



**Bharati Vidyapeeth Institute of Environment
Education and Research (BVIEER), Katraj,
Pune - Maharashtra**



Internship Report

**Title 1: Reconstruction of Historical Glacial Changes of
Din Gad Valley (Dokriani Glacier): Garhwal
Himalayas**

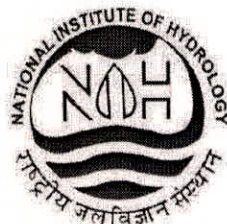
&

**Title 2: Hydrological Modelling in a part of Netravati
Basin using SWAT Model**

By

**Shubham Gude
(MSc. Geoinformatics)**

**Supervised by
Dr. Renoj J Thayyen**



**National Institute of Hydrology, Roorkee
July 2017**



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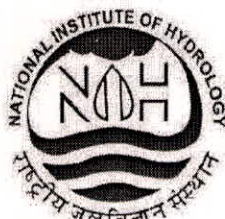
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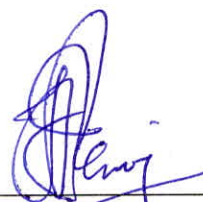
CERTIFICATE

This is to certify that **Mr. Shenvi Gude Shubham Uday**, M.Sc. final year student of Bharati Vidyapeeth Deemed University - Institute of Environment Education and Research, Pune, under the guidance of **Dr. Renoj J. Thayyen**, has successfully completed his internship and worked on two short projects, title 1: "**Reconstruction of Historical Glacial Changes of Din Gad Valley (Dokriani Glacier): Garhwal Himalayas**" & title 2: "**Hydrological Modelling in a part of Netravati Basin using SWAT Model**" in partial fulfilment of the Master Degree in Geoinformatics during the academic year 2016-2017.

The work has been completed to our satisfaction and standards. The said Internship Report has not been submitted for any other degree or diploma and any such material which has been obtained from other source has been acknowledged in the Report.



Shubham Gude
M.sc. Geoinformatics
(BVIEER - Pune)



Dr. Renoj J. Thayyen
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Duration of internship: **20 February 2017 to 31 July 2017**

Project 1

Reconstruction of Historical Glacial Changes of Din Gad Valley (Dokriani Glacier): Garhwal Himalayas

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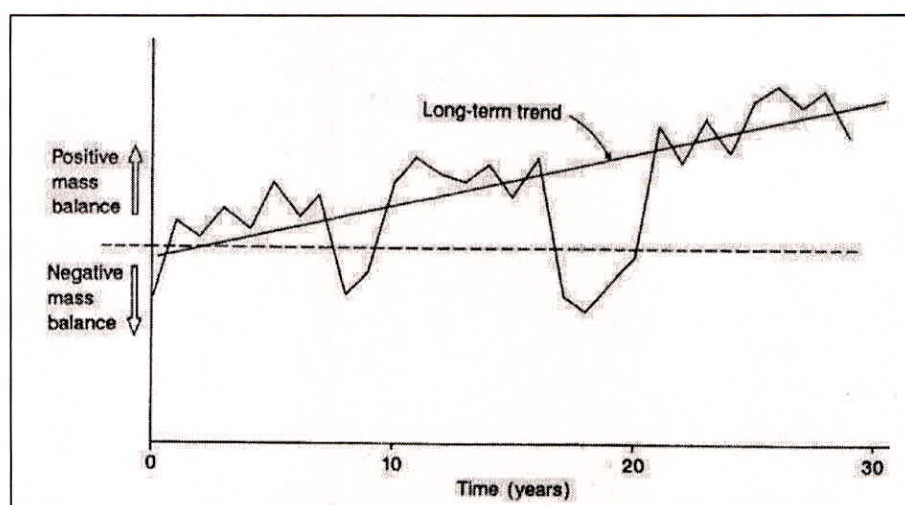
Introduction

Global Climate Change and Glacier Response

The Earth's climate has changed throughout history. For example, fossils from the Cretaceous period (144 to 65 million years ago) show that Earth was much warmer than it is today. Fossilized plants and animals that normally live in warm environments have been found at much higher latitudes than they could survive at today. For instance, breadfruit trees, now found on tropical islands, grew as far north as Greenland. Earth has also experienced several major ice ages, at least four in the past 500,000 years. During these periods, Earth's temperature decreased, causing an expansion of ice sheets and glaciers.

A glacier is formed when the surplus snow that collects above the permanent snowline, where the losses to summer melting are less than the gains from winter accumulation slowly turn in to ice over a period of time and starts its down slope movement. The size of a glacier is determined primarily by climate. Changes in climate will cause its margins to expand or contract, because climate controls a glacier's mass balance. If the balance is positive (accumulation greater than ablation) it will expand and grow. If it is negative then the glacier will contract. If the accumulation equals ablation for a long time, the glacier remain in steady state. Glaciers are constantly responding to changes in their mass balance budget, adjusting to annual variations as well as to long-term trends (Glacial Geology – Ice Sheet and Landforms, 2009).

Fig 1: Short-term and long term trends in mass balance

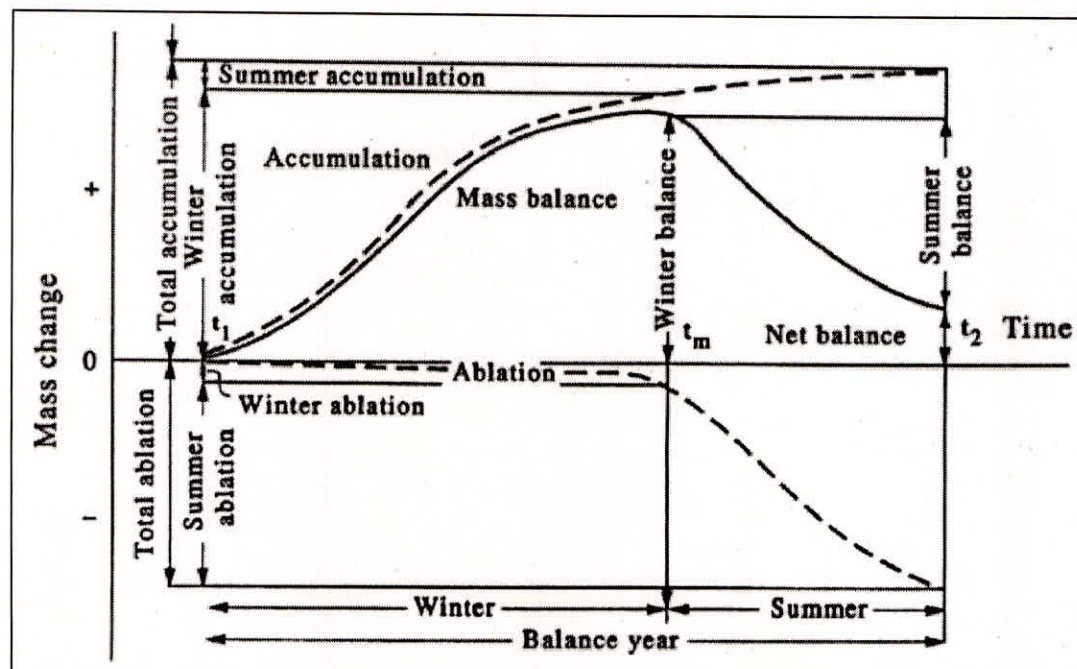


Source: *Glacial Geology – Ice Sheet and Landforms, 2009*

A glacier always crosses the permanent snowline from the area of snow gain to the zone of ice loss (Trevor Chinn, 2008). The altitude of this permanent snowline is the equilibrium line. It marks the altitude at which snow gain (accumulation) is exactly balanced by melt (ablation). If the temperature or snowfall changes even a little, the altitude of the equilibrium line shifts dramatically, with consequent change to the volume

of the glacier. It is this mass balance that makes glaciers sensitive climate instruments that record year-by-year climate in the mountains (Jim Salinger, 2008).

