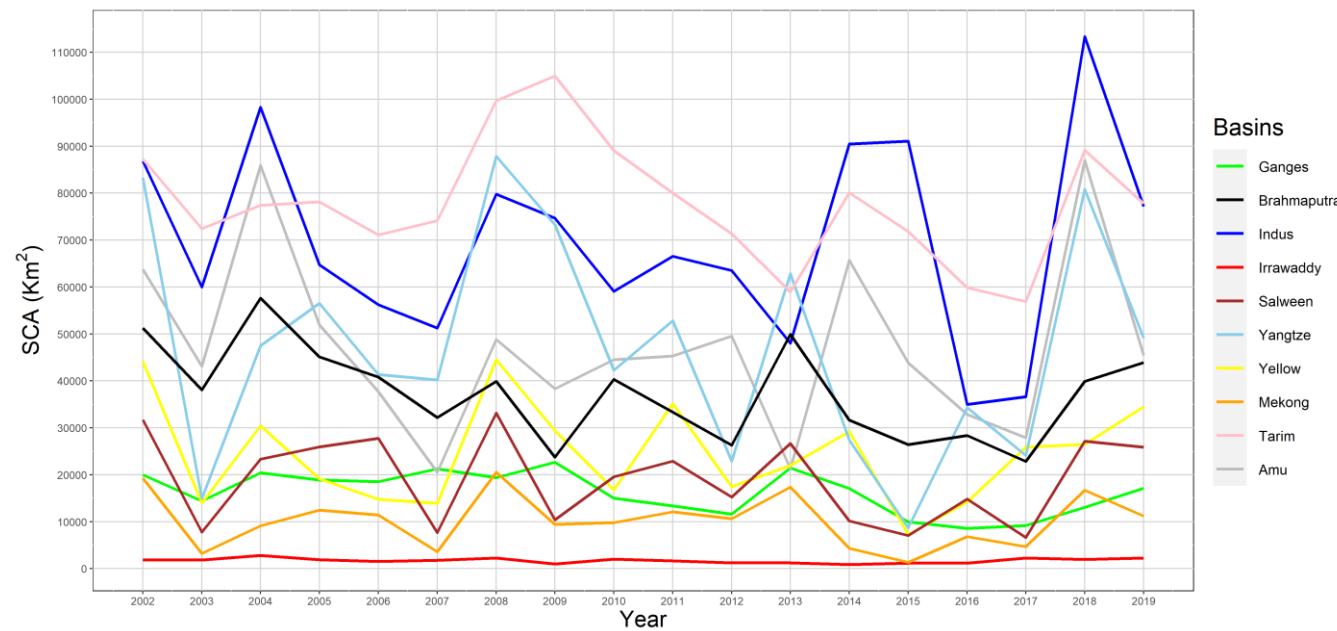
P-Value	
Yangtze	0.0435
Indus	0.6505
Irrawaddy	0.1082
Ganges	0.0357
Salween	0.0638
Brahmaputra	0.0765
Mekong	0.0235
Yellow	0.0235
Amu	0.1494
Tarim	0.0435

