Template/Pro forma for Submission

NMHS-Himalayan Institutional Fellowship Grant

FINAL TECHNICAL REPORT (FTR)

NMHS Reference No.:	NMHS/HF/2018-19/IF-30/08

Date of Submission:	1	2	0	3	2	0	2	2
	d	**d**	**m**	**m**	**y**	**y**	**y**	**y**

NMHS-Fellowship Grant Evaluation during 7th HRC-2022

Sanctioned Fellowship Duration: *from* (**19.12.2018**) *to* (**12.03.2022**).

Extended Fellowship Duration (if applicable): *from* (dd.mm.yyyy) *to* (dd.mm.yyyy).

Submitted to:

Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies, GBP NIHE HQs
Ministry of Environment, Forest & Climate Change (MoEF&CC), New Delhi
E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; kodali.rk@gov.in

Submitted by:

[*Dr.Vijay Kumar*
SENSE, VIT Vellore,Katpadi,Vellore, 632014]
[*Contact No.: +91-8110019925…………*.]
[*E-mail:vijaykumar@vit.ac.in …….*]

GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to be commenced from the date of start of the Institutional Fellowship (as per the Sanction Order issued at the start of the Fellowship) till its completion. Each detail has to comply with the NMHS Sanction Order.
2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset process. Colored Photographs (4-5 good action photographs), tables and graphs should be accommodated within the report or should be annexed with captions. Sketches and diagrammatic illustrations may also be given giving step-by-step details about the methodology followed in technology development/modulation, transfer and training. Any correction or rewriting should be avoided. Please give information under each head in serial order.
3. Training/ Capacity Building Manuals (with detailed contents of training programme, technical details and techniques involved) or any such display material related to fellowship activities along with slides, charts, photographs should be sent at the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.
4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time-to-time, so each section of the NMHS-FTR needs to duly filled by the Fellowship Coordinator/ PI and verified by the Head of the Implementing Institution/ University.
5. Five (5) bound hard copies of the NMHS-Institutional Fellowship Final Technical Report (FTR) and a soft copy should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand** *via* e-mail nmhspmu2016@gmail.com.

The FTR is to be submitted into following two parts:

Part A – Cumulative Fellowship Summary Report

Part B – Comprehensive Report

Following Financial and other necessary documents/certificates need to be submitted duly signed and verified along with Final Technical Report (FTR):

Annexure I	Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE), including interest earned for the last Fiscal year including the duly filled GFR-19A (with year-wise break-up)
Annexure II	Consolidated Interest Earned Certificate
Annexure III	Consolidated Manpower Certificate and Direct Benefit Transfer (DBT) Details showing the education background, i.e. NET/GATE etc. qualified or not, Date of joining and leaving, Salary paid per month and per annum (with break up as per the Sanction Order and year-wise).
Annexure IV	Details and Declaration of Refund of Any Unspent Balance as Real-Time Gross System (RTGS) in favor of NMHS GIA General
Annexure V	Details of Technology Transfer and Intellectual Property Rights developed.

***DSL:** Date of Sanction Letter*

1	8	1	2	**2**	**0**	**1**	**8**
d	d	m	m	y	y	y	y

***DFC:** Date of Fellowship Completion*

1	8	1	2	**2**	**0**	**2**	**1**
d	d	m	m	y	y	y	y

Part A: CUMULATIVE SUMMARY REPORT

(to be submitted by the Coordinating Institute/Coordinator)

1. Details Associateship/Fellowships

1.1 Contact Details of Institution/University

NMHS Fellowship Grant ID/ Ref. No.:	NMHS/HF/2018-19/IF-30/08
Name of the Institution/ University:	VIT Vellore
Name of the Coordinating PI:	Dr.Vijay Kumar
Point of Contacts (Contact Details, Ph. No., E-mail):	8110019925, vjijaykumar@vit.ac.in

1.2 Research Title and Area Details

i.	Institutional Fellowship Title:						
ii.	IHR State(s) in which Fellowship was implemented:	**Tamil Nadu**					
iv.	Scale of Fellowship Operation	Local:		Regional:		Pan-Himalayan:	
iii.	Study Sites covered (*site/location maps to be attached*)	Gangotri					
v.	Total Budget Outlay (Crore) :	INR 0.**3641616.00**					

1.3 Details Himalayan Research /Project Associates/Fellows inducted

Type of Fellowship	Nos.	Work Duration	
		From	To
Research Associates	1	03-07-2019	02-07-2020
Sr. Research Fellow			
Jr. Research Fellows	1	18-03-2020	18-03-2021
Project Fellows			

2. Research Outcomes

2.1. Abstract (not more than 1000 words) (it should include background of the study, aim, objectives, methodology, approach, results, conclusion and recommendations based on the institutional fellowship proposal sanctioned under the NMHS).

***Background*:**

Monitoring landslide prone zones using conventional methods is risky at the hilly terrain and extreme climatic situations. There is a need of continuous monitoring of the landslide prone zones to assess the vulnerability and predict the landslide for the safety measures to the nearby livelihood. Satellite remote sensing is an alternate method to conventional data collection to explore the measurements and surface conditions. Active microwave remote sensing of C-band SAR data can be explored to study the terrain with a 6 -12 days interval from Copernicus mission. It has an advantage of data acquiring over optical sensors irrespective of any climatic conditions and cloud cover.

Objectives/ Aim:

i. Land Deformation estimation using repeat pass SAR interferometry techniques SBAS/ PSInSAR

ii. Development of a model to predict the landslide in the Himalayas.

(It has been suggested to focus on glacier movement studies using SAR Data in the second meeting)…… …… ……
……

Methodology(ies):… The satellite based InSAR technique involves comparing the phase information from two SAR images to potentially detect millimeter to centimeter scale ground deformation patterns (Gabriel et al., 1989). Over the last decade, interferometry has become an important tool for mapping topography, studying surface deformation, observing glacial flows, and classification of terrains (Massonnet & Feigl, 1998). InSAR provides high resolution terrain displacements associated with geophysical processes like surface movement, landslides etc.

Surface flow measurements are fundamentally important for studying the mass balance and strain rate changes of surface using InSAR and offset tracking approaches (Joughin et al., 1998; Gray et al., 2001; Rignot 2002). Synthetic Aperture Radar Interferometry (InSAR) is a powerful technique for measuring the surface and strain rate (velocity gradient) with high accuracy. Interferograms are generated by multiplying a SAR signal with the complex conjugate of a signal acquired with slightly different orbital geometry but with same satellite track. In this way phase difference calculated between two satellites is the sum of many components and given by (Hanssen, 2001)

Approach: *1.InSAR and Advanced InSAR approach SBAS have been exploited for land surface deformation studies.* …2. SAR offset tracking methods have been adopted to decipher the surface movement ……… ……… …… … … …………………… ………… ……………
……………… … … ……………………………………..

Results:

i. SBAS based time series C-Band SAR data analysis during 2003 to 2007 have shown deformation in Gangotri and adjoin areas such as Joshimath because of landslides might have triggered by precipitation and high snow fall on highly inclined planes. But it has to be further investigated proper causes of landslide. At some points land slide rate varies from -10 mm/year to -28 mm/year while at others it varies from zero

in year 2003 to -30 mm/year in year 2007.

ii. Major glaciers in the region have not shown significant variation in surface velocity and it has been observed that velocity of Gangotri glacier is around 10cm/day.

iii. A new methodology has been developed using ascending and descending pass SAR offset tracking information to quantify the 3D velocity of glaciers in the Himalayas.

Conclusion: We attempted the SBAS DInSAR approach for time series movement estimation of the Gangotri glacier. ASAR ascending pass InSAR pairs are processed for deformation measurements using this algorithm. It is observed that glacier area does not show coherence at least as much as 0.25 and hence no any deformation signal could be produced on glaciers. But, this approach has produced very important information of land deformation (land slide or rock slide) which varies from -30 mm/year to10 mm/year. Himalayan region is highly sensitive area in terms of tectonics activities and settlement on the slopes of the mountain facilitates the land slides. SBAS is an important tool which can be used for precise deformation studies in mm order of accuracy and has a potential to be exploited for Himalayan deformation studies.

SAR offset tracking has produced significant results using C-band SAR data and it has emerged as an alternative tool to SAR interferometry for deformation studies. Glaciers in the area have shown velocity in the order of 10 cm/day.

Recommendation:

i. It is highly desirable to use advanced modeling approaches to automate the study process

ii. AI and ML tools can be used to automatic extraction of deformations using SAR data after massive training using results obtained

iv. Glacier surface velocity extraction can be automated using RNN and CNN approaches.

v. Accessibility of the region can improved for field expeditions for validating the results.

2.2. Objective-wise Major Achievements

S. No.	Cumulative Objectives	Major achievements (in bullets points)
1.	Surface deformation estimation	• Time Series Envisat ASAR data processing using InSAR processing chain • InSAR Interferograms and coherence map generated. • Time series deformation map generated. • Gangotri and siachen area glacier movement study is carried out • Multi sensor results have been compared • Offset tracking based 3D velocity estimation approach is developed and implemented over the test site Gangotri glacier.
2.	Land Slide modelling	Time series deformation is estimated.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, and Reason thereof:
1.	• In context of **Glacier Dynamics and Snow Cover Studies**, generating the database using the following: ✓ Remote sensing, ✓ Meteorology, and ✓ Field surveys. • Landslide Monitoring and Modeling for hazards prediction (landslide); • Development of Landslide Prediction model; • Validate and refine the model;	• Glacier Dynamics • Time series deformation studies	• Gangotri glacier surface movement • Siachen glacier movement studies	RA left the project in between on medical grounds and could not make significant progress.
2.	• Baseline data collection and generating the database on: (i) Time series of past events (landslides), (ii) Present meteorological data; • Land deformation estimation using microwave remote	• SAR data collection over four years	• Time series deformation studies in Gangotri area	JRF Left without registering as PhD after less than a year and joined somewhere in Germany and later on this position could not be filled.

	sensing techniques; • Documentation of compiled seasonal reports; • Peer-reviewed Journal Publications (2). Registration for PhD.			

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Enclosures
1.	New Methodology developed:	3D surface deformation approach.	
2.	New Models/ Process/ Strategy developed:		
3.	New Species identified:		
4.	New Database established:		
5.	New Patent, if any:	NA	
	I. Filed (Indian/ International)		
	II. Granted (Indian/ International)		
	III. Technology Transfer (if any)		
6.	Others, if any:		

3. Technological Intervention

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology		
2.	Diffusion of High-end Technology in the region		
3.	Induction of New Technology in the region		
4.	Publication of Technological / Process Manuals		
	Others (if any)		

4. New Data Generated over the Baseline Data

S. No.	New Data Details	Existing Baseline	Additionality and Utilisation of New data (*attach supplementary documents*)

1.			
2.			
3.			
4.			

