| | |
|---|---|
| 氏　　　　　　名 | **MAHMOODZADA ABDUL BASIR** |
| 学位（専攻分野の名称） | 博　士（学術） |
| 学　位　記　番　号 | 甲　第0013号 |
| 学位授与の日付 | 令和3年3月20日 |
| 学　位　論　文　題　目 | **Assessment of Seasonal Snowmelt in the Hindu Kush Himalaya of Afghanistan and Its Impact on the Amu Riverbank Erosion Using Remote Sensing Data** |
| 論　文　審　査　委　員 | 主査　教　　授・博士（農学）　岡　澤　　宏 |
| | 教　　授・博士（地球環境科学）　島　田　沢　彦 |
| | 教　　授・博士（農学）　鈴　木　伸　治 |
| | 准　教　授・博士（農業工学）　関　山　絢　子 |
| | 博士（学術）　VARADE Divyesh＊ |


# 論文内容の要旨

## Chapter 1: Background and objectives

This study introduces the significance of high elevated mountain regions of Pamir Hindu Kush in Afghanistan, which are substantial resources for downstream areas in terms of hydrology and water resource management. The seasonal snowmelt dynamics from the Pamir Hindu Kush ranges significantly influence the flow of the Amu River in Afghanistan. That introduces the issues of flooding and riverbank erosion in Afghanistan. It also describes the research statements of the problem, research questions, and objectives, of this research, the general study area, data, and the implementation tools used in the experiments to achieve the defined objectives.

Most of the streams flow and rivers in Afghanistan originate from mountain ranges that are usually covered by semi-permanent and permanent snow and glaciers. Snow water runoff is the majority of the water resources in indispensable ranges. The population of this country is mainly dependent upon mountain snowpack meltwater for irrigation, hydropower, and domestic purposes. The effects on people, communities, and ecosystems can be devastated with the most visible impacts including catastrophic floods, riverbank erosion, landslides, and droughts. Flooding is the most frequently occurring natural hazard in Afghanistan, caused by a combination of steep slopes in the headwaters, and either heavy rains or rapid snowmelt. Lack of vegetation and denudation of mountain areas further contribute to the occurrence of flooding and riverbank erosion associated with loss of life, houses, infrastructures, agricultural lands, and damage to assets.

＊ Indian Institute of Technology Jammu, Assistant Professor

## Chapter 2: Monitoring of Riverbank Erosion and Shoreline Movement at Amu River Using Remote Sensing and GIS

We examine the quantification of riverbank erosion trend, by detecting the shoreline changes and river migration of Amu River, during the 14 years in Qarqin district of Afghanistan. This study may provide the advocatory potential inputs to policymakers in war-torn countries to manage riverbank erosion. In this study, Landsat images (TM/ETM/OLI TRI) from 2000 to 2014 were used to categorize the eroded area and identify shoreline change locations. Furthermore, the images were classified into five different classes, i.e., water, built-up, barren land, sandbank, and agricultural land. River boundaries were digitized from the shorelines on the images from 2000 to 2014. Digital Shoreline Analysis System (DSAS) was applied to calculate shoreline movement. Endpoint Rate (EPR) and Linear Regression Rate (LRR), were used to compute long-term changes for the analysis.

The study found that the river movement was toward the Afghanistan side, i.e., the south-word. The threat of losing the land of Afghanistan was estimated to be ca. 362.4 ha/y. The total eroded area was calculated to be 1,984 ha, 1,410 ha, and 1,680 ha from 2000-2005, 2005-2010, and 2010- 2014, respectively. The shoreline was demarcated in each image and the area was categorized into three zones correspond to the erosion trend, i.e., lower as moderate eroded zone, central as high eroded zone, and upper as the lower eroded zone. The comprehensive and quantitative assessment of the Amu River movement in the long term requires Spatio-temporal analysis of the snowmelt dynamics and the hydrological potential of seasonal snow in the Pamir Hindu Kush ranges. Furthermore, the river discharge or the runoff is largely dependent upon the hydrological potential of the seasonal snow in the Pamir Hindu Kush ranges.