### Median Annual Snow Line Elevation in HKH in Summer



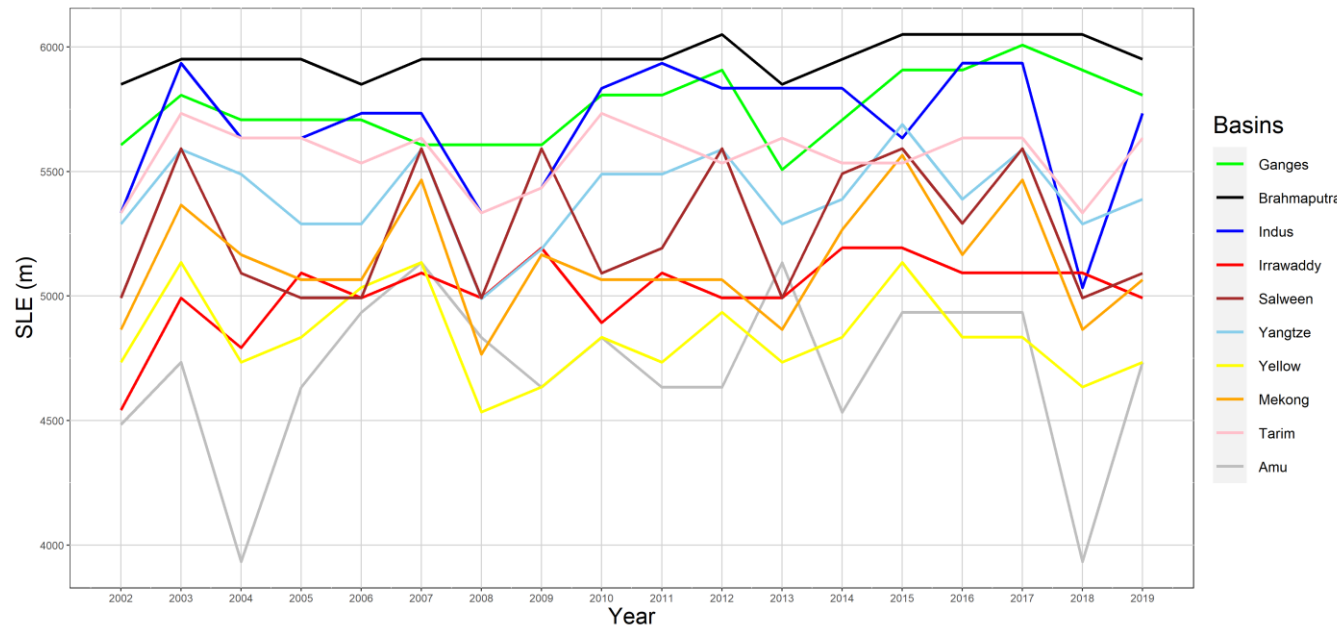
P-Value	
Yangtze	0.00544894
Indus	0.11642113
Irrawaddy	0.0012018
Ganges	9.10E-05
Salween	0.062762819
Brahmaputra	0.085388113
Mekong	0.014996755
Yellow	0.244105114
Amu	0.115955336
Tarim	0.014607587

### Median Snow Cover Area in HKH in Autumn



P-Value	
Yangtze	0.4487
Indus	0.8202
Irrawaddy	0.4954
Ganges	0.0339
Salween	0.3247
Brahmaputra	0.069
Mekong	0.7619
Yellow	1
Amu	0.7049
Tarim	0.4047

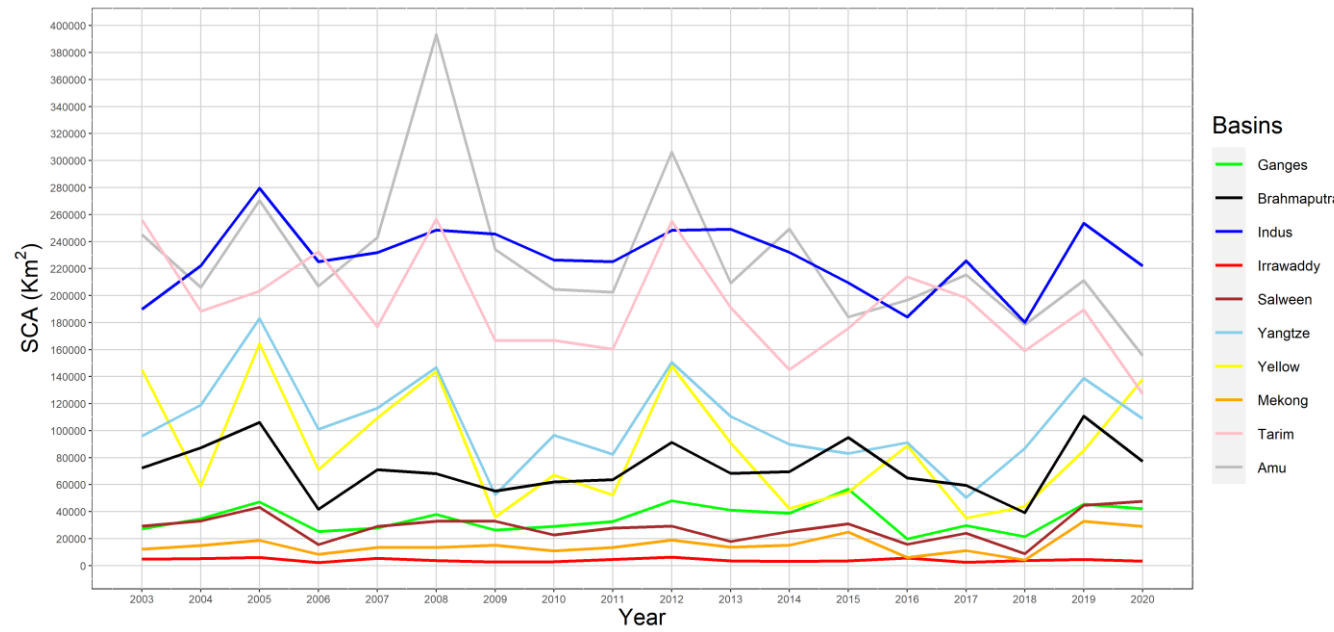
### Median Annual Snow Line Elevation in HKH in Autumn