5. Linkages with Regional & National Priorities (SDGs, INDC, etc.)/ Collaborations

S. No.	Linkages /collaborations	Details	No. of Publications/ Events Held	Beneficiaries
1.	Sustainable Development Goals (SDGs)			
2.	Climate Change/INDC targets		one	
3.	International Commitments			
4.	National Policies			
5.	Others collaborations			

6. Financial Summary (Cumulative)*

*Please attach the **consolidated and audited Utilization Certificate (UC) and Consolidated and *Year-wise* Statement of Expenditure (SE)** separately, *ref*. **Annexure I.**

7. Quantification of Overall Research Progress

S. No.	Parameters	Total (Numeric)	Attachments* with remarks
1.	IHR State(s) Covered:	*2*	*UK and J&K*
2.	Fellowship Site/ LTEM Plots developed:	*1*	*Gangotri*
3.	New Methods/ Model Developed:	*1*	
4.	New Database generated:		
5.	Types of Database generated:	*4*	
6.	No. of Species Collected:		
7.	New Species identified:		
8.	Scientific Manpower Developed (PhDs awarded/ JRFs/ SRFs/ RAs):	*2*	*One JRF and One RA*
9.	No. of SC Himalayan Researchers benefited:		
10.	No. of ST Himalayan Researchers benefited:		
11.	No. of Women Himalayan Researchers empowered:		
12.	No. of Knowledge Products developed:		
13.	No. of Workshops participated:	*2*	
14.	No. of Trainings participated:		
15.	Technical/ Training Manuals prepared:		
	Others (if any):		

***** Please attach the soft copies of supporting documents word files and data files in excel.

8. Knowledge Products and Publications*

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures**
		National	International		
1.	Journal Research Articles/ Special Issue (Peer-reviewed/ Google Scholar)		1	5	Accepted **Two journals are under review**
2.	Book Chapter(s)/ Books:				
3.	Technical Reports/ Popular Articles				
4.	Training Manual (Skill Development/ Capacity Building)				
5.	Papers presented in Conferences/ Seminars				
6.	Policy Drafts (if any)				
7.	Others (specify)				

*Please append the list of KPs/ publications (with impact factor and URL link details) with due Acknowledgement to NMHS.

**Please provide supporting copies of the published documents.

9. Recommendation on Utility of Research Findings, Replicability and Exit Strategy

9.1 Utility of the Fellowship Findings

S. No.	*Research Questions Addressed*	*Succinct Answers (within 150–200 words)*
1.	Land deformation studies	Advanced DInSAR processing done using time series data (ENVISAT ASAR Sentinel - 1A & 1B Interferometric Wide Mode) for estimating the land deformation and mentioned in conclusion section.
2.	Glacier movement	Gangotri and Siachen glacier movement have been monitored using Microwave SAR data.

9.2 Recommendations on Replicability and Exit Strategy:

Particulars	Recommendations
Replicability of Fellowship, if any	
Exit Strategy:	*Please describe the Exit Strategy of the fellowship, self-sustaining and benefitting the stakeholders and target communities*: Research work carried out by RA and JRF has wide significance in terms of climate change effects over snow and ice deposition in the Himalaya. Two different regions have shown contrasting glacier movement showing different amount of snow deposition. Time series deformation studies in the Gangotri basin area has shown -30 mm/year to 30 mm/year. Extensive field validation is required. … Following are recommendations based on this study. i. It is highly desirable to use advanced modeling approaches to automate the study process ii. AI and ML tools can be used to automatic extraction of deformations using SAR data after massive training using results obtained vi. Glacier surface velocity extraction can be automated using RNN and CNN approaches. vii. Accessibility of the region can improved for field expeditions for validating the results.

(**NMHS FELLOWSHIP COORDINATOR**)

(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)

(Signed and Stamped)

Place: ………………..
Date: …../……/……..

PART B: COMPREHENSIVE REPORT (including all sanctioned positions of Researchers)

Based on the Fellowship Proposal submitted/approved at the time of sanction, the co-ordinating Principal Investigator shall submit a comprehensive report including report of all individual researchers.

The comprehensive report shall include an **Executive Summary** and it should have separate chapters on (1) **Introduction** (2) **Methodologies, Strategy and Approach** (3) **Key Findings and Results** (4) **Overall Achievements** (5) **Impacts of Fellowship in IHR** (6) **Exit Strategy and Sustainability** (7) **References/ Bibliography** and (8) **Acknowledgements** (It should have a mention of financial grant from the NMHS, MoEF&CC).

Further, description of Technical Activities, List of Trainings/ Workshops/ Seminars with details of trained resources, list of New Products developed under the fellowship, Manual of Standard Operating Procedures (SOPs) developed, Technology developed/Transferred etc should be enclosed as Appendix.

Report (hard copy) should be submitted to:

Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies (NMHS)
G.B. Pant National Institute of Himalayan Environment (GBP NIHE)
Kosi-Katarmal, Almora 263643, Uttarakhand

Report (soft copy) should be submitted at:

E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; kodali.rk@gov.in

PART B: COMPREHENSIVE REPORT

EXECUTIVE SUMMARY

The Executive Summary of the fellowship should not be more than 3–5 pages, covering all essential features in precise and concise manner as stated in Part A (Cumulative Fellowship Summary Report) and Part B (Comprehensive Report).

Fellowship Report No.: ***1of 2*** *(n = Sequential number; N= Total no. of fellowships granted to the Institute/ University)*

Researchers Details

Type of Fellowship (HRA/HJRF/HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HRA	ABHILASH YELLALA	03-07-2019	02-07-2020 (No any researcher joined on this project as HRA during Corona period)	**Landslide monitoring using InSAR/ DInSAR / SBAS / PSInSAR time series over Himalayan region**	Dr. Vijay Kumar Professor, ECE, VIT Vellore
(*in case of continuation of fellowship*)					

*If the appointed researcher resigned in the mid of the fellowship duration, then also mention the name of the Himalayan researcher who carried forward the fellowship.

1 INTRODUCTION

1.1 Background/ Summary of the Associateship / Fellowship Study undertaken (max. 500 words)

Monitoring landslide prone zones using conventional methods is risky in the hilly terrain and adverse climatic situations like in the Himalayas. There is a need of continuous monitoring of the surface deformations such as land slide caused by local microclimatic conditions and seismic activities. Landslide prone zones can be demarked and monitored frequently or nearly in real time to assess the vulnerability and predict the landslide for the safety measures to the nearby livelihood.

Satellite remote sensing is an alternate method to conventional data collection to explore the measurements and surface conditions. Active microwave remote sensing of C-band SAR data can be explored to study the terrain deformation with a 6 -12 days interval from Copernicus mission satellites. It has an advantage of data acquiring over optical sensors in terms of irrespective of any climatic conditions and cloud cover. This study can be carried out with other wavelengths SAR systems such as X- band and L-band sensors upon availability of the datasets and fund. L-band signals can penetrate the surface a bit extent compared to C- and X- band signals. SAR interferometry (InSAR) and advanced InSAR techniques such as SBAS and PSInSAR to be used to quantify landslides in the affected areas over the test sites in the Himalayas. On the basis of deformation studies, it is planned to develop a model for predicting the landslide using microwave remote sensing data, terrain model and ancillary data.

1.2 Baseline and Scope of the Associateship / Fellowship (max. 1000 words)

Landslides are abrupt short-lived geomorphic events that constitute the rapid downward motion of soil and rock materials occurring in sloping terrains. The triggering mechanism may include excessive precipitation, earthquakes, or deforestation which upset the natural stability of the slope, resulting in falling, sliding or flowing of landmass under gravity. Aerial photography has been used extensively to characterize landslides and to produce landslide inventory maps, particularly because of their stereo viewing capability and high spatial resolution. Airphotos were used to identify steep slopes underlain by weak soils, slopes undercut by rivers and waves, tension cracks, steep hummocky topography, failed surface scarps, anomalous bulges and lumps, terraced slopes, discontinuous bedding planes, drainage-vegetation patterns and elongated ponds on hillslopes (Alföldi 1973; Mollard 1977; Nilsen & Brabb 1977; Mollard & Janes 1984; Cruden & Lu 1992; Savigny 1993).

Various methods are exists in 20th century to assess the landslide prone zones in terms of qualitative and quantitative. Geomorphological hazard mapping, heuristic or index-based methods are quantitative and direct methods. Analysis of landslide inventories, functional, statistically based models, geotechnical or physically based models are indirect methods (Jibson 1993; Guzzetti et al. 1999). Landslide susceptibility map in the Kakuda-Yahiko Mountains of Central Japan has been generated with GIS and statistical approaches (Carrara et al. 1991; Ayalew & Yamagishi 2005). Landslide prediction using SAR data with the help of 3D terrain models is one of the relevant is suitable approach to predict the vulnerability zones (Fruneau et al. 1996; Leva et al. 2003; Tarchi et al. 2003; Strozzi et al. 2005; Colesanti & Wasowski 2006; Nouguès et al. 2010). The daily movement of La Valette (southern French Alps) has been identified with 9 years SAR interferometric observations as 0.4 – 1 cm/day during 1991-1999 (Squarzoni et al. 2003). Persistent scatter interferometry with X-band SAR data has been found that PS density from COSMO Sky Med SAR data is from ~ 3 to 11 times higher than from ASAR (Bovenga et al. 2012).

SAR interferometry and optical images can be used to analyse the characterization of the landslide. Where the flow slide has been identified with the help of SAR and air-borne imagery (Singhroy et al. 1998). Interferometric and ground based measurements with DGPS have established a correlation and found the reason that landslides are sensitive to rainfall (Herrera et al. 2009).

Researches exist in India about landslide suspect ability and early warning system from several academic and research institutions: IIRS, IIT's, NDMA, NRSC, IIST…... etc. Landslide susceptibility has been estimated and analysed from GIS database and statistical approaches (Sarkar et al. 1995; Sarkar & Kanungo 2005; Das et al. 2010; Westen et al. 2012; Pardeshi et al. 2013; Kumar et al. 2017). Rainfall intensity and the duration have an impact slope stability which may further leads to slides (Ering & Babu 2016). Most of the studies are carried out in India in the places such as GARHWAL HIMALAYA, Kumaun Himalaya, Northern Himalaya, Malin – Pune, Western Ghats and north-Sikkim. Remote sensing (SAR) based landslide prediction has been attempted from researches (Iverson 2000; Rodriguez et al. 2002; Singh et al. 2005; Bhandari 2006; Delacourt et al. 2009; Martha & Kumar 2013; Pareek et al. 2013; Bhattacharya et al. 2015; Vöge et al. 2015; Pham et al. 2017).