Fig 2: Variation of accumulation, ablation, and mass balance during a glaciological year for a glacier with distinct accumulation and ablation seasons



Source: *Glacier Mass Balance*, Fairbanks & McCarthy, 2010, Geophysical Institute, University of Alaska, Fairbanks

Glaciers are sensitive climate proxies and variations in their length, area and volume provide insights into past climate variability, placing contemporary changes into a long-term context (Solomina, 2016). Historic records of glacier length contain valuable information on past climate. Valley glaciers are more sensitive to climate change. Records of glacier fluctuations contain many examples of changes in glacier length of several kilometres within the last century. Glaciers of different geometry, located in different climatic regimes, will react in different ways to a climatic signal (Oerlemans, 1997).

Individual glaciers' response times to changes in climate vary from 5 to more than 100 years (Jim Salinger, 2008). At a simple level the larger the ice body the slower the response time. Large ice sheets will respond only to large and sustained changes in mass balance, whereas small cirque or valley glaciers will often respond quickly to minor fluctuations. The rate of response of these smaller ice bodies is influenced by their morphology (Book). Glaciers are influenced by local meteorological and topographic variables and one hypothesis is that length fluctuations of glaciers reflect mainly temperature changes, as indicated by modelling studies of 20th Century glacial retreat (Oerlemans, 1997).

The reaction of a glacier to a climatic change involves a complex chain of processes (Nye 1960, Meier 1984). Changes in atmospheric conditions (solar radiation, air temperature, precipitation, wind, cloudiness, etc.) influence the mass and energy balance at the glacier

surface. Air temperature thereby plays a predominant role as it is related to the long-wave radiation balance, turbulent heat exchange and solid/liquid precipitation. Over time periods of years to several decades, cumulative changes in mass balance cause volume and thickness changes, which in turn affect the flow of ice via altered internal deformation and basal sliding. This dynamic reaction finally leads to glacier length changes, the advance or retreat of glacier tongues. In short, the advance or retreat of glacier tongues (i.e., the 'horizontal' length change) constitutes an indirect, delayed and filtered but also enhanced and easily observed signal of climatic change, whereas the glacier mass balance (i.e., the 'vertical' thickness change) is a more direct and undelayed signal of annual atmospheric conditions.

Understanding the interaction of climate, mass balance and glacier response is important not only in examining the response of glaciers to relatively minor climatic fluctuations but also to the more dramatic and long-term fluctuations associated with the onset of a glacial cycle. Different behaviours are encountered at heavily debris-covered glaciers with reduced melting and strongly limited 'retreat', glaciers ending in deep water bodies causing enhanced melting and calving, and glaciers periodically undergoing mechanical instability and rapid advance ('surge') after extended periods of stagnation and recovery. Glaciers (those not affected by these special conditions) are recognised to be among the best indicators within global climate related monitoring (WGMS).

Glacier History of Earth

The most recent Ice Age began about 2 million years ago and peaked about 20,000 years ago. The ice caps began retreating 18,000 years ago. They have not disappeared completely, however. Their presence in Antarctica and Greenland suggests the Earth is still in a sort of ice age. Climatologists look for evidence of past climate change in many different places. Glaciers leave many clues behind them. They scratch and scour rocks as they move. They deposit sediment known as glacial till. This sediment sometimes forms mounds or ridges called moraines. Glaciers also form elongated oval hills known as drumlins. All of these geographic features on land that currently has no glaciers suggest that glaciers were once there.

The most recent maximum extent of glaciers was at the end of the last cool period for our region, the Little Ice Age or LIA. The term Little Ice Age was originally coined by F Matthes in 1939 to describe the most recent 4000 year climatic interval (the Late Holocene) associated with a particularly dramatic series of mountain glacier advances and retreats, analogous to, though considerably more moderate than, the Pleistocene glacial fluctuations. This relatively prolonged period has now become known as the Neoglacial period. The term Little Ice Age is, instead, reserved for the most extensive recent period of mountain glacier expansion and is conventionally defined as the 16th–mid 19th century period (Michael E Mann, 2002).

During this time, average global temperatures were 1 to 1.5 degrees Celsius (2-3 degrees Fahrenheit) cooler than they are today. A change of one or two degrees was enough to cause some pretty massive effects. For instance, glaciers grew larger and sometimes engulfed whole mountain villages. Winters were longer than usual, limiting the growing seasons of crops.

In northern Europe, people deserted farms and villages to avoid starvation. Then there was some warming from about 1910 to the mid-1970s, and especially in the 1950s, which caused a massive wastage of glaciers. These glaciers have kept their LIA areas for all but the last couple of decades. Most of the relatively thick ice filling their over-deepened valleys was a remnant from the LIA, insulated by mantles of rocky moraine (Jim Salinger, 2008). However, no single period of common global glacier retreat of centennial duration, except for the past century, has yet been identified. In contrast, the view that the Little Ice Age was a period of global glacier expansion beginning in the 13th century (or earlier) and reaching a maximum in 17th and 19th centuries (Solomina, 2016). Moraines were deposited at positions beyond present-day ice limits throughout the 19th and early 20th centuries.

One way scientists have learned about the Little Ice Age is by studying the rings of trees that are more than 300 years old. The thickness of tree rings is related to the amount of the trees' annual growth. This in turn is related to climate changes. During times of drought or cold, trees could not grow as much. The rings would be closer together.

Glaciers reached their first maximum of the past millennium in the 12th century. They were only slightly more extensive than today in the 13th century, but advanced at least twice in the 14th and 15th centuries to near their maximum Little Ice Age positions. Glaciers probably fluctuated around these advanced positions from the 15th century to the beginning of the 18th century. They achieved their greatest extent between A.D. 1690 and 1720. Glaciers advanced in the second half of the Holocene between 4.4 and 4.2 ka (ka = thousand years), 3.8 - 3.4 ka, 3.3 - 2.8 ka, at 2.6 ka, between 2.3 and 2.1 ka, 1.5 - 1.4 ka, 1.2 - 1.0 ka, and 0.7 - 0.5 ka. (Solomina, 2016). Many scientists believe we are in an interglacial period, when warmer temperatures have caused the ice caps to recede. Many centuries from now, the glaciers may advance again.

Himalayan glacier history

The Himalayas has the largest collection of glaciers outside the polar region with the total glacier cover of around 33000km² and the total number of approximately 9600 glaciers in the Indian Himalayas (Bhambari et al., 2011). Glaciers play an important role in maintaining ecosystem stability as they act as buffer and regulate water supply from high mountains to the plain. Most of the glaciers in Himalayas are of winter accumulation type and ablation takes place simultaneously in summer (Fujita et al., 1997). Glaciers can be active, passive or dead. Its morphological characteristics is based on the size, shape and their relationship with the topography upon which they flow (Knight, 1999). On the basis

of their mode of occurrence and dimensions, glaciers have been classified into three categories: valley glaciers, Piedmont glaciers and continental glaciers. Himalayan glaciers are mainly valley glacier

Major glaciations cycles are known to have occurred in the past. The classical studies in the Alps had initially established the existence of four period of glaciations, separated by warm periods designated as the interglacial. These repeated glaciations covered by the Pleistocene ('most recent' from 2.5 million years to 10000 years) period. More elaborate studies have similar uncovered evidence for a larger number of glaciations periods in Europe and North America, extending to pre-Pleistocene periods, and in the case of Antarctica to the Mid-Miocene period (10 million years ago). In the Himalaya, four glacial periods and corresponding interglacial periods were initially identified from the Karewa sediments of Kashmir, establishing the parallel with Europe. Farther researches cast doubt on the existence of the oldest of the four glaciations periods. This is because the Himalaya attained their majestic height only in the late Pleistocene period and early glaciations did not perhaps produce much effect here. There are reliable records only for the later three glaciations periods.

The direct evidence for earlier glaciations in the Himalaya consists of the old glacier moraines deposited at the glacier termini. The terminus moraines characteristic U-shaped valleys and epigenetic gorges enter changed in their lower reaches. The glaciers which act as a sort of convergence belt for transporting the rock debris produced on the surrounding mountains, dump these at their termini or stack them along the flanks. Each major glaciations period lasted for a few thousand years, the moraines ridges and dumps grew considerably and are quite prominent.