P-Value	
Yangtze	0.64152
Indus	0.29738
Irrawaddy	0.07452
Ganges	0.02956
Salween	0.50048
Brahmaputra	0.01353
Mekong	0.81538
Yellow	0.69687
Amu	0.5382
Tarim	0.8722

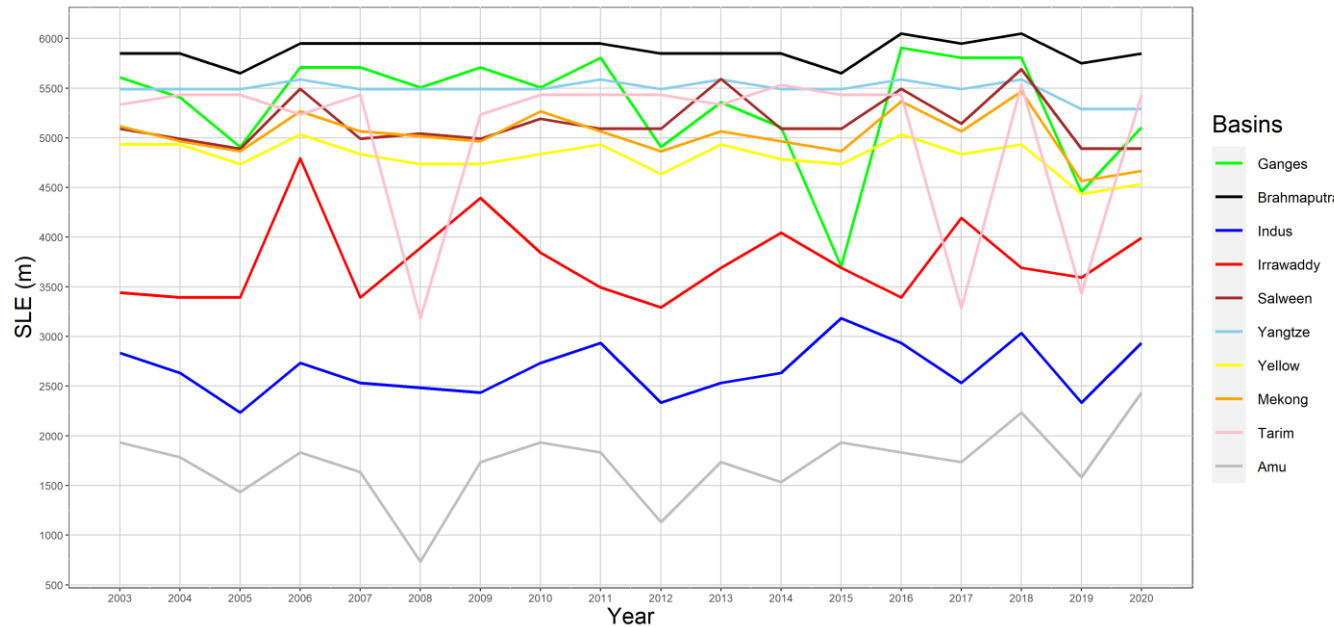


### Median Snow Cover Area in HKH in Winter



P-Value	
Yangtze	0.25582
Indus	0.64945
Irrawaddy	0.44872
Ganges	0.36332
Salween	0.49537
Brahmaputra	0.93961
Mekong	0.36332
Yellow	0.22548
Amu	0.03391
Tarim	0.05824