There are several research organizations and funding agencies who are actively involved in this hazard prediction and early warning system. IPL (International Program on Landslides) has been working in landslide risk reduction. The main contributions of this program are risk reduction activities in Rome 2011 (WLF2) and Beijing 2014 (WLF3). This IPL is a program of ICL (International consortium on landslides). NASA has granted research fund for University of Dayton in collaboration with University of Arizona to study the conditions that trigger landslides in Himalaya and K2 Range Mountains.

This study monitors the land deformation in the NW Himalaya comprising Gangotri glacier basin area. Study area is shown in the Fig.1. This fellowship focusses on landslides in the region as well as glacier movement estimation. SAR data has been used in conjunction with optical.

1.2.1Study Area (max. 150 words)

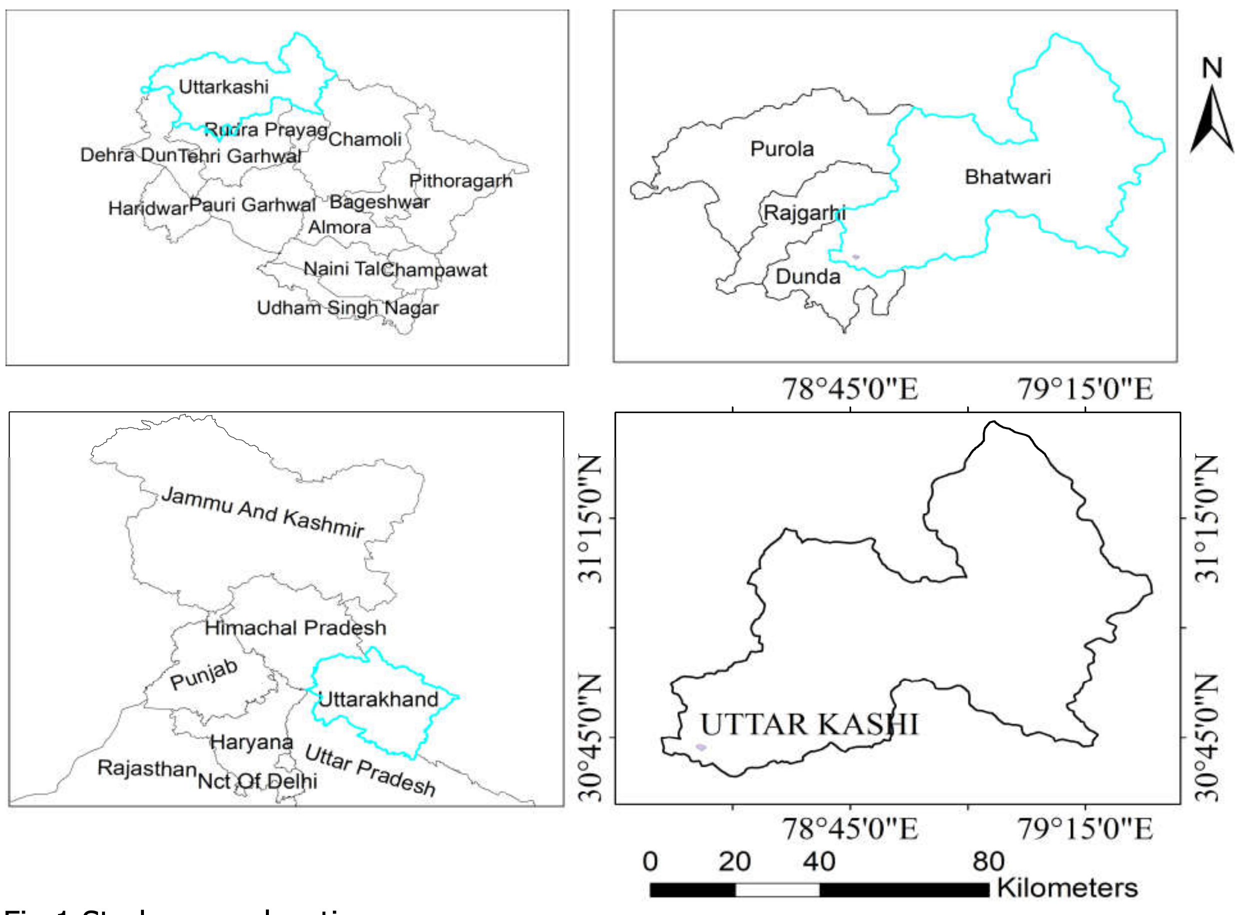

Fig.1 Study area location map

UTTARKASHI is a district in Uttarakhand state. The landslide in 2003 from Varunavat hill (Gupta & Bist 2004) lead to damage to the sustainability of living beings in the location. In 2012-2013 floods caused severe disaster to the livelihood and man-made constructions over the area. The parameters such as surface, water and climate parameters has to be studied continuously around the area to quantify deformation in the landslide prone areas. Model for landslide will be developed for future prediction on the basis of this study.

As a part of glacier dynamics studies, Gangotri glacier has been chosen as nearest glacier to the proposed test site and other glacier also has been studied in the same acquired scene. For observing the contrasting results Siachen glacier is also chosen as attest site.

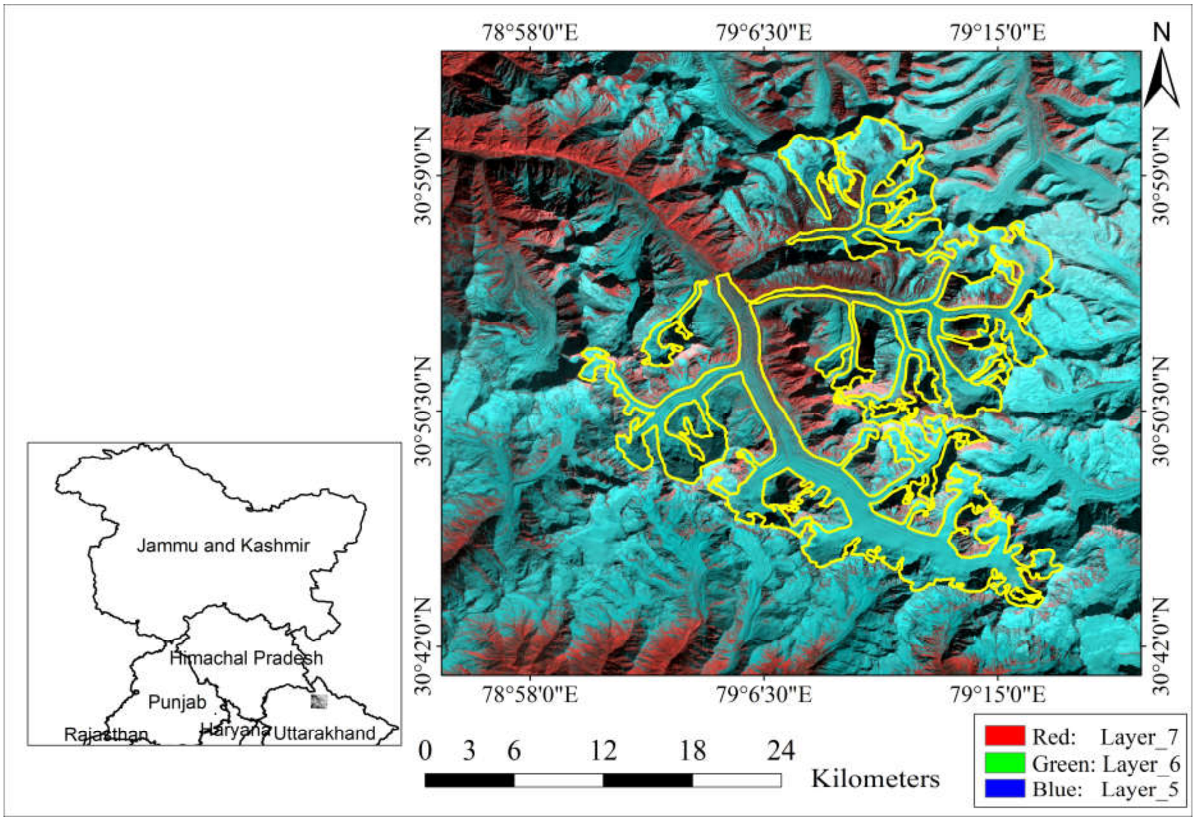

Fig.2. Gangotri glacier basin map superimposed over Sentinnel-1B optical image.

1.3 Overview of the Major Issues to be addressed (max. 1000 words)

- SAR data Acquisition
- SAR data Pre-processing and calibration
- Differential SAR Interferometry using Multiple SAR Pairs
- Advanced SAR interferometry algorithms SBAS application for deformation studies
- A flow chart in Fig.3 depicts the major work to be carried out

1.4 Brief summary of the activities under taken by the researcher (max. 1000 words)

[Providing full details of Field study, experimental set up, methods adopted, data collected supported by necessary table, charts, diagrams & photographs (**Data, table and figures should be attached as separate source file (.docx, .xls, jpg, .jpeg, .png, .shp, etc.)]**.

2 METHODOLOGIES, STARTEGY AND APPROACH

2.1 Methodologies used for the study (max. 1000 words)

D.1. Interferometric SAR (InSAR) for land deformation studies

The satellite based InSAR technique involves comparing the phase information from two SAR images to potentially detect millimetre to centimetre scale ground deformation patterns (Gabriel et al. 1989). Over the last decades, interferometry has become an important tool for mapping topography, studying surface deformation, observing glacial flows, and classification of terrains (Massonnet & Feigl 1998). InSAR provides high resolution terrain displacement associated with geophysical processes like surface movement, landslides and land subsidence etc.

Surface flow measurements are fundamentally important for studying the mass balance and strain rate changes of surface using InSAR and offset tracking approaches (Joughin et al. 1998; Gray et al. 2001; Rignot et al. 2002). Synthetic Aperture Radar Interferometry (InSAR) is a powerful technique for measuring the surface and strain rate (velocity gradient) with high accuracy. Interferograms are generated by multiplying a SAR signal with the complex conjugate of a signal acquired with slightly different orbital geometry but with same satellite track. In this way phase difference calculated between two satellites is the sum of many components and given by (Hanssen 2001).

$$\phi_{InSAR} = \phi_{def} + \phi_{topo} + \phi_{atm} + \phi_{orbit} + \phi_{noise}$$

Where, ϕ_{def} is deformation phase due to displacement in LOS during repeat SAR acquisitions. ϕ_{topo} topographic phase, which has been removed from DEM simulated phase. ϕ_{orbit} is phase due to incorrect knowledge of the satellite orbits, ϕ_{atm} is phase changes due to different atmospheric delay between the

acquisitions, and ϕ_{noise} is additive noise due to variability in scattering from the pixel, SAR system thermal noise and co-registration errors. Phase components due to topography, atmosphere and system noises has to be minimized and modelled for estimating the deformation phase. Interferograms can be flattened and then unwrapped using statistical-cost,
network flow algorithm for phase unwrapping (SNAPHU) developed by Chen and Zebker, 2000, and phase due to displacement of surface in radar line of sight (LOS) can be calculated.