In general, Himalayan glaciers have been retreating throughout the period AD 1850 to 1960. Similarly, advance records play a secondary role appearing only during the period AD 1850 to 1910.

Trans-Himalayan glaciers display a more complicated fluctuation record. Retreat forms the primary component of this record during AD 1850 to 1860, AD 1880 to 1890, and AD 1910 to 1960. Stillstand records are available for the period AD 1890 to 1940. The most dramatic perturbation in the record comes during the period AD 1890 to 1910 when advances dominate. This major period of advance is followed by a gradual decline in the number of advancing termini. During this period of decline, the number of stillstand records increases moderately and is suggestive of the beginning of a transition back to a retreat regime. The peak in number of advance records noted during the period AD 1860 to 1870 is based upon only a limited number of observations. In fact, this period may be better characterized as transitional between advance and retreat as is the period AD 1870 to 1880.

Another important consideration is glacier response time. The response time of a glacier can be approximated by Paterson's (1969:208) relation:

$$R = \frac{1}{4(\partial \epsilon_x / \partial t)}$$

where R is response time in years, ϵ_x is the longitudinal strain rate at the surface, τ is time, and $\partial \epsilon_x / \partial \tau$ is in y^{-1} ; as noted by Paterson (1969: 208) the strain rate for valley glaciers is commonly on the order of 10^{-1} to $10^{-2} y^{-1}$ yielding response times on the order of 2.5 to 25 yr. Absolute values of Trans-Himalayan and Himalayan glacier response times are not known, but the physical characteristics of these glaciers would suggest that their response times are similar to those of other valley glaciers. If we suppose that the natural range of response times of temperate glaciers is 2.5 to 25 yr, two possibilities can be cited; for fast response times, the Trans-Himalayan glacier advances during the period AD 1900 to 1909 may reflect increased mountain precipitation during approximately the same period. This first possibility infers that the diminished monsoon rainfall of principally the lowland stations was not reflected in the northern mountainous regions. For long response times, the advances during AD 1900 to 1909 may have resulted from the earlier maxima in the monsoon rainfall series centered around AD 1880 to 1889.

Glacial history of Garhwal Himalaya

In the Garhwal Himalayas, On the basis of sediments and landforms, 3 glacial stage has been recognised. Namely the Bhagirathi Glacial Stage, the Shivling Glacier Stage and the Bhujbas Glacier Stage (Milap Chand Sharma, 1996) The Bhagirathi Glacial Stage is represented by an extensive valley glaciation, when glaciers advanced and coalesced with the main Bhagirathi Valley Glacier to extend down-valley as far as Jhala. It is suggested that the Gangotri Glacier advanced around 40 km beyond its present limits, reaching an altitude of 2300m. The ELA depression during this stage was ca. 640 ka. The Bhagirathi Glacial Stage is constrained by optically stimulated luminescence dates of 63 ka and 5 ka BP, and this glaciation is considered equivalent to the Last Glaciation elsewhere in the world. The maximum extent of ice occurred 63 ka BP. This, however, does not correlate with the Last Glacial Maximum for the northern hemisphere ice sheets (20-18 ka BP). The Shivling Glacial Advance must have occurred after 5 ka BP, after the Bhagirathi Glacial Stage moraines had formed at Bhuj Gaddi. Accordingly, it is proposed that the Shivling Advance is of mid to late Holocene age. Steep sharp-crested lateral moraines of this advance are well preserved in all glacial forefields, indicating an advance of between 1.5 and 3 km beyond present ice fronts with ELA depression of between 40 and 100 m and ice thickening of between 50 and 150 m. These moraines formed during the mid-Holocene are termed as the Shivling Glacial Advance. During the Bhujbas Glacial Advance glaciers reached positions between 1 and 2.2 km beyond the present snouts. This correlates with the Little Ice Age in the Himalayas and elsewhere in the world. Small moraines are inset into these and are dated at about 200 to 300 BP. ELA depressions of between 20-60 m occurred during the Bhujbas Glacial Advances (Milap Chand Sharma, 1996).

Recent changes in Garhwal Himalayan glaciers

It is a well-established fact that glaciers are in recessional phase worldwide. However, enhanced recession rates of glaciers during the recent past initiated widespread discussions on global warming and its effects on the cryosphere. Himalayan glaciers also follow the same trend. However, the rate of recession and amount of volume change are irregular for glaciers across the Himalayan arc mainly because of climatological and topographic factors. Glaciers have fluctuated noticeably within the Garhwal Himalayas. In the Saraswati / Alaknanda basin, the area of the glaciers investigated changed from 324.78.4km² in 1968 to 306.3 9.5km² in 2006, a decrease of 18.42 km² or 5.7%. The number of glaciers increased from 69 to 75 due to the disintegration of ice bodies. The loss in glacier area of individual glaciers ranged from 0.9% to 42.5%. On average, small glaciers (less than 1 km²) lost 19% of their area between 1968 and 2006 (Rakesh Bhambri, 2011).

In the upper Bhagirathi basin, the glacierized area changed from 275.1km² in 1968 to 266.1km² in 2006. A decrease of 8.9km² or 3.3%. The loss in glacier area ranged from 2% to 28% in this basin. The glacierized area in the basin decreased from 599.9km² to 572.5km², a decrease of 27.4km² or 4.6. On an average the, glaciers with areas <1.0 km² lost a larger percentage of their area, than glaciers with areas >50km². For all glaciers, a strong positive correlation between absolute area change of glaciers and glacier area (Rakesh Bhambri, 2011). This indicates that smaller glaciers are more sensitive to climate change than larger glaciers.

Longitudinal profiles along the centre line of Dokriani glacier for the years various years show significant changes in the elevation as well as surface morphology. The maximum elevation change of 30 m was observed between 1995 – 2007 in the lower ablation and the minimum of 14m in upper ablation zone near the equilibrium. However, the surface elevation shows significant changes with maximum of about 80 m in the lower reaches (3800-4200m), and 20m in the upper region (5200-5400 m). The continuous thinning of Glacier in the lower region is significant. The long term mass balance of Dokriani glacier calculated for the period 1992-2000 is negative (Dobhal, et al., 2010).

Fig 3: Dokriani Glacier changes

Sl. Parameters No.	1962	1995	2007
1. Glacierised area km ²	10.1	9.58	-----
2. Glacier area km ²	7.74	7.02	7.00
3. Accumulation area km ²	-----	4.74	4.50
4. Ablation area km ²	-----	2.26	2.50
5. Glacier Length km	6.0	5.5	5.25
6. Elevation Extension m asl	6400-3810	6400-3880	6400-3910
7. Snout position m asl	3810	3886	3910
8. ELA m asl	-	5060	3910
9. Average surface slope	11 ⁰	12 ⁰	5085
10. Average ice thickness m	72.5	65	12 ⁰
11. Glacier Ice volume 10 ⁶ m ³	330	283	-----
12. Average net balance 10 ⁶ m ³	-1.41	-2.19	2.25