## Chapter 3: The role of seasonal snow as a primary water resource in the Pamir ranges of northern Afghanistan

Subsequently, this study was designed to devise strategies based on active microwave remote sensing for the monitoring of snow depth and Snow Water Equivalent (SWE) during the early winter and the melt season. For the estimation of snow depth and SWE, we utilized multi-temporal C-band (5.405 GHz) Sentinel-1 dual polarimetric Synthetic Aperture Radar (SAR) with a Differential Interferometric SAR (DInSAR)-based framework. In the proposed approach, the estimated DInSAR line of sight displacements in the vertical transmit-vertical receive (VV) and vertical transmit-horizontal receive (VH) channels were improved by incorporating modeled information of snow permittivity and snow density, and the scale was enhanced by utilizing snow depth information from the available ground stations, SWE is estimated as the product of snow depth and density.

Two seasonal datasets were considered for the experiments corresponding to the peak winter season (February 2019) and early melt season (March 2019). The spatial distribution of the snow depth and the SWE were also analyzed upon masking for the SCA. Due to the extensive cloud cover in March, the SCA from February derived from Landsat-8 imagery was used. The results were validated with the available nearest field measurements. A good correlation determined by the coefficient of determination of 0.82 and 0.57, with Root Mean Square Errors of 2.33 and 1.44 m, for the peak winter and the early melt season, respectively, was observed between the snow depth estimates and the field measurements. Further, the snow depth estimates from the proposed approach were observed to be significantly better than the DInSAR displacements based on the correlation with respect to the field measurements. Moreover, SWE comparison between the results observed from Sentinel-1 data with respect to field observations showed very high agreement determined by the overall correlation of coefficient of 0.926, and a Root Mean Square Error of 2.597 mm.

**Chapter 4: High-resolution mapping of seasonal snow cover extent using machine learning-based integration of multi-sensor data.**

Precise determination of Snow Cover Area (SCA) is significant in hydrological and climate modeling. Additionally, when utilizing radar data for the estimation of hydrological parameters such as the SWE, the total hydrological capacity of the watershed requires precise information on the SCA. Typically, the SCA products available from moderate resolution sensors such as MODIS are not suitable for regional-scale analysis. Due to the extensive cloud cover in winters, high-resolution spaceborne multispectral data such as the Landsat-8 or the Sentinel-2 do not yield sufficient information for the mapping of SCA.

Thus, a framework is proposed to derive a high-resolution SCA product from freely available spaceborne remote sensing data. The proposed framework utilizes the Sentinel-1 multi-temporal products and MODIS surface reflectance data. Both these products are available at much higher repeatability and spatial coverage when compared with Sentinel-2 or Landsat-8 data. The proposed methodology makes use of the sensitivity of the parameters derivable from the Sentinel-1 datasets with respect to snow. Different parameters such as the Entropy Alpha, backscatter coefficients ( $\sigma^0$), interferometric coherence, etc. are integrated with the spatially resampled NDSI derived from MODIS surface reflectance bands to estimate the SCA. These parameters are incorporated in an ML-based regression framework for the supervised classification which yields a simulated composite NDSI which is thresholded to retrieve the SCA. The reference data in this study for the training of the ML model and validation is generated from corresponding pan-sharpened Landsat-8 imagery which yields the same resolution of 15m as the processed Sentinel-1 products.

## Chapter 5: Assessment of riverbank erosion and channel shifting of the Amu Darya in northern Afghanistan

Riverbank erosion is an issue of major importance to channel shifting in the Amu River basin of Afghanistan. Afghanistan has been constantly losing precious land over the years due to the Amu riverbank erosion. It is known that the flooding events caused by abrupt flows in the Amu River riverbank erosion are governed by hydrological parameters including those determined from the seasonal snow in the Pamir Hindu Kush ranges and the precipitation. The use of existing models of riverbank migration without adequate calibration can lead to large systematic errors in the prediction of bank erosion rates. This is due to the fact that there is a significant lack of knowledge in quantifying the riverbank erosion and relating it to the hydro-meteorological phenomenon in the Pamir Hindu Kush ranges.

Earlier it was determined that the seasonal snowmelt in the Pamir Hindu Kush ranges is one of the major factors in the Amu River flooding in northern Afghanistan. Riverbank erosion and shoreline changes caused by flooding events are some of the most significant geomorphological environment and natural disaster problems in the non-vegetated regions of the Amu River in northern Afghanistan. Riverbank erosion is an issue of major importance to channel shifting in the Amu River basin of Afghanistan. Afghanistan has been constantly losing precious land over the years due to the Amu riverbank erosion. It is known that the flooding events caused by abrupt flows in the Amu River which results in riverbank erosion are governed by hydrological parameters including those determined from the seasonal snow in the Pamir Hindu Kush ranges and the precipitation. The use of existing models of riverbank migration without adequate calibration can lead to large systematic errors in the prediction of bank erosion rates. This is due to the fact that there is a significant lack of knowledge in quantifying the riverbank erosion and relating it to the hydro-meteorological phenomenon in the Pamir Hindu Kush ranges.