D.2. Advanced InSAR techniques

Advanced DInSAR approaches such as small baseline subset (SBAS) and permanent scatterer InSAR (PSInSAR) are able to quantify mm to cm level deformation signals by involving a time series SAR images (Ferretti et al. 2001). Frequent spatial and temporal decorrelation in the Himalayan region is a strong impediment in precise deformation estimation using conventional interferometric SAR (InSAR) approach. Herein, SBAS and DInSAR approaches will be exploited for millimetre to centimetre scale accurate surface displacement estimation and time series deformation studies in north - western (NW) Himalayan test sites.

The main limiting factors are atmospheric artifacts that can introduce a bias in the phase measurement (Zebker et al. 1997), another limitation is spatial baseline decorrelation that occurs when the interferometric baseline is not exactly zero. Since the radar receives the coherent sum of all independent scatterers within the resolution cell, these contributions are added slightly differently due to the different geometry. Spatial decorrelation leaves many interferometric combinations infeasible in areas with steep terrain. Effects of various decorrelation phenomena can be reduced by combining multiple SAR observations using multitemporal InSAR techniques. Using more than two SAR scenes leads to redundant measurements that can be utilized for more advanced time series methods such as SBAS and PSInSAR. SBAS methods use SAR image combinations with a short spatial baseline to reduce the effects of spatial and temporal decorrelation (Berardino et al. 2002; Schmidt & Bürgmann 2003; Lanari et al. 2007; Hooper 2008). Herein, we investigate the potentiality of advanced SBAS DInSAR approach for landslide studies in Himalayan region using ENVISAT ASAR data sets in ascending mode. Atmospheric delays affecting a SAR interferogram are measured as a double difference, both in time and space, of propagation delays from satellite to ground then back to satellite. There is no absolute delay measured by SAR interferometry. It is useful to decompose the atmospheric delays into those due to atmospheric stratification and those due to a laterally variable, “turbulent”, atmospheric state (Hanssen 2001).

D.3. SAR offset tracking

Two repeat pass SAR images acquired from slightly different orbital configurations can be exploited for terrain deformation estimation using offset tracking (intensity or coherence tracking) approach as well as InSAR processing. In the case of decorrelation due to rapid and incoherent flow, SAR intensity tracking procedure is an alternative to SAR interferometry for the estimation of surface motion (Michel & Rignot 1999; Gray et al. 2001). This technique is based on cross-correlation optimization between SAR intensity image patches. Success of this technique is dependent on nearly identical SAR intensity values due to back scattering of identical features in two repeat pass images. The technique is particularly appropriate when either the surface motion or temporal separation of the data acquisitions is even large (Derauw 1999) and interferometry cannot give appropriate result because of coherence loss. Even in these circumstances, offset tracking techniques can yield two dimensional (2-D) motions, albeit with reduced accuracy in the range direction (Singhroy et al. 1998).

In this procedure SAR intensity tracking technique is used for 2-D displacement estimation. A correlation matching is commonly used to obtain both azimuth and range-direction offsets based on intensity pattern patches of two repeat-pass SAR image acquisitions. Through oversampling of the correlation surface, the matching peak can be determined to a small fraction of a pixel. The range offset δr and azimuth offset δa detected from cross-correlation matching include a non-motion component contributed by the imaging geometry (baseline effect and orbital crossing) and topography effects. The topography-induced offsets only occur in the range direction and can be removed by using a digital elevation model. The geometry-induced terms in the range and azimuth offset has been modeled and removed using two linear equations (Liu et al. 2007).

$$dr = \delta r - (a_0 + a_1 x + a_2 y) \quad (3.1)$$

$$da = \delta a - (b_0 + b_1 x + b_2 y) \quad (3.2)$$

where dr and da are, respectively, the surface displacements in the range and azimuth directions measured in pixels, x and y are the range and azimuth coordinates of the slant range image, a_0, a_1, and a_2 are coefficients for accounting for the geometry term in range direction, and b_0, b_1, and b_2 are coefficients for accounting for the geometry term in the azimuth direction. These coefficients are calculated for stationary points outside the surface area and used for estimating the offsets.

D.4. Model development workflow

The following diagram Fig. 2 represent the overall flow of the work. The data has to be collected in various modes from various academic and R&D institutions / Govt. or NGO or Private . The soil data can be collected from field work and Soil and Land use survey of India (SLUSI), Remote sensing (optical and active micro wave) data can be collected from various space agencies. Precipitation and micro climate data can be collected from Meteorology and nearest rain-gauge. A database can be formed from all these datasets and simulated through past incidence readings to develop a model to assess and predict the future landslide

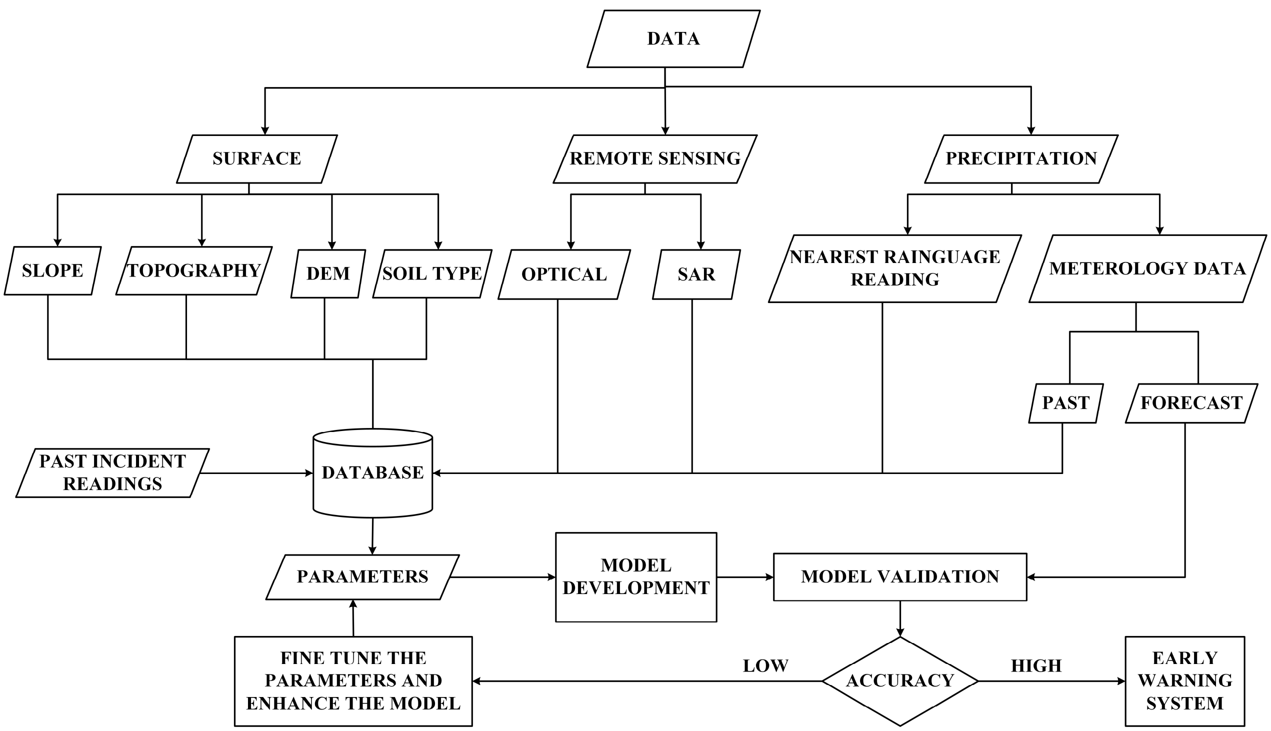

Fig.3. Flow chart for Deformation modeling

2.2 Details of Scientific data collected and Equipments Used (max 500 words)

SAR data from ENVISAT ASAR and Sentinnel-1A/1B satellites have been collected and used in this study. Table-1 shows ENVISAT ASAR data used for time series deformation studies.

Table 3.1 ENVISAT ASAR InSAR pairs of ascending mode used for SBAS DInSAR based study in north-western Himalayas.

Sr. No.	Date1	Date 2	Perpendicular Baseline (m)	Temporal base line (days)
1.	29-04-2003	30-12-2003	-318.00	245
2.	**13-04-2004**	**12-08-2003**	**449.00**	**245**
3.	13-04-2004	30-12-2003	-633.00	105
4.	18-05-2004	29-04-2003	-605.00	385
5.	18-05-2004	12-08-2003	749.00	280
6.	**18-05-2004**	**30-12-2003**	**-287.00**	**140**
7.	**18-05-2004**	**13-04-2004**	**345.00**	**35**
8.	27-07-2004	29-04-2003	-697.00	455
9.	**27-07-2004**	**12-08-2003**	**-703.00**	**350**
10.	27-07-2004	30-12-2003	-379.00	210
11.	**27-07-2004**	**13-04-2004**	**253.00**	**105**
12.	**27-07-2004**	**18-05-2004**	**-92.00**	**70**
13.	05-10-2004	29-04-2003	-186.00	525
14.	**05-10-2004**	**30-12-2003**	**132.00**	**280**
15.	05-10-2004	13-04-2004	765.00	175
16.	**05-10-2004**	**18-05-2004**	**420.00**	**140**
17.	**05-10-2004**	**27-07-2004**	**511.00**	**70**
18.	18-01-2005	29-04-2003	-898.00	630
19.	18-01-2005	29-04-2003	-497.00	630
20.	18-01-2005	30-12-2005	-179.00	385
21.	18-01-2005	13-04-2004	453.00	280
22.	18-01-2005	18-05-2004	-108.00	245
23.	18-01-2005	27-07-2004	199.00	175