Source: Own Draft

Table 1: Recession of Himalayan glaciers through last century

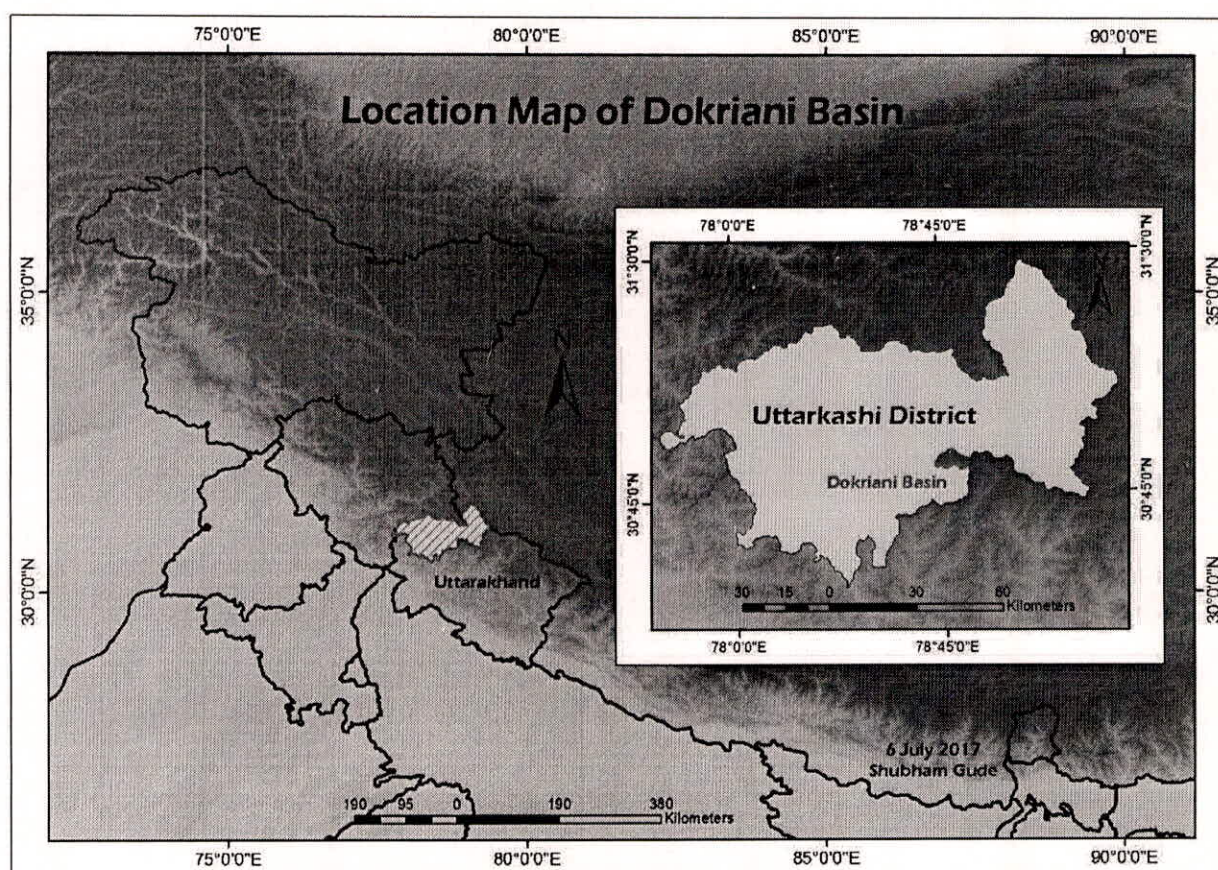
Glacier	Period	Years	Recession (m)	Average rate (m/yr)
Pindari Glacier	1845-1966	121	2840	23.40
Gangotri Glacier	1842-1935	93	683.5	7.4
	1935-1996	61	1147	18.80
	1996- 1999	3	76	25.33
	1842-1999	157	1906	12.14
Milam Glacier	1849- 1997	148	2472	16.7
Dokriani Glacier	1962-2000	38	641.5	16.88
Shankulpa Glacier	1881-1957	76	518	6.8
Poting Glacier	1906-1957	51	262	5.13
Bara Shigri Glacier	Advancement (AD 1860-1893)	16	1000	62.5
	1890-1906	39	799.5	20.5
	1906-1945	7	196	28
	1956-1963			
Sonapani Glacier	1909-1963	57	905	15.9
Kolahoi	1857-1909	52	800	15.4
	1912-1961	49	800	16.3
Tipra bank Glacier	1960-86	26	325	12.5
Zemu Glacier	1907-65	56	440	7.9
	1975-90	15	247	19.8
Glacier No.3 Arwa valley	1932-1956	24	198	8.25
Chiba	1961-2000	39	1050	26.9
Meola	1961-2000	39	1350	34.6
Jhulang	1962-2000	38	400	10.5
Hamta	1963-98	35	600	17
Nagpo- Tokpo,	1962-1998	36	2300	63.8
Changme Khangpu	1975-90	15	133	8.8
Chhota Shigri	1962-1989	26	195	7.5

Source: (1) Vohra, 1981 (2) Vohra, 1993 (3) Dobhal, 2004 (4) Naithani et al. 2001 (5) Shukla & Siddiqui, 1999 (6) Dobhal et al. 2007 (7) cf. Mayewski & Jeschke, 1979 (8) cf. Dobhal et al. 2004 (9) Oberoi et al. 2001 (10) Oberoi et al. 1999. (11). Kumar and Dobhal, 1994

Study area

The Dokriani glacier is located in Uttarkashi district of Uttarakhand. The glacier lies 25km east of Bhukki village. It extends from latitude 31°49' to 35°52' N and from longitude 78°47' to 78°51' E. the total length of glacier is 5km. The total area of the glacier catchment is 9.58km², of which 5.76km² is glacierized. Three-quarters of the glacier ablation area is covered by debris. The accumulation area of the glacier is about 2.5km². The equilibrium line is at ~4960m (Renoj J. Thayyen, 1999). The melt water of Dokriani glacier forms the Din Gad (stream), which joins the Bhagirathi River near village Bhukki. Dokriani is a small valley glacier that originates from the Draupadi ka Danda (5,713 m amsl) and Janoli (6,632 m amsl) peaks (A. BHATTACHARYYA, 2011). The altitudinal distribution of the glacier area shows that the major part of the glacier is concentrated above 5000m in the basin (Pratap Singh, 2003).

Map 1: Location Map of Dokriani Basin



Source: Own Draft

Aims and Objectives

Aim

- Understanding the advance and retreat history of glaciers in the Garhwal region

Objective

- To reconstruct glacier extent for various stages of glacier advancement
- To estimate glacier thickness, volume and ELA corresponding to different glacier stages
- To assess the recent glacier change of Dokriani glacier in the context of historic changes

Methodology

The historic glacier advancement stages are reconstructed using various data sources. The moraines are the main indicators of the historic advancement. Moraines may form through a number of processes, depending on the characteristics of sediment, glacier and the location on the glacier in which the moraines are formed. Lateral moraines are formed at the side of the glacier and terminal moraines at the foot, marking the maximum advance of the glacier. Height of the lateral moraines from the de-glaciated valley bottom or from the surface of the existing glacier gives good estimation of glacier thickness at the time of formation of the moraine. These moraines were identified using Google Earth image and the glacier extent of different advancement stages has been mapped. In this study, height of the moraines are considered for construct glacier surface and thickness.

For each advancement stage, Surface profile of the moraines is constructed based on which the surface altitude at that particular location is interpolated. Surface profiles are constructed throughout the glacier at an interval of 200 to 500 m. the surface slope was constructed based on the interpolated surfaces from surface profile. The difference between the reconstructed glacier surface and that of valley bottom/glacier surface was calculated to obtain the spatially distributed glacial thickness of corresponding stages of advancement. The average thickness was calculated by averaging the depth of all the locations.

The volume of the glacier is one of the important factors when it comes to quantify a glacier. Glacier volume is strongly influenced by climate factors, such as temperature and precipitation. Changes in glacier ice volumes give some indication of changing climate conditions. The volume is calculated using area volume scaling formula.