A study is proposed to determine the impact of snowmelt runoff on the historical shifts of Amu River riverbank erosion by relating the average rate of river width with river discharge and for understanding the inter-relationship between the snow hydrological parameters and identifying the significant parameters that affect the total river discharge. We used multiple parameters from hydrometeorological data with observed river discharge from the available ground stations. The hydro-meteorological data was retrieved for the entire catchment from ERA5 reanalysis data which is freely available. To validate the results we used the daily observed river discharge from the eight gauge stations. Observed river discharge typically can only present a small amount of water that flows only from the Afghanistan side. While the upper Amu River basins also cover a part of Tajikistan, where the required data is not available for this study. As an alternative, we demonstrate a methodology for deriving riverbank erosion rates from precipitation and different hydrological parameters with historical river plans from remote sensing data, which can present precise river shifting information. The results demonstrated a better correlation between the predicted river discharge and the river width. This research illustrates a general framework that can be adapted for the development of an improved empirical model for riverbank erosion.

**Chapter 6: Conclusion**

Riverbank erosion is an issue of major importance to channel shifting in the Amu river basin of Afghanistan. Afghanistan has been constantly losing precious land over the years due to the Amu riverbank erosion. It is known that the flooding events caused by abrupt flows in the Amu River which results in riverbank erosion are governed by hydrological parameters including those determined from the seasonal snow in the Pamir Hindu Kush ranges and the precipitation. The use of existing models of riverbank migration without adequate calibration can lead to large systematic errors in the prediction of bank erosion rates. This is due to the fact that there is a significant lack of knowledge in quantifying the riverbank erosion and relating it to the hydro-meteorological phenomenon in the Pamir Hindu Kush ranges.

In this study, an effort is made to present some progress towards the assessment of the hydro-meteorological particularly snow parameters that have a significant impact on the river migration. Remote sensing provides us the means to investigate the spatial variability of these parameters for the entire watershed. It is therefore beneficial to utilize remote sensing data, especially freely available data for the investigations of the highly influential hydro-meteorological parameters. The potential of ERA5 Reanalysis data was further investigated to quantify the riverbank erosion in northern Afghanistan. It was observed that the modeled river discharge using ERA5 reanalysis data could predict significantly the Amu river width. However, it is also worth mentioning that the ERA5 reanalysis data is available at 9 km spatial resolution, implying that information at higher resolution may well result in a significant improvement in the modeling process. The utilization of the developed SWE and the SCA products at 15 m as mentioned earlier may play a critical role in the development of new empirical models for estimating the riverbank erosion rates. Further incorporation of these products for the downscaling of the ERA5 Reanalysis hydrological parameters is proposed in future works.

## 審 査 報 告 概 要

アフガニスタンにおいて河岸侵食をもたらすアム川の洪水イベントは，パミール・ヒンド

ゥークシュ山脈の季節的な雪と降水量から決定される水文学的パラメータによって支配される。しかし，河岸侵食の現状を定量化し，それを水文気象学的現象に関連付ける知見が不足しているのが現状である。本研究では，流量や河川の移動に最も大きな影響を与える水文気象学的要素，特に積雪に関するパラメータの評価に向けて，リモートセンシング技術を用い，冬季における雪の水文学的パラメータとしての積雪深，積雪相当水量（SWE），積雪被覆面積（SCA）を推定する手法を提案した。また，上記パラメータと ECMWF（欧州中期予報センター）の再解析値 ERA5 を用い河川流量を予測し，この値とアム川の川幅変動との関係性を示すことができた。本研究により開発された 15 m 分解能での予測モデルは，他地域への適用が可能であり，データが不足する高山地域の積雪・水文プロセスの解明に重要な役割を果たす可能性が示された。

複数時期デュアル偏光合成開口レーダー（SAR）衛星データの差分干渉手法をベースとし，雪の誘電率と雪密度の情報を組み込んだ改良積雪深推定手法を提案したことは，非常に新規性に富む研究内容である。また、積雪情報を広域・定量的に衛星画像から推定でき，流量予測や河岸侵食の対策に資する情報として提供できることを示した点において高く評価できることから，審査員一同は博士（学術）の学位を授与する価値があると判断した。