24.	18-01-2005	05-10-2004	-312.00	105
25.	**05-09-2006**	**12-08-2003**	**297.00**	**1120**
26.	05-09-2006	30-12-2003	-785.00	980
27.	**05-09-2006**	**13-04-2004**	**-152.00**	**875**
28.	**05-09-2006**	**18-05-2004**	**-497.00**	**840**
29.	**05-09-2006**	**27-07-2004**	**-405.00**	**770**
30.	05-09-2006	18-01-2005	-605.00	595
31.	23-01-2007*	29-04-2003	-662.00	1365
32.	23-01-2007	12-08-2003	738.00	1260
33.	23-01-2007	30-12-2003	-344.00	1120
34.	23-01-2007	13-04-2004	-289.00	1015
35.	23-01-2007	18-05-2004	-56.00	980
36.	23-01-2007	27-07-2004	-35.00	910
37.	23-01-2007	05-10-2004	-476.00	840
38.	**23-01-2007**	**18-05-2004**	**-56.00**	**980**
39.	23-01-2007	18-01-2005	-164.00	735
40.	**23-01-2007**	**05-09-2006**	**-441.00**	**140**
41.	08-05-2007	12-08-2003	552.00	1365
42.	08-05-2007	30-12-2003	-560.00	1225
43.	08-05-2007	13-04-2004	73.00	1120
44.	**08-05-2007**	**18-05-2004**	**272.00**	**1085**
45.	**08-05-2007**	**27-07-2004**	**180.00**	**1015**
46.	08-05-2007	05-10-2004	-692.00	945
47.	08-05-2007	18-01-2005	-380.00	840
48.	**08-05-2007**	**05-09-2006**	**225.00**	**245**
49.	**08-05-2007**	**23-01-2007**	**-215.00**	**105**

***Master geometry for co-registering all SAR images**

2.3 Primary Data Collected (max 500 words)

SAR data used glacier dynamics studies is shown in the table-2

Data sets Used in this study:

i. Gangotri glacier 3D velocity estimation

	Sensor Sentinnel-1A	Date (DD-MM-YYYY & DD-MM-YYYY)	Mode	Polarization	Day's Difference
1	S-1	13-04-2017 & 20-04-2018	ASCE	VV	372
2	S-1	21-04-2017 & 16-04-2018	DESC	VV	360

ii. Siachen glacier Velocity Estimation

Table 1. Multi sensor optical and SAR data and specifications

S. No.	SENSOR	DATE (DD/MM/YYYY & DD/MM/YYYY)	TYPE	RESOLUTION (METERS)	PASS	BEAM MODE	POLARIZATION	Day difference
1	L-8	03-11-2013 & 21-10-2014						352
2		21-10-2014 & 08-10-2015						352
3		08-10-2015 & 13-12-2016						432
4		13-12-2016 & 30-11-2017	OPTICAL	15				352
5		30-11-2017 & 03-12-2018						368
6	S-2	30-11-2015 & 14-12-2016						380
7		14-12-2016 & 29-12-2017	OPTICAL	10				380
8		29-12-2017 & 14-12-2018						350
9	S-1	14-12-2014 & 09-12-2015						360
10		09-12-2015 & 21-12-2016						378
11		21-12-2016 & 16-12-2017	SAR	20	DESC	IW	VV	360
12		16-12-2017 & 17-12-2018						366

Note. L-8: Landsat-8; S-2: Sentinel-2; S-1: Sentinel-1; Desc: Descending; IW: Interferometric Wide Swath.

2.4 Details of Field Survey arranged (max 500 words)

Corner Reflectors fixed at Tapovan area in the right hand side bank of the Gangotri glacier above 300 ft from glacier surface have been used to calibrate the results as a fixed stationary points.

2.5 Strategic Planning for each Activities (max. 1000 words)

2.6 Activity-wise Timeframe followed using Gantt/ PERT Chart (max. 1000 words)

TASK / TIME ↓ →	Sub Task	0 – 6 Months	7 – 12 Months	13 – 18 Months	19 – 24 Months	25 – 30 Months	30 – 36 Months
Data collection	1. Satellite data		✓	✓			
	2. Previous incident readings		✓	✓			
	3. Past climate readings						
	4. Forecast data collection						
	5. Field measurements			✓			
Data Analysis and Model development	Model development			✓			
	Analysis			✓			
	Validate and refine the model						
Reporting and Documentation.	Prepare seasonal reports			✓			
	Paper work / documentation			✓			
	Final report of the project						✓

3 KEY FINDINGS AND RESULTS

3.1 Major Research Findings (max. 1000 words)
Glacier dynamics: (a) Gangotri glacier

- 3D surface velocity of Gangotri glacier is derived from the ascending pass and descending pass acquired data over near range duration of the same hydro-cycle. The derived 3D velocity has shown maximum than the both individual pass velocities.
- Major contributions of this study are (i) sub pixel offset tracking based processing of SAR and optical data over the study area for the first time comparative analysis of surface velocity derived from recent three sensors Sentinnel (S-1, S-2) and Landsat-8 during 2013–2018 and (ii) geospatial variation of the glacier surface movement along and across the extents are studied for spatio-temporal analysis.
- A time series land surface deformation studies have been carried out Uttatkashi district using time series ENVISAT ASAR data. Advanced InSAR processing algorithm SBAS is used to decipher land deformation in the study area with major sites Joshimath , Gangotri glacier basin area. It has been slow deformation over the certain points ranging from -30mm/year to 10mm/year.

3.2 Conclusion of the study undertaken (maximum 500 words in bullets)

- In this study Gangotri glacier three-dimensional movement has been derived using ascending and descending pass Sentinel-1 SAR data by employing SOT and sensor parameters. Conclusions of this study are:

i. Ascending and Descending pass mean velocities complements each other.

ii. 3-D mean velocity is observed as higher than both pass mean velocities.

iii. Velocity shows the decreasing trend from the accumulation zone to terminus zone.

- In this study Siachen glacier surface velocity has been estimated by employing SOT over SAR and optical images. The inter sensor velocity results were analyzed in different zones of the glacier and have shown high correlation along and across the glacier. Major conclusions of this study are: (1) the total movement of this glacier is variant during 1996-2018. Mean velocity is decreased from 108 ma^{-1} in 1996 to ~90 ma^{-1} in 2003, and then increased again to ~125 ma^{-1} during 2013-2018 (Table.2) (2) all three sensors provided similar along and across velocity trend over the entire glacier during the same period, (3) Sentinel -2 and Sentinel-1 have shown ~90% correlation in mean velocity. The high inter-sensor correlation validates movement each other with ± 10% deviation, (4) Upper part of ablation zone has shown maximum velocity among all other zones of this glacier due to high mass flux from its tributaries. (5) Movement variation of this glacier is associated with snow fall / snow cover variation. It is observed that the deviation in annual velocity of the glacier from SAR (S-1) and optical data range from 4% to 13% at each year. Only optical data (S-2 and L-8) deviation has been noticed in range 1% to 16%. The study confirms accuracy level of Sentinel-1, Sentinel-2 and Landast-8 data for glacier velocity estimation in the Himalayas.

- We attempted the SBAS DInSAR approach for time series movement estimation of the Gangotri glacier. ASAR ascending pass InSAR pairs are processed for deformation measurements using this algorithm. It is observed that glacier area does not show coherence at least as much as 0.25 and hence no any deformation signal could be produced on glaciers. But, this approach has produced very important information of land deformation (land slide or rock slide) which varies from -30 mm/year to10 mm/year. Himalayan region is highly sensitive area in terms of tectonics activities and settlement on the slopes of the mountain facilitates the land slides. SBAS is an important tool which can be used for precise deformation studies in mm order of accuracy and has a potential to be exploited for Himalayan deformation studies.

4 OVERALL ACHIEVEMENTS

4.1 Achievements on Objectives [Defining contribution of deliverables in overall Mission (max. 1000 words)]

- A new approach is developed for 3D velocity estimation in the Himalayas
- A time series study of continuous deformation has been tracked in different parts of NW-Himalaya

4.2 Establishing New Database/Appending new data over the Baseline Data (max. 1500 words, in bullet points)

- The study has contributed in terms of Himalayan deformation (glacier dynamics and land surface) studies and out comes have been reported in high impact factor journals.

4.3 Generating Model Predictions for different variables (if any) (max 1000 words in bullets)
NA (Research Scholar resigned)

4.4 Technological Intervention (max. 1000 words)
In this study, microwave remote sensing technology has been used for producing the results. Spaceborne synthetic aperture radar (SAR) data from Sentinnel and Envisat ASAR sensors have been used as input SAR interferometry SBAS algorithms for deciphering the surface deformation.

4.5 On-field Demonstration and Value-addition of Products (max. 1000 words, in bullet points)
4.6 Developing Green Skills in IHR
4.7 Addressing Cross-cutting Issues (max. 500 words, in bullet points)
Study produces a cross cutting observation between climate change effects over glacier dynamics and land deformation in associated areas.

5 IMPACTS OF FELLOWSHIP IN IHR

5.1 Socio-Economic Development (max. 500 words, in bullet points)

- It gives primary input regarding land deformation locational information may be helpful in transportation modeling
- Change Glacier dynamics can be treated a proxy change mass balance of the glacier and negative mass balance is associated with global warming effects over glaciers.

5.2 Scientific Management of Natural Resources In IHR (max. 500 words, in bullet points)

- Snow and ice runoff modeling needs various data for prediction and forecast

5.3 Conservation of Biodiversity in IHR (max. 500 words, in bullet points)
5.4 Protection of Environment (max. 500 words, in bullet points)
5.5 Developing Mountain Infrastructures (max. 500 words, in bullet points)
5.6 Strengthening Networking in IHR (max. 700 words, in bullet points)

6 EXIT STRATEGY AND SUSTAINABILITY

6.1 How effectively the fellowship findings could be utilized for the sustainable development of IHR (max. 1000 words)

- Partial use (Less than one third only) of sanctioned has paved the way for sustainable development of the Himalayan region in terms of land deformation prone areas.
- Snow and ice deposition should be protected by reducing the factors of climate change in the region

6.2 Efficient ways to replicate the outcomes of the fellowship in other parts of IHR (max. 1000 words)

- The approach developed here can be used in other parts of the Himalaya such as Sikkim Himalaya, Lahaul Spiti region, and other all Himalayan parts.

6.3 Identify other important areas not covered under this study, but needs further attention (max. 1000 words)

- Lahaul Spiti region, Chamoli region are important parts could not be covered

6.4 Major recommendations for sustaining the outcomes of the fellowship in future (500 words in bullets)

Following are recommendations based on this study.

- It is highly desirable to use advanced modeling approaches to automate the study process
- AI and ML tools can be used to automatic extraction of deformations using SAR data after massive training using results obtained
- Glacier surface velocity extraction can be automated using RNN and CNN approaches.
- Accessibility of the region can improved for field expeditions for validating the results.