If the area of the glacier is less than 2 km, volume = $0.024 * \text{Area}^{1.36}$

If the area of the glacier is more than 2 km, volume = $0.027 * \text{Area}^{1.36}$

The equilibrium line altitude (ELA) is a critical information to understand the state of the glacier because it divides the glacier into ablation and accumulation areas. There are various methods to calculate the ELA of a glacier. In this study Toe-to-Headwall Altitude Ratio (THAR) method is used to estimate the paleo ELA's at each stages of studied glacial advancement.

$$\text{ELA} = A_t + \text{THAR} (A_h - A_t)$$

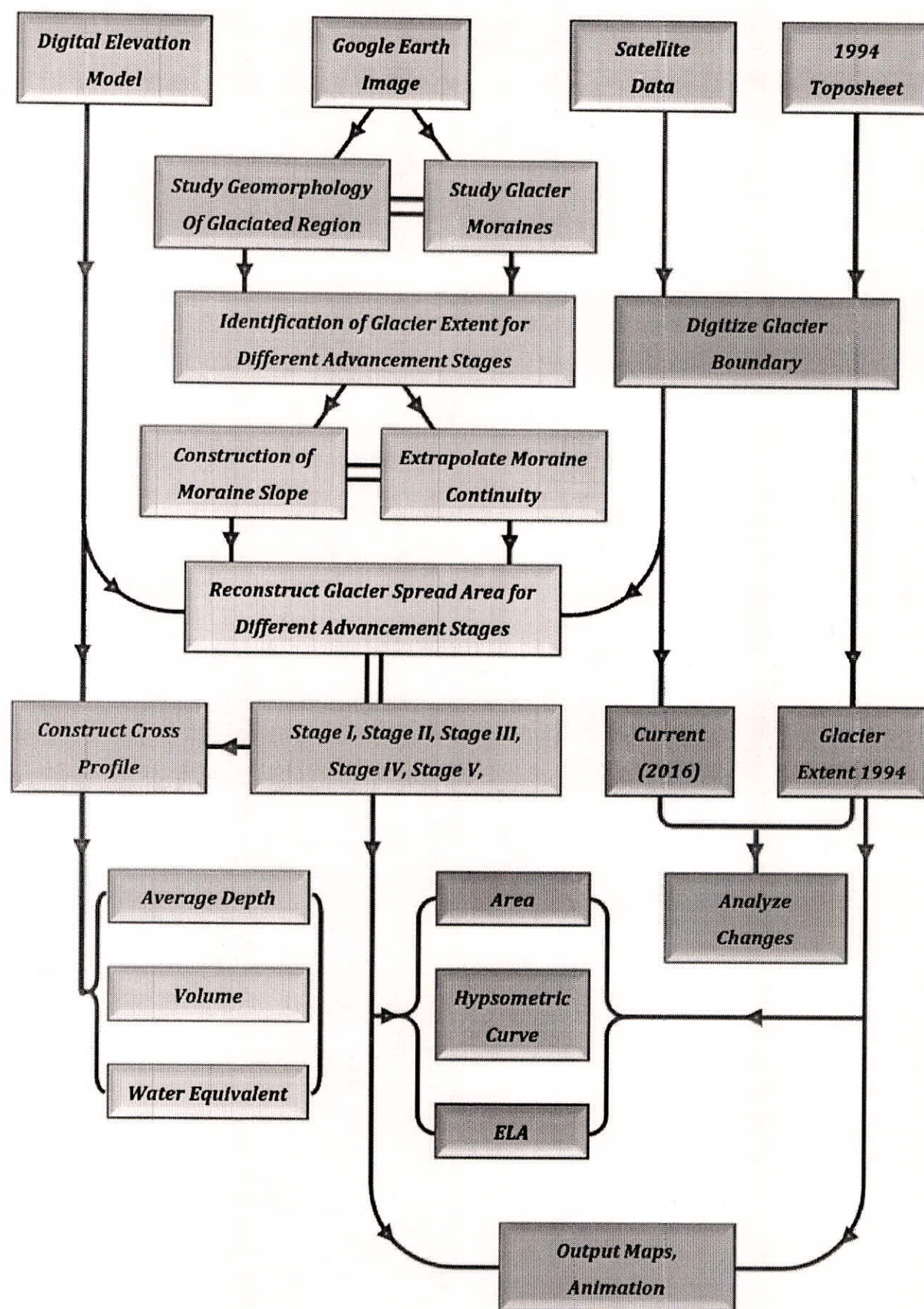
Where,

A_t = Glacial toe Altitude

A_h = Headwall Altitude

The Hypsometry of the glacier for each historic advancement stage is studied by constructing a Hypsometric curve using ASTER Digital Elevation Model. The curve is constructed at elevation class interval of 200mt. Fig 18 shows Hypsometric Curve of various Advancement Stages for Dokriani Glacier.

Fig 4: Methodology flowchart



Source: Own Draft

To reconstruct the advancement extent of historic glacier stages, understanding the geomorphology of glaciated region is very important. The existence of historic glaciers are indicated by various features created by the glacier. Moraines are one of the important features from which we can study the behaviour of glacier. For this project, Google earth image is used to study the moraines as it is high resolution image and contains altitude information along with spatial data. For reconstruction of slope and cross profiles, the ASTER digital elevation model is used. The current extent of Dokriani glacier is derived from satellite data. To derive 1995 glacier extent the Survey of India Toposheet of 1995 is used. The details of data sources is given in *Table 2*.

Table 2: List of data used in project and their sources

Data Type	Source	Spatial / Temporal Resolution	Description
Topography	USGS Earth Explorer	30 m	ASTER Digital Elevation Model
	(https://earthexplorer.usgs.gov/)		
Satellite Data	ESA Copernicus	10 m	Sentinel 2A
	(https://scihub.copernicus.eu/dhus/#/home)		
1995 Toposheet	Survey of India	1:10000	Glacier Toposheet
	(NIH, Roorkee)		
Google Earth	Google	High Resolution	High Resolution Satellite Data
	(Google Earth)		

Source: Own Draft

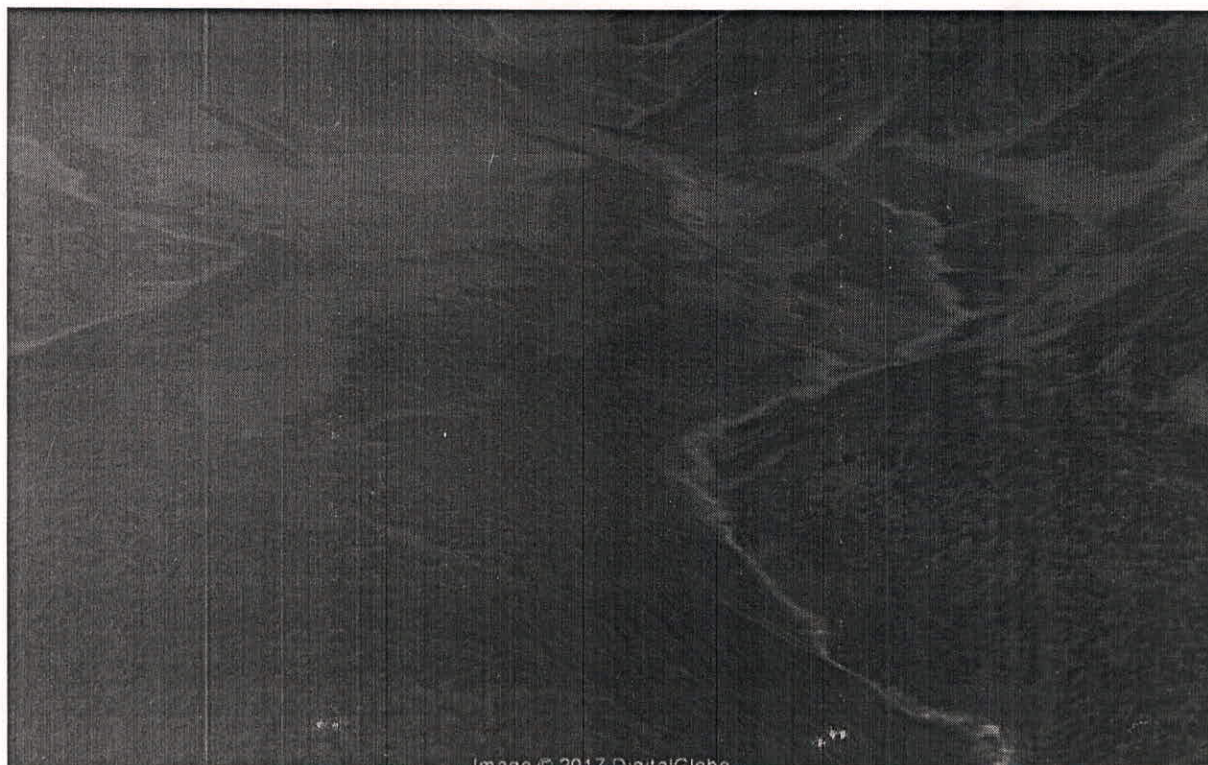
After constructing the extent of glaciers, various responses of glacier have been calculated. Like area, Volume, Hypsometric curve, Equilibrium line Altitude, water equivalent, distance from Current terminus. The moraines of historic stages are shown in fig x. For reconstructing glacier spread area, samples of moraines are taken at an interval of 10 – 20mt altitude depending on terrain. The moraine slope is constructed using ASTER DEM in ArcGIS.