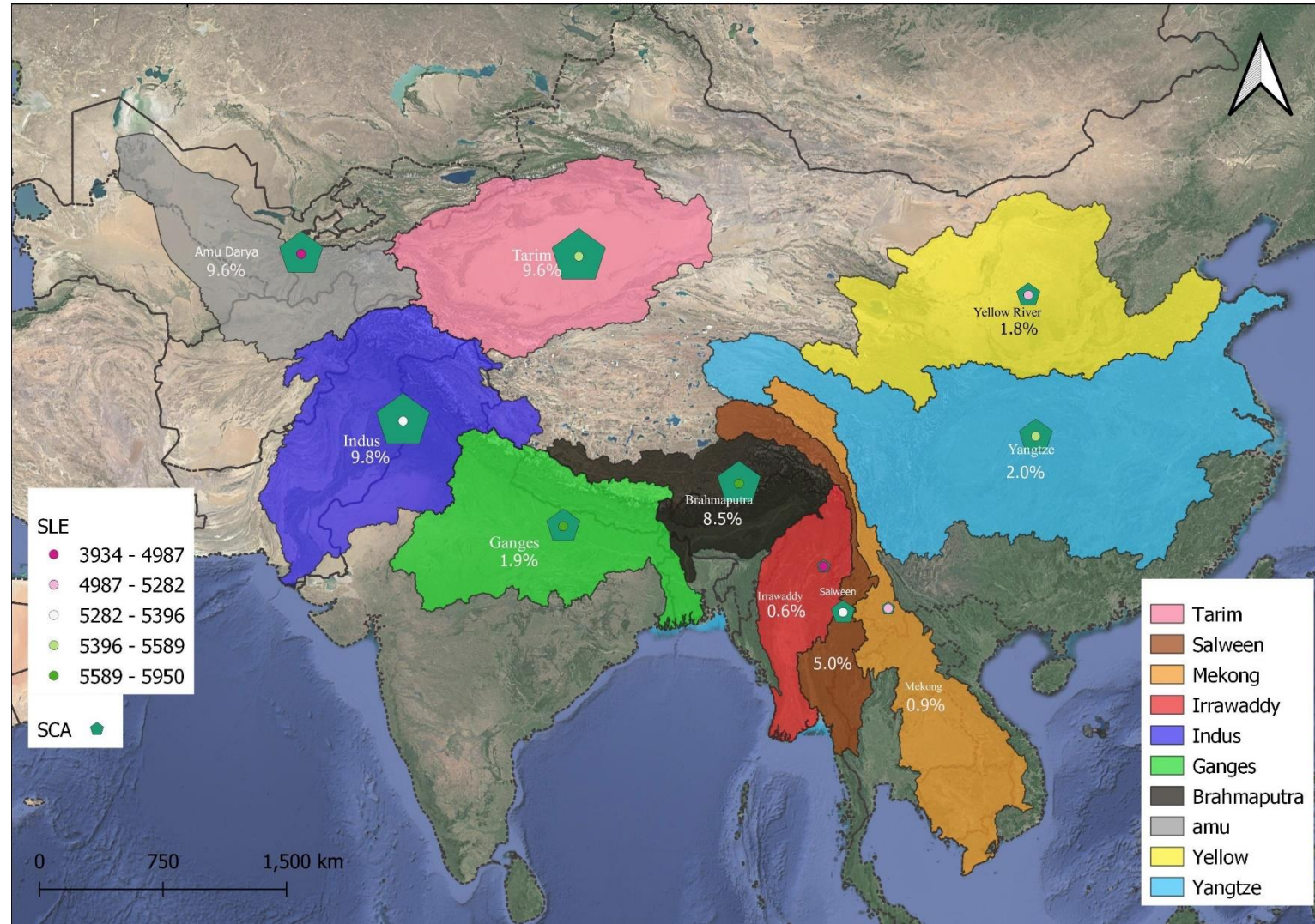
### Median Annual Snow Line Elevation in HKH in Winter



P-Value	
Yangtze	0.72428
Indus	0.3801
Irrawaddy	0.51589
Ganges	0.78937
Salween	0.37495
Brahmaputra	0.87261
Mekong	0.51445
Yellow	0.2454
Amu	0.37987
Tarim	0.54097

# CONCLUSION

- NW Basins highest SCA and SCA%, SE basin the lowest,
- Least SCA during July-Aug, high during Jan-Feb,
- Summer - low SCA high SLE, winter - high SCA low SLE,
- Annually, SLE clustered around 5000m-5500m, significant increasing trends in all basins except Yellow River,
- Minimum SLE in Jan-Feb, lowest for Amu Darya and highest for Brahmaputra,





# THANK YOU!