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8 ACKNOWLEDGEMENTS

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APPENDICES

Appendix 1 – Details of Technical Activities: **Attached/Enclosed**
Appendix 2 – Copies of Publications duly Acknowledging the Grant/ Fund Support of NMHS: **Attached/Enclosed**
Appendix 3 – List of Trainings/ Workshops/ Seminars with details of trained resources and dissemination material and Proceedings
Appendix 4 – List of New Products (utilizing the local produce like NTFPs, wild edibles, bamboo, etc.)
Appendix 5 – Copies of the Manual of Standard Operating Procedures (SOPs) developed
Appendix 6 – Details of Technology Developed/ Patents filed
Appendix 7 – Any other (specify)

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(Signature of HRA/HJRF/HPF)

(**NMHS FELLOWSHIP COORDINATOR**)

(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)

(Signed and Stamped)

Place: ………………..
Date: ……../……/……

Annexure-I

Consolidated and Audited
Utilization Certificate (UC) and Statement of Expenditure (SE)

For the Period: ……………………………………….

1.	Title of the fellowship/Scheme:	
2.	Name of the Principal Investigator & Organization:	
3.	NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand Letter No. and Sanction Date of the Fellowship:	
4.	Amount received from NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand during the fellowship period (Please give number and dates of Sanction Letter showing the amount paid):	
5.	Total amount that was available for expenditure (including commitments) incurred during the fellowship period:	
6.	Actual expenditure (excluding commitments) incurred during the fellowship period:	
7.	Unspent Balance amount refunded, if any (Please give details of Cheque no. etc.):	
8.	Balance amount available at the end of the fellowships:	
9.	Balance Amount:	
10.	Accrued bank Interest:	

Certified that the expenditure of **Rs.____________________ (Rupees _________________________)** mentioned against Sr. No. 6 was actually incurred on the fellowship/scheme for the purpose it was sanctioned.

Date:

(Signature of Principal Investigator)	(Signature of Registrar/ Finance Officer)	(Signature of Head of the Institution)

OUR REF. No.

ACCEPTED AND COUNTERSIGNED

Date:

COMPETENT AUTHORITY
NATIONAL MISSION ON HIMALAYAN STUDIES (GBP NIHE)

Statement of Consolidated Expenditure

[Institution Name here]

Statement showing the expenditure of the period from
Sanction No. and Date :

1. Total outlay of the Fellowship :

2. Date of Start of the Fellowship :

3. Duration :

4. Date of Completion :

a) Amount received during the fellowship period :

b) Total amount available for Expenditure :

S. No.	Budget head	Amount received	Expenditure	Amount Balance/ excess expenditure
1	Salaries			
2				
3				
4				
5				
6				
7				
8				
9				
10	Institutional charges			
11	Accrued bank Interest			
12	**Total**			

Certified that the expenditure of **Rs.___________________ (Rupees:_____________________________)** mentioned against Sr. No.12 was actually incurred on the fellowship/ scheme for the purpose it was sanctioned.

Date:

(Signature of Principal Investigator)	(Signature of Registrar/ Finance Officer)	(Signature of Head of the Institution)

OUR REF. No.

ACCEPTED AND COUNTERSIGNED

Date:

COMPETENT AUTHORITY
NATIONAL MISSION ON HIMALYAN STUDIES (GBP NIHE)

Annexure-II

Consolidated Interest Earned Certificate

Please provide the detailed interest earned certificate on the letterhead of the grantee/ Institution and duly signed.

Annexure-III

DIRECT BENEFIT TRANSFER (DBT) DETAILS

Scheme Name:	**National Mission on Himalayan Studies (NMHS)**
Scheme Type:	**Central Sector (CS) Grant-in-Aid Scheme**
Scheme Code:	**NMHS**
Category:	**Fellowship Grant**
Month-Year:	

PRO FORMA FOR DBT DETAILS

University/Institution Name: ………………………………………………………….

S#	Position (H-RA, H-JRF/ H-JPF)	Name	DoB*	DoI*	PI	Research title	Objectives	Study Area, IHR State	Contact details (Complete corresponding address), Mobile No., E-mail ID	Bank details (Account number, IFSC Code)	Emoluments /Fellowship	Aadhaar No.
1.												

Note: For each month, the DBT Details Pro forma dully filled and signed for each Himalayan Fellowship Grant under NMHS must be submitted at finance.nmhspmu2017@gmail.com; nmhspmu2016@gmail.com. *DoB (Date of Birth); DoJ (Date of Joining).

(Authorized Signatory)

Month **2019 – Latest Updated List of Himalayan Researchers or Fellows** *(working in the current time)*

S#	Name	Fellowship (RA/JRF/JPF)
1.		
2.		

Details and Declaration of Refund of Any Unspent Balance

Please provide the details of refund of any unspent balance as RTGS (Real-Time Gross System) in favor of **NMHS GIA General** and declaration on the official letterhead duly signed by the Head of the Institution.

Kindly note the further Bank A/c Details as follows:

Name of NMHS A/c:	NMHS GIA General
Bank Name & Branch:	Central Bank of India (CBI), Kosi Bazar, Almora, Uttarakhand 263643
IFSC Code:	CBIN0281528
Account No.:	3530505520 (Saving A/c)

In case of any queries/ clarifications, please contact the NMHS-PMU at e-mail: nmhspmu2016@gmail.com

Annexure-V

Technology Transfer and/ or Intellectual Property Rights Certificate

With a view to encourage the institutions to file patent applications on their innovations, motivate them to transfer their technologies for commercialization, and facilitate them to reward their inventions, the following instructions are issued.

1. In these instructions:

(a) **"Institution"** means any technical, scientific or academic establishment where research work is carried out through funding by the Central / State Government.

(b) **"Intellectual Property Rights"** include patents, registered designs, copyrights and layout design of integrated circuits.

(c) **"Inventor"** means an employee of the institution whose duties involve carrying out of scientific or technical research.

2. Scope: These instructions apply to those institutions receiving funds for research projects/ fellowships from NMHS, the Ministry of Environment, Forest and Climate Change (MoEF&CC).

3. Inventions by institutions: Institutions shall be encouraged to seek protection of Intellectual Property Rights (IPR) to the results of research through R&D projects/ fellowships. While the patent may be taken in the name(s) of inventor(s), the institutions shall ensure that the patent is assigned to it & DBT, GOI. The institution shall take necessary steps for commercial exploitation of the patent on non-exclusive basis. The institution is permitted to retain the benefits and earnings arising out of the IPR. However, the institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall be limited to 1/3rd of the actual earnings.

4. Inventions by institutions and industrial concerns: IPR generated through joint research by institution(s) and industrial concern(s) through joint efforts can be owned jointly by them as may be mutually agreed to by them and accepted by the Department through a written agreement. The institution and industrial concern may transfer the technology to a third party for commercialization on exclusive/non-exclusive basis. The third party, exclusively licensed to market the innovation in India, must manufacture the product in India. The joint owners may share the benefits and earnings arising out of commercial exploitation of the IPR. The institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall not exceed $1/3^{rd}$ of the actual earnings.

5. Patent Facilitating Fund: The institution shall set apart not less than 25 per cent of such earnings for crediting into a fund called Patent Facilitating Fund. This Fund shall be utilized by the institution for updating the innovation, for filing new patent applications, protecting their rights against infringements, for creating awareness and building competency on IPR and related issues.

6. Information: The institutions shall submit information relating to the details of the patents obtained, the benefits and earnings arising out of IPR and the turnover of the products periodically to the Department/Ministry, which has provided funds.

7. Royalty-free license: The Government shall have a royalty-free license for the use of the intellectual property for the purposes of the Government of India.

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

PART B: COMPREHENSIVE REPORT

EXECUTIVE SUMMARY

The Executive Summary of the fellowship should not be more than 3–5 pages, covering all essential features in precise and concise manner as stated in Part A (Cumulative Fellowship Summary Report) and Part B (Comprehensive Report).

Fellowship Report No.: ***2of2*** *(n = Sequential number; N= Total no. of fellowships granted to the Institute/ University)*

Researchers Details

Type of Fellowship(HRA/HJRF/HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJRF	SHANMUGA PRIYA SELVARAJ	18-03-2020	18-03-2021 (No any researcher joined on this project as HJRF during Corona period)	Land deformation studies (Landslide) in the Himalayas using InSAR and advanced InSAR approaches	Dr. Vijay Kumar Professor, ECE, VIT Vellore
(*in case of continuation of fellowship*)					

*If the appointed researcher resigned in the mid of the fellowship duration, thenalso mention the name of the Himalayan researcher who carried forward the fellowship.

1 INTRODUCTION

1.1 Background/ Summary of the Associateship / FellowshipStudy undertaken (max. 500 words)

The information obtained from satellite remote sensing has greater potential for better understanding of landslide processes and landslide hazard assessment. Landslides are abrupt short-lived geomorphic events that constitute the rapid downward motion of soil and rock materials occurring in sloping terrains. The triggering mechanism may include excessive precipitation, earthquakes, or deforestation which upset the natural stability of the slope, resulting in falling, sliding or flowing of landmass under gravity. Traditionally, landslides assessment has been monitored using ground-based measurements and GPS based techniques, which are often handicapped by observational bias, inaccessibility, high risk exposure and are mostly point measurements **(Savvaidis, 2003)**.Due to the number and large extent of landslide prone areas in the Himalayan region, conventional methods are not suited for rapid detection and estimation of hotspot areas.

On the other hand, remote sensing-based SAR interferometric techniques enable spatial continuous data at different spatial scales covering wide area **(Balmer and Hartl, 1998)**. Estimation results from such space-borne observations can yield deformation information at very high accuracies. Also, it can map displacement of approximately 100 km^2 with a single acquisition geometry. However, problems due to changes in scattering mechanism involved with changes in Earth's surface features with time and look direction limits the applicability of InSAR. Deformation measurements using this approach in Himalayan challenged terrain of high relief variations affected by atmospheric artifacts **(Kumar et al., 2008).**

For long-term displacement monitoring and to monitor deformation occurring in slow deformation rates, multi-temporal InSAR techniques have been deployed. Moreover, increasing number of earth observation satellite constellations such as ESA's Sentinel mission (Sentinel -1A and Sentinel-1B) with high temporal resolution favors effective monitoring of mass landslide movements. In this work, we investigate the potential of InSAR, DInSAR and especially advanced class of DInSAR techniques such as Small Baseline Subset (SABS) **(Berardino et al., 2002)** and Persistent Scatterers (PS) **(Colesanti and Wasowski, 2006)** interferometry to estimate the temporal behaviour of land displacement due to landslides in the Indian Himalayan region.

1.2 Baseline and Scope of the Associateship / Fellowship (max. 1000 words)

Landslides are abrupt short-lived geomorphic events that constitute the rapid downward motion of soil and rock materials occurring in sloping terrains. The triggering mechanism may include excessive precipitation, earthquakes, or deforestation which upset the natural stability of the slope, resulting in falling, sliding or flowing of landmass under gravity. Aerial photography has been used extensively to characterize landslides and to produce landslide inventory maps, particularly because of their stereo viewing capability and high spatial resolution. Airphotos were used to identify steep slopes underlain by weak soils, slopes undercut by rivers and waves, tension cracks, steep hummocky topography, failed surface scarps, anomalous bulges and lumps, terraced slopes, discontinuous bedding planes, drainage-vegetation patterns and elongated ponds on hillslopes(Alföldi 1973; Mollard 1977; Nilsen&Brabb 1977; Mollard&Janes 1984; Cruden& Lu 1992; Savigny 1993).