Moraine

As the glacier grows, it erode huge landmass and deposit them along its peripheries. When the glacier recede subsequently under favourable climate conditions these landform features get exposed and known as moraines. Moraines ridges formed at different stages of glaciation vary in height and composition depending on the length of time the ice remained at a particular location and thickness it gained and on the materials being eroded. Often they are composed of glacial till. Glacial tills are sediments of mixed character, with many rocks and stones, laid down as the ice rapidly melts. There are several different subtypes of moraines. For example lateral moraines, terminal moraines, medial moraines, etc.

End moraines are irregular ridges of glacial sediments that form at the margin or edge of the glacier. These landforms represent a still stand of the glacier ice, having formed as the ice margin remained in one position while internally the ice was bringing sediment forward and continuously depositing it at the margin. Alternatively, end moraines may form as a glacier re-advances and "pushes" soft sediment in front of it, creating what is often called a small "push moraine". The outermost end moraine is given the special name "terminal moraines". All others are referred to as recessional moraines, since they mark a recessional position of the ice marginal moraine.

Fig 5: *Historic moraines of Dokriani Glacier*



Source: Google Earth

Fig 6: Striations on the Bedrock carved by Glacier



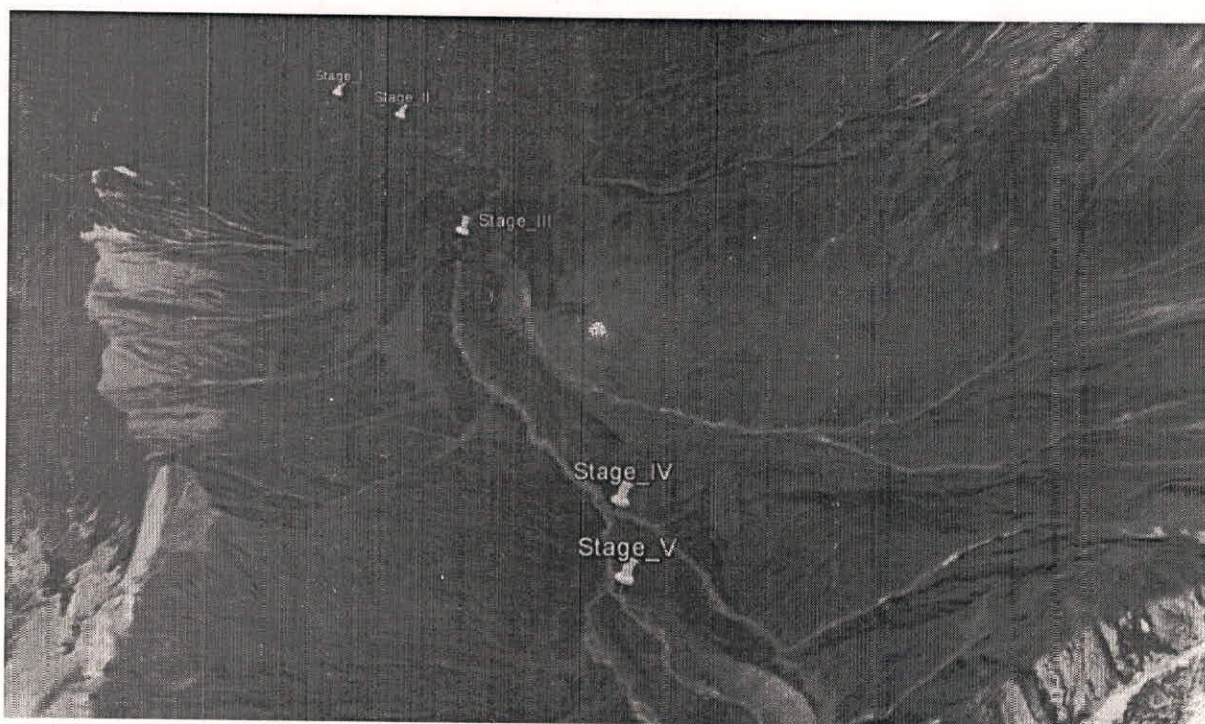
Source: Google Earth

Fig 7: Bergschrund at Dokriani Glacier



Source: Google Earth

Fig 8: Identifying Marginal Moraines of Historic advances of Dokriani Glacier



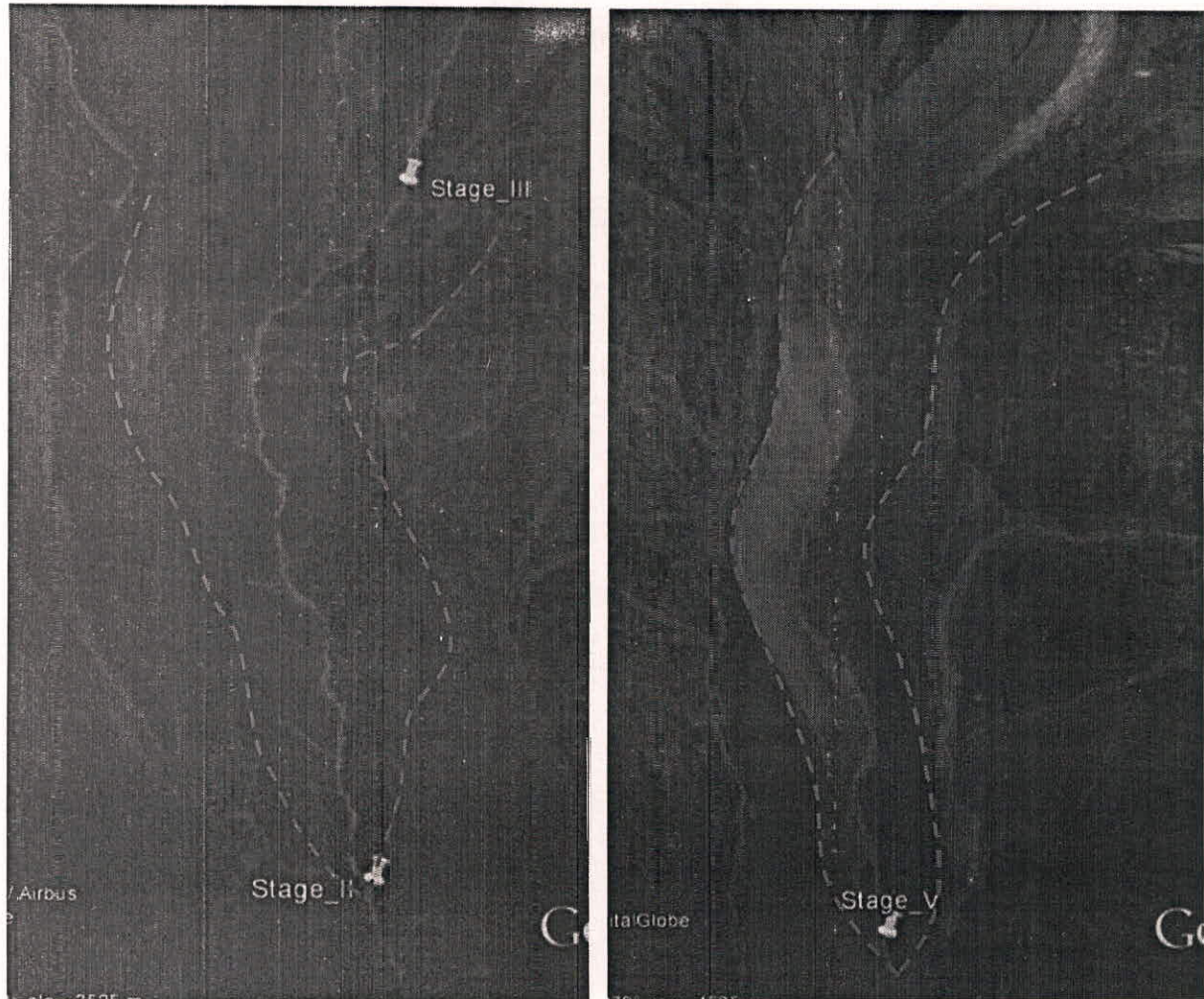
Source: Google Earth

Fig 9: Samples collected of Marginal Moraines of Historic advancement



Source: Google Earth

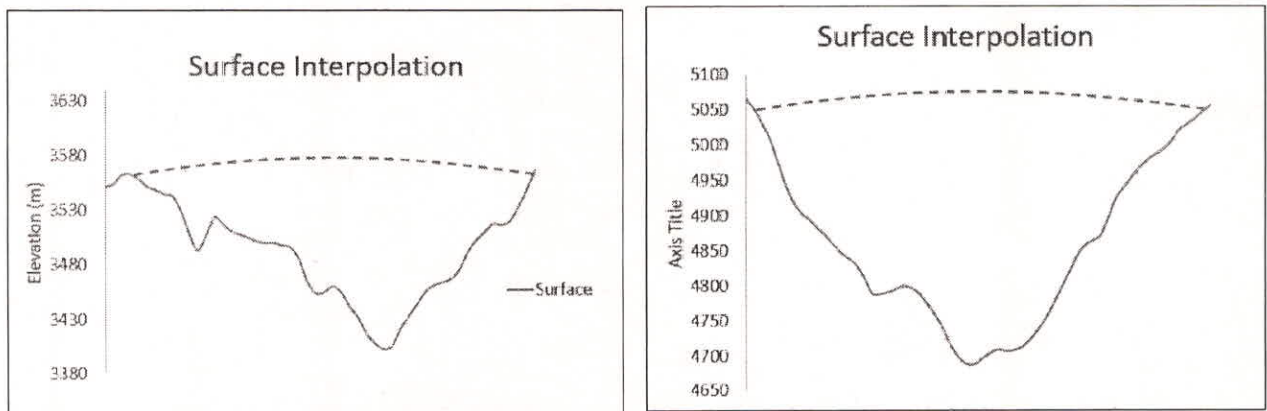
Fig 10: Historic moraines of Dokriani Glacier



Source: Google Earth

Cross profiles of all the stages is constructed at interval of 200 to 500 m for interpolating the surface. On the basis of interpolated surfaces

Fig 11: Interpolation of glacier surface for construction of surface slope



Source: Own Draft

Result and Discussion

Glaciers grow and shrink due both to natural variability and external forces. Variability in temperature, precipitation, and englacial and subglacial hydrology can strongly determine the evolution of a glacier in a particular season. Therefore, one must average over a decadal or longer time-scale to smooth out the local short-term variability and obtain a glacier history that is related to climate. Climate change is understood either as a natural process subject to little or no human influence or as anthropogenic. The most significant climate processes since the middle to late Pliocene (approximately 3 million years BP) are the glacial and interglacial cycles. Glaciers leave behind moraines that contain a wealth of material, including organic matter, quartz, and potassium that may be dated recording the periods in which a glacier advanced and retreated.

According to the objective of study, efforts have been made to identify and reconstruct the glacial advancement extent at different historic periods (stages). Five stages have been identified based on the moraines in the Din Gad Valley with reference to the glacial history of Garhwal Himalaya and Gangotri glacier region (Sharma and Own, 1997). These different stages has been identified based on Google earth image. Google earth image is used as it provides high resolution images along with elevation data. Sample points marking glacier boundary were created for every stage. The points were marked at 10 – 20mt interval depending on moraine behaviour.

These moraines indicate the historic periods of intense glaciation. There are moraines in the Din Gad valley that extends up to 8.4 km from the present glacier terminus. These are the indicators of climate change. Moraines ending at different altitudes which lie within on another indicates that the climate fluctuates over a period of time. In the cold climate there is glacial advancement, followed by the warmer climatic condition in which there is recession of glaciers. The limitation is that we cannot predict the amount of recession as the next advancement overrides the terminal moraines of the recession period. If we compare the area of different stages, we can get the idea of climatic conditions of that particular period.

In the Garwal region, 3 historic stages have been identified, namely the Bhagirathi stage, the Shivling stage and the Bhujba stage which can be correlated with little ice age. These stages are the impact of natural climate change process which can be dated approximately 6300 to 200 years BP. The stage 5 in this project can be correlated with the Bhujba glacial advance where the glaciers reached positions between 1 and 2.2 km beyond the present snouts. This stage occurred approximately 300 to 200 years BP (Milap Chand Sharma, 1996). The stage 4 in the project can be related to Shivling glacial advancement where the glaciers reached positions between 1.5 and 3 km beyond the present snouts. This stage occurred approximately 5000 years BP. The stage 1 in the project can be correlated with the Bhagirathi glacial advance stage. The terminus altitude reached up to 2300 masl in this stage. Since Dokriani is a small glacier the terminus altitude obtained after reconstruction was 2831 masl. These stage is dated approximately about 63000 to 5000 years BP.

The Table 3 shows the area of glacier, the % of area covered by glacier in a basin and distance from glacial terminus for glacial advancement stages identified from moraines.

Table 3: Table showing Area, percentage of basin area covered by glacier and distance from current terminus

Stages	Area (km ²)	% Basin Area	Distance(km) from current terminus
Stage V	9.40	18.63	1.58
Stage IV	10.44	20.70	2.07
Stage III	12.77	25.34	4.60
Stage II	24.77	49.18	6.98
Stage I	31.83	63.25	8.04

Source: Own Draft

Various components of the advancement stages are calculated and are listed in tables below. The maps and the slope for all the glacier stages are given below. The table x shows the Headwall altitude, terminus altitude and Equilibrium Line Altitude (ELA using THAR of 0.4) for historic advancement stages.

Table 4: Table showing Headwall, terminus and ELA Altitude for all advancement stages

Stages	Headwall (m a. s. l.)	Terminus (m a. s. l.)	ELA (m)
Stage V	5500	3733	4932
Stage IV	5500	3646	4875
Stage III	5500	3445	4732
Stage II	5500	3032	4393
Stage I	5500	2831	4205

Source: Own Draft

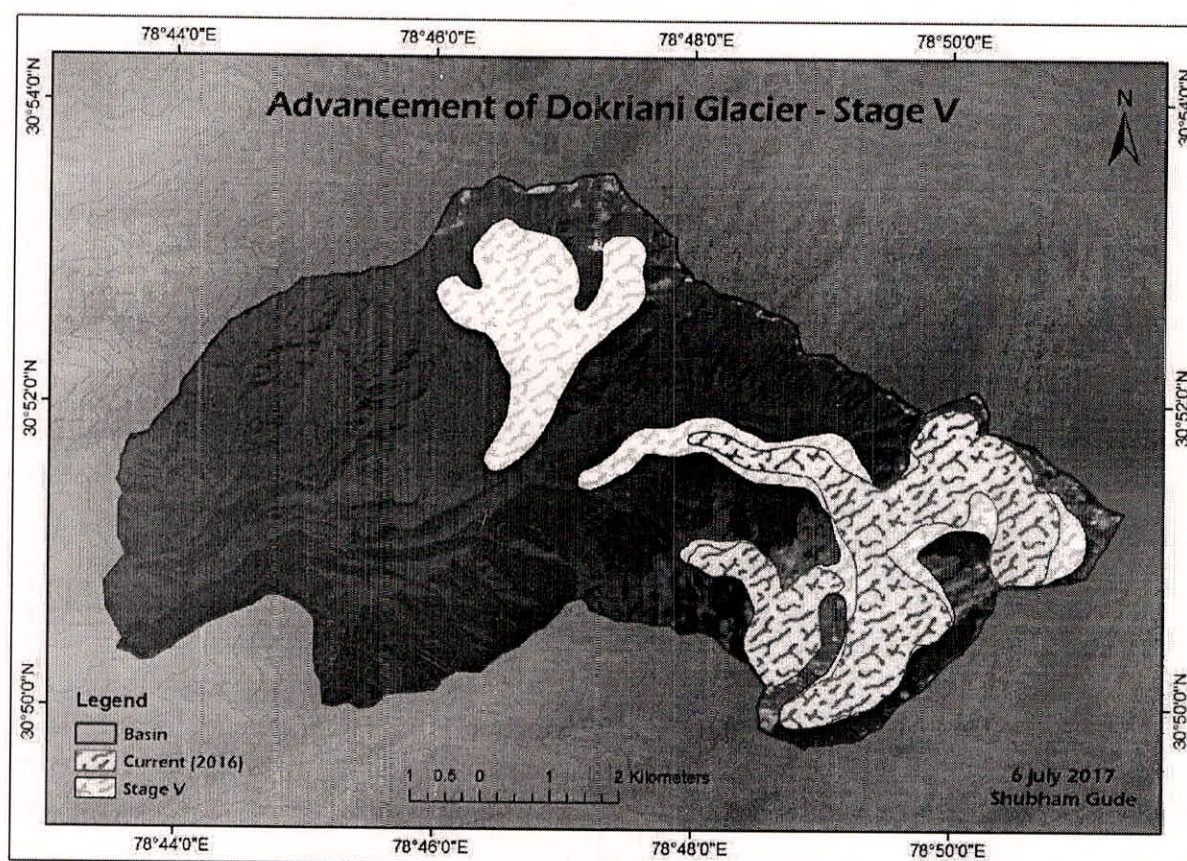
Table 5: Table showing average depth, volume and water equivalent for historic advancement stages

Stage	Average Depth (m)	Volume (km ³)	Water Equivalent
Stage V	89.06	0.57	0.05
Stage IV	98.06	0.66	0.06
Stage III	136.30	0.86	0.08
Stage II	217.36	2.12	0.19
Stage I	303.52	2.99	0.27

Source: Own Draft

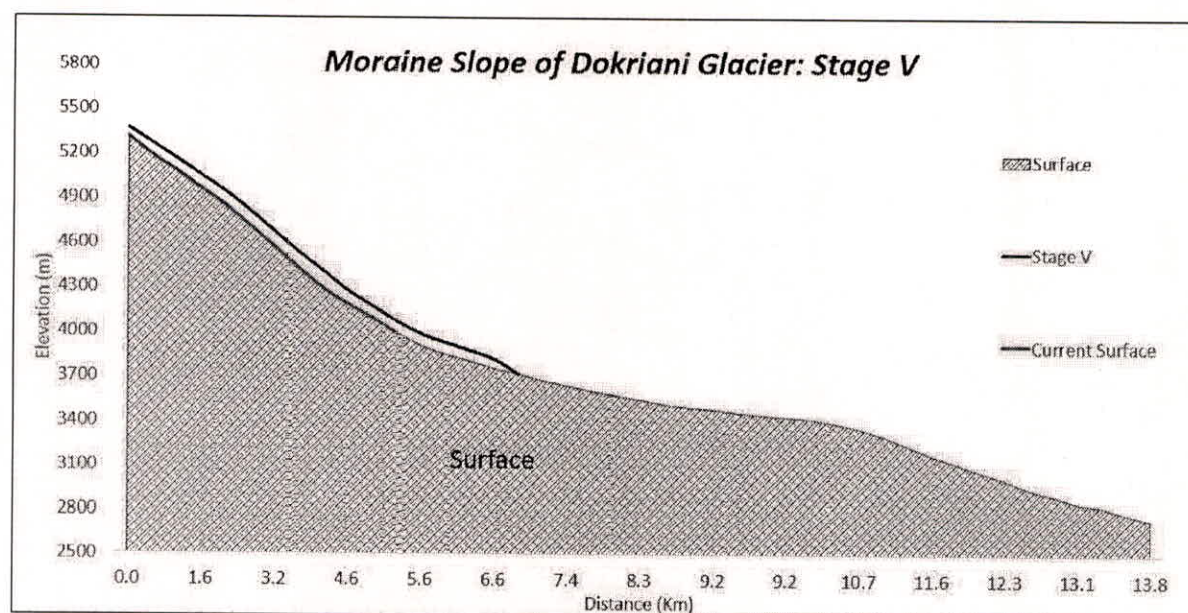
Stage V

Map 2: Extent of Dokriani Glacier – Stage V



Source: Own Draft

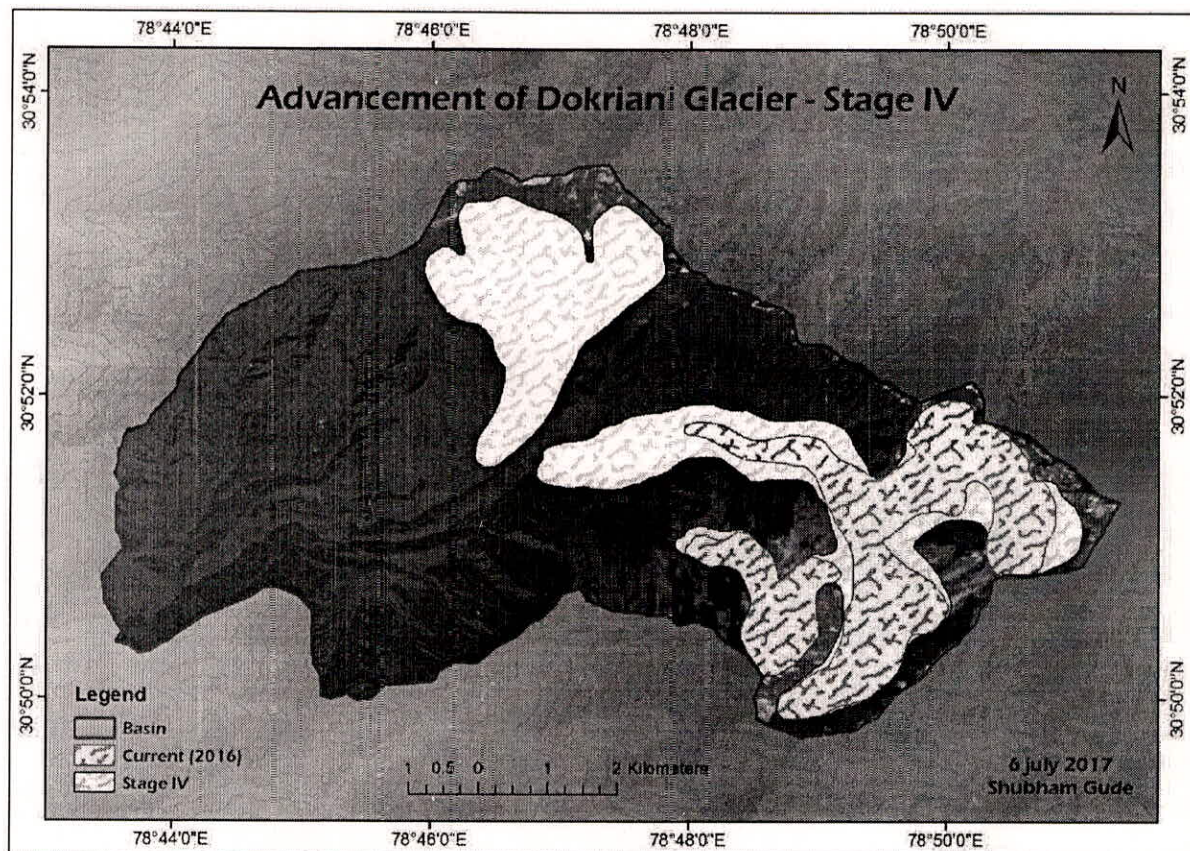
Fig 12: Surface Slope of Dokriani Glacier: Stage V



Source: Own Draft