Various methods are exists in 20th century to assess the landslide prone zones in terms of qualitative and quantitative. Geomorphological hazard mapping, heuristic or index-based methods are quantitative and direct methods. Analysis of landslide inventories, functional, statistically based models, geotechnical or physically based models are indirect methods (Jibson 1993; Guzzetti et al. 1999). Landslide susceptibility map in the Kakuda-

Yahiko Mountains of Central Japan has been generated with GIS and statistical approaches(Carrara et al. 1991; Ayalew&Yamagishi 2005). Landslide prediction using SAR data with the help of 3D terrain models is one of the relevant is suitable approach to predict the vulnerability zones (Fruneau et al. 1996; Leva et al. 2003; Tarchi et al. 2003; Strozzi et al. 2005; Colesanti&Wasowski 2006; Nouguès et al. 2010). The daily movement of La Valette (southern French Alps) has been identified with 9 years SAR interferometric observations as 0.4 – 1 cm/day during 1991-1999(Squarzoni et al. 2003). Persistent scatter interferometry with X-band SAR data has been found that PS density from COSMO Sky Med SAR data is from ~ 3 to 11 times higher than from ASAR (Bovenga et al. 2012).

SAR interferometry and optical images can be used to analyse the characterization of the landslide. Where the flow slide has been identified with the help of SAR and air-borne imagery (Singhroy et al. 1998). Interferometric and ground based measurements with DGPS have established a correlation and found the reason that landslides are sensitive to rainfall (Herrera et al. 2009).

Researches exist in India about landslide suspect ability and early warning system from several academic and research institutions: IIRS, IIT's, NDMA, NRSC, IIST…... etc. Landslide susceptibility has been estimated and analysed from GIS database and statistical approaches (Sarkar et al. 1995; Sarkar&Kanungo 2005; Das et al. 2010; Westen et al. 2012; Pardeshi et al. 2013; Kumar et al. 2017). Rainfall intensity and the duration have an impact slope stability which may further leads to slides(Ering&Babu 2016). Most of the studies are carried out in India in the places such as GARHWAL HIMALAYA, Kumaun Himalaya, Northern Himalaya, Malin – Pune, Western Ghats and north-Sikkim. Remote sensing (SAR) based landslide prediction has been attempted from researches (Iverson 2000; Rodriguez et al. 2002; Singh et al. 2005; Bhandari 2006; Delacourt et al. 2009; Martha & Kumar 2013; Pareek et al. 2013; Bhattacharya et al. 2015; Vöge et al. 2015; Pham et al. 2017).

In this study advanced InSAR processing algorithm small baseline SAR Interferometry (SBAS) is proposed to quantify time series deformation in the NW Himalaya. The work has been started with ENVISAT ASAR data processing and planned to use Sentinnel-1 data for time series analysis.

1.2.1Study Area (max. 150 words)

Fig.1 Study area location map

UTTARKASHI is a district in Uttarakhand state. The landslide in 2003 from Varunavat hill (Gupta &Bist 2004) lead to damage to the sustainability of living beings in the location. In 2012-2013 floods caused severe disaster to the livelihood and man-made constructions over the area. The parameters such as surface, water and climate parameters has to be studied continuously around the area to quantify deformation in the landslide prone areas. Model for landslide will be developed for future prediction on the basis of this study.

As a part of glacier dynamics studies, Gangotri glacier has been chosen as nearest glacier to the proposed test site and other glacier also has been studied in the same acquired scene. For observing the contrasting results Siachen glacier is also chosen as attest site.

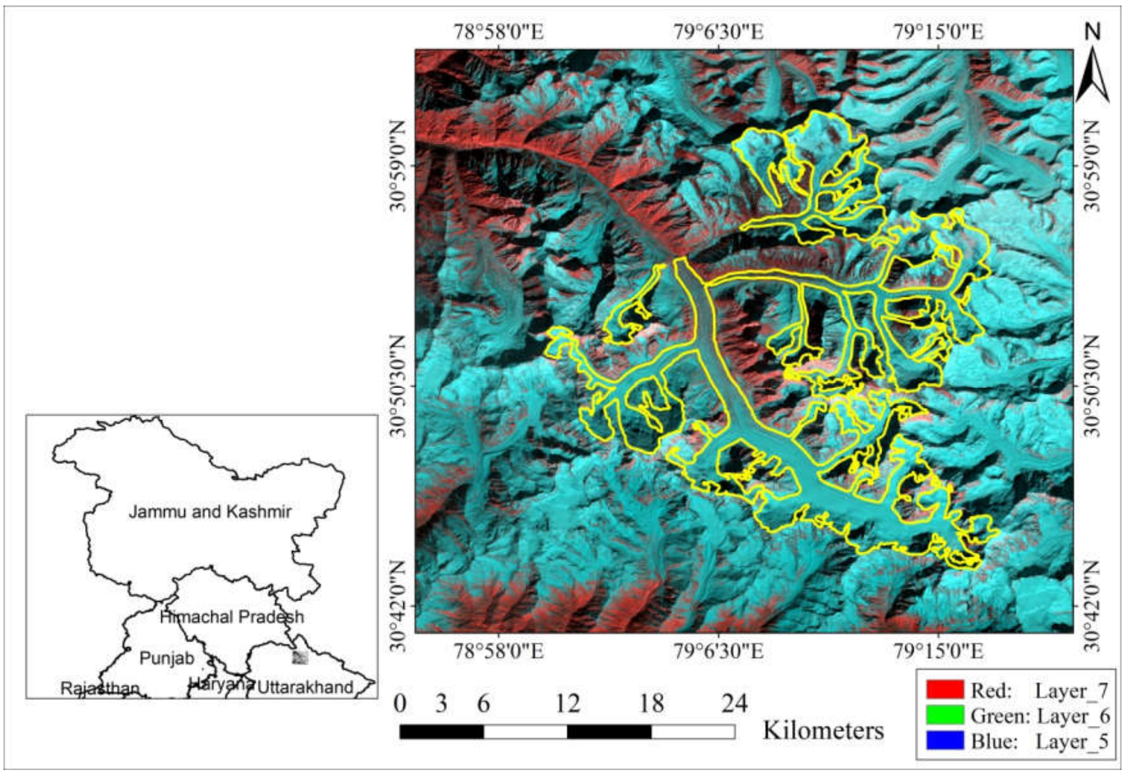

Fig.2. Gangotri glacier basin map superimposed over Sentinnel-1B optical image.

1.3 Overview of the Major Issues to be addressed (max. 1000 words)

- SAR data Acquisition
- SAR data Pre-processing and calibration
- Differential SAR Interferometry using Multiple SAR Pairs
- Advanced SAR interferometry algorithms SBAS application for deformation studies

1.4 Brief summary of the activities under taken by the researcher (max. 1000 words)

[Providing full details of Field study, experimental set up, methods adopted, data collected supported by necessary table, charts, diagrams & photographs (**Data, table and figures should be attached as separate source file (.docx, .xls, jpg, .jpeg, .png, .shp, etc.)].**

2 METHODOLOGIES, STARTEGY AND APPROACH

2.1 Methodologies used for the study (max. 1000 words)

D.1. Interferometric SAR (InSAR) for land deformation studies

The satellite based InSAR technique involves comparing the phase information from two SAR images to potentially detect millimetre to centimetre scale ground deformation patterns (Gabriel et al. 1989). Over the last decades, interferometry has become an important tool for mapping topography, studying surface deformation, observing glacial flows, and classification of terrains (Massonnet&Feigl 1998). InSAR provides high resolution terrain displacement associated with geophysical processes like surface movement, landslides and land subsidence etc.

$\phi_{InSAR} = \phi_{def} + \phi_{topo} + \phi_{atm} + \phi_{orbit} + \phi_{noise}$ Surface flow measurements are fundamentally important for studying the mass balance and strain rate changes of surface using InSAR and offset tracking approaches (Joughin et al. 1998; Gray et al. 2001; Rignot et al. 2002). Synthetic Aperture Radar Interferometry (InSAR) is a powerful technique for measuring the surface and strain rate (velocity gradient) with high accuracy. Interferograms are generated by multiplying a SAR signal with the complex conjugate of a signal acquired with slightly different orbital geometry but with same satellite track. In this way phase difference calculated between two satellites is the sum of many components and given by (Hanssen 2001).

Where, ϕ_{def} is deformation phase due to displacement in LOS during repeat SARacquisitions. ϕ_{topo} topographic phase, which has been removed from DEM simulatedphase. ϕ_{orbit} is phase due to incorrect knowledge of the satellite orbits, ϕ_{atm} is phasechanges due to different atmospheric delay between the acquisitions, and ϕ_{noise} isadditive noise due to variability in scattering from the pixel, SAR system thermalnoise and co-registration errors. Phase components due to topography, atmosphereand system noises

has to be minimized and modelled for estimating the deformationphase. Interferograms can be flattened and then unwrapped using statistical-cost,
network flow algorithm for phase unwrapping (SNAPHU) developed by Chen andZebker, 2000, and phase due to displacement of surface in radar line of sight (LOS)can be calculated.

D.2. Advanced InSAR techniques

Advanced DInSAR approaches such as small baseline subset (SBAS) and permanent scattererInSAR (PSInSAR) are able to quantify mm to cm level deformation signals by involving a time series SAR images (Ferretti et al. 2001). Frequent spatial and temporal decorrelation in the Himalayan region is a strong impediment in precise deformation estimation using conventional interferometric SAR (InSAR) approach. Herein, SBAS and DInSAR approaches will be exploited for millimetre to centimetre scale accurate surface displacement estimation and time series deformation studies in north - western (NW) Himalayan test sites.

The main limiting factors are atmospheric artifacts that can introduce a bias in the phase measurement (Zebker et al. 1997), another limitation is spatial baseline decorrelation that occurs when the interferometric baseline is not exactly zero. Since the radar receives the coherent sum of all independent scatterers within the resolution cell, these contributions are added slightly differently due to the different geometry. Spatial decorrelation leaves many interferometric combinations infeasible in areas with steep terrain. Effects of various decorrelation phenomena can be reduced by combining multiple SAR observations using multitemporalInSAR techniques. Using more than two SAR scenes leads to redundant measurements that can be utilized for more advanced time series methods such as SBAS and PSInSAR. SBAS methods use SAR image combinations with a short spatial baseline to reduce the effects of spatial and temporal decorrelation(Berardino et al. 2002; Schmidt &Bürgmann 2003; Lanari et al. 2007; Hooper 2008). Herein, we investigate the potentiality of advanced SBAS DInSAR approach for landslide studies in Himalayan region using ENVISAT ASAR data sets in ascending mode. Atmospheric delays affecting a SAR interferogram are measured as a double difference, both in time and space, of propagation delays from satellite to ground then back to satellite. There is no absolute delay measured by SAR interferometry. It is useful to decompose the atmospheric delays into those due to atmospheric stratification and those due to a laterally variable, "turbulent", atmospheric state (Hanssen 2001).

2.2 Details of Scientific data collected and Equipments Used (max 500 words)

SAR data from ENVISAT ASAR and Sentinnel-1A/1B satellites have been collected and used in this study. Table-1 shows ENVISAT ASAR data used for time series deformation studies.

Table 3.1 ENVISAT ASAR InSAR pairs of ascending mode used for SBAS DInSAR

based study in north-western Himalayas.

Sr. No.	Date1	Date 2	Perpendicular Baseline (m)	Temporal base line (days)
1.	29-04-2003	30-12-2003	-318.00	245
2.	**13-04-2004**	**12-08-2003**	**449.00**	**245**
3.	13-04-2004	30-12-2003	-633.00	105
4.	18-05-2004	29-04-2003	-605.00	385
5.	18-05-2004	12-08-2003	749.00	280
6.	**18-05-2004**	**30-12-2003**	**-287.00**	**140**
7.	**18-05-2004**	**13-04-2004**	**345.00**	**35**
8.	27-07-2004	29-04-2003	-697.00	455
9.	**27-07-2004**	**12-08-2003**	**-703.00**	**350**
10.	27-07-2004	30-12-2003	-379.00	210
11.	**27-07-2004**	**13-04-2004**	**253.00**	**105**
12.	**27-07-2004**	**18-05-2004**	**-92.00**	**70**
13.	05-10-2004	29-04-2003	-186.00	525
14.	**05-10-2004**	**30-12-2003**	**132.00**	**280**
15.	05-10-2004	13-04-2004	765.00	175
16.	**05-10-2004**	**18-05-2004**	**420.00**	**140**
17.	**05-10-2004**	**27-07-2004**	**511.00**	**70**
18.	18-01-2005	29-04-2003	-898.00	630
19.	18-01-2005	29-04-2003	-497.00	630

20.	18-01-2005	30-12-2005	-179.00	385
21.	18-01-2005	13-04-2004	453.00	280
22.	18-01-2005	18-05-2004	-108.00	245
23.	18-01-2005	27-07-2004	199.00	175
24.	18-01-2005	05-10-2004	-312.00	105
25.	**05-09-2006**	**12-08-2003**	**297.00**	**1120**
26.	05-09-2006	30-12-2003	-785.00	980
27.	**05-09-2006**	**13-04-2004**	**-152.00**	**875**
28.	**05-09-2006**	**18-05-2004**	**-497.00**	**840**
29.	**05-09-2006**	**27-07-2004**	**-405.00**	**770**
30.	05-09-2006	18-01-2005	-605.00	595
31.	23-01-2007*	29-04-2003	-662.00	1365
32.	23-01-2007	12-08-2003	738.00	1260
33.	23-01-2007	30-12-2003	-344.00	1120
34.	23-01-2007	13-04-2004	-289.00	1015
35.	23-01-2007	18-05-2004	-56.00	980
36.	23-01-2007	27-07-2004	-35.00	910
37.	23-01-2007	05-10-2004	-476.00	840
38.	**23-01-2007**	**18-05-2004**	**-56.00**	**980**
39.	23-01-2007	18-01-2005	-164.00	735
40.	**23-01-2007**	**05-09-2006**	**-441.00**	**140**
41.	08-05-2007	12-08-2003	552.00	1365
42.	08-05-2007	30-12-2003	-560.00	1225
43.	08-05-2007	13-04-2004	73.00	1120
44.	**08-05-2007**	**18-05-2004**	**272.00**	**1085**
45.	**08-05-2007**	**27-07-2004**	**180.00**	**1015**
46.	08-05-2007	05-10-2004	-692.00	945

47.	08-05-2007	18-01-2005	-380.00	840
48.	**08-05-2007**	**05-09-2006**	**225.00**	**245**
49.	**08-05-2007**	**23-01-2007**	**-215.00**	**105**

***Master geometry for co-registering all SAR images**

2.3 Primary Data Collected (max 500 words)

SAR data used glacier dynamics studies is shown in the table-2

2.4 Details of Field Survey arranged (max 500 words)

Corner Reflectors fixed at Tapovan area in the right hand side bank of the Gangotri glacier above 300 ft from glacier surface have been used to calibrate the results as a fixed stationary points.

2.5 Strategic Planning for each Activities (max. 1000 words)

2.6 Activity-wise Timeframe followed using Gantt/ PERT Chart (max. 1000 words)

TASK / TIME ↓ →	Sub Task	0 – 6 Months	7 – 12 Months	13 – 18 Months	19 – 24 Months	25 – 30 Months	30 – 36 Months
Data collection	1. Satellite data			✓			
	2. Ancillary data			✓			
	3. Past climate readings						
	4. Forecast data collection						
	5. Field measurements						
Data Analysis and Model development	Model development			✓	✓		
	Analysis				✓		
	Validate and refine the model						
Reporting and Documentation.	Prepare seasonal reports			✓	✓		
	Paper work / documentation			✓			
	Final report of the project						✓

3 KEY FINDINGS AND RESULTS

3.1 Major Research Findings (max. 1000 words)

- A time series land surface deformation studies have been carried out Uttatkashi district using time series ENVISAT ASAR data. Advanced InSAR processing algorithm SBAS is used to decipher land deformation in the study area with major sites Joshimath , Gangotri glacier basin area. It has been slow deformation over the certain points ranging from -30mm/year to 10mm/year.

3.2 Conclusion of the study undertaken (maximum 500 words in bullets)

- We attempted the SBAS DInSAR approach for time series movement estimation of the Gangotri glacier. ASAR ascending pass InSAR pairs are processed for deformation measurements using this algorithm. It is observed that glacier area does not show coherence at least as much as 0.25 and hence no any deformation signal could be produced on glaciers. But, this approach has produced very important information of land deformation (land slide or rock slide) which varies from -30 mm/year to10 mm/year. Himalayan region is highly sensitive area in terms of tectonics activities and settlement on the slopes of the mountain facilitates the land slides. SBAS is an important tool which can be used for precise deformation studies in mm order of accuracy and has a potential to be exploited for Himalayan deformation studies.

4 OVERALL ACHIEVEMENTS

4.1 Achievements on Objectives [Defining contribution of deliverables in overall Mission (max. 1000 words)]

- A new approach is developed for 3D velocity estimation in the Himalayas
- A time series study of continuous deformation has been tracked in different parts of NW-Himalaya

4.2 Establishing New Database/Appending new data over the Baseline Data (max. 1500 words, in bullet points)

- The study has contributed in terms of Himalayan deformation (glacier dynamics and land surface) studies and out comes have been reported in high impact factor journals.

4.3 Generating Model Predictions for different variables (if any) (max 1000 words in bullets)

NA (Research Scholar resigned)

4.4 Technological Intervention (max. 1000 words)

In this study, microwave remote sensing technology has been used for producing the results. Spaceborne synthetic aperture radar(SAR) data from Sentinnel and Envisat ASAR sensors have been used as input SAR interferometry SBAS algorithms for deciphering the surface deformation.

4.5 On-field Demonstration and Value-addition of Products (max. 1000 words, in bullet points)
4.6 Developing Green Skills in IHR
4.7 Addressing Cross-cutting Issues (max. 500 words, in bullet points)

Study produces a cross cutting observation between climate change effects over glacier dynamics and land deformation in associated areas.

5 IMPACTS OF FELLOWSHIP IN IHR

5.1 Socio-Economic Development (max. 500 words, in bullet points)

- It gives primary input regarding land deformation locational information may be helpful in transportation modeling
- Change Glacier dynamics can be treated a proxy change mass balance of the glacier and negative mass balance is associated with global warming effects over glaciers.

5.2 Scientific Management of Natural Resources In IHR (max. 500 words, in bullet points)

- Snow and ice runoff modeling needs various data for prediction and forecast

5.3 Conservation of Biodiversity in IHR (max. 500 words, in bullet points)
5.4 Protection of Environment (max. 500 words, in bullet points)
5.5 Developing Mountain Infrastructures (max. 500 words, in bullet points)
5.6 Strengthening Networking in IHR (max. 700 words, in bullet points)

6 EXIT STRATEGY AND SUSTAINABILITY

6.1 How effectively the fellowship findings could be utilized for the sustainable development of IHR (max. 1000 words)

- Partial use (Less than one third only) of sanctioned has paved the way for sustainable development of the Himalayan region in terms of land deformation prone areas.
- Snow and ice deposition should be protected by reducing the factors of climate change in the region

6.2 Efficient ways to replicate the outcomes of the fellowship in other parts of IHR (max. 1000 words)

- The approach developed here can be used in other parts of the Himalaya such as Sikkim Himalaya, LahaulSpiti region, and other all Himalayan parts.

6.3 Identify other important areas not covered under this study, but needs further attention (max. 1000 words)

- LahaulSpiti region, Chamoli region are important parts could not be covered

6.4 Major recommendations for sustaining the outcomes of the fellowship in future (500 words in bullets)

Following are recommendations based on this study.

- It is highly desirable to use advanced modeling approaches to automate the study process
- AI and ML tools can be used to automatic extraction of deformations using SAR data after massive training using results obtained
- Glacier surface velocity extraction can be automated using RNN and CNN approaches.
- Accessibility of the region can improved for field expeditions for validating the results.

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APPENDICES

Appendix 1 – Details of Technical Activities :**Attached/Enclosed**
Appendix 2 – Copies of Publications duly Acknowledging the Grant/ Fund Support of NMHS :**Attached/Enclosed**

Appendix 3 – List of Trainings/ Workshops/ Seminars with details of trained resources and dissemination material and Proceedings
Appendix 4 – List of New Products (utilizing the local produce like NTFPs, wild edibles, bamboo, etc.)
Appendix 5 – Copies of the Manual of Standard Operating Procedures (SOPs) developed
Appendix 6 – Details of Technology Developed/ Patents filed
Appendix 7 – Any other (specify)

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(Signature of HRA/HJRF/HPF)

(**NMHS FELLOWSHIP COORDINATOR**)

(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)

(Signed and Stamped)

Place: ………………..
Date: ……../……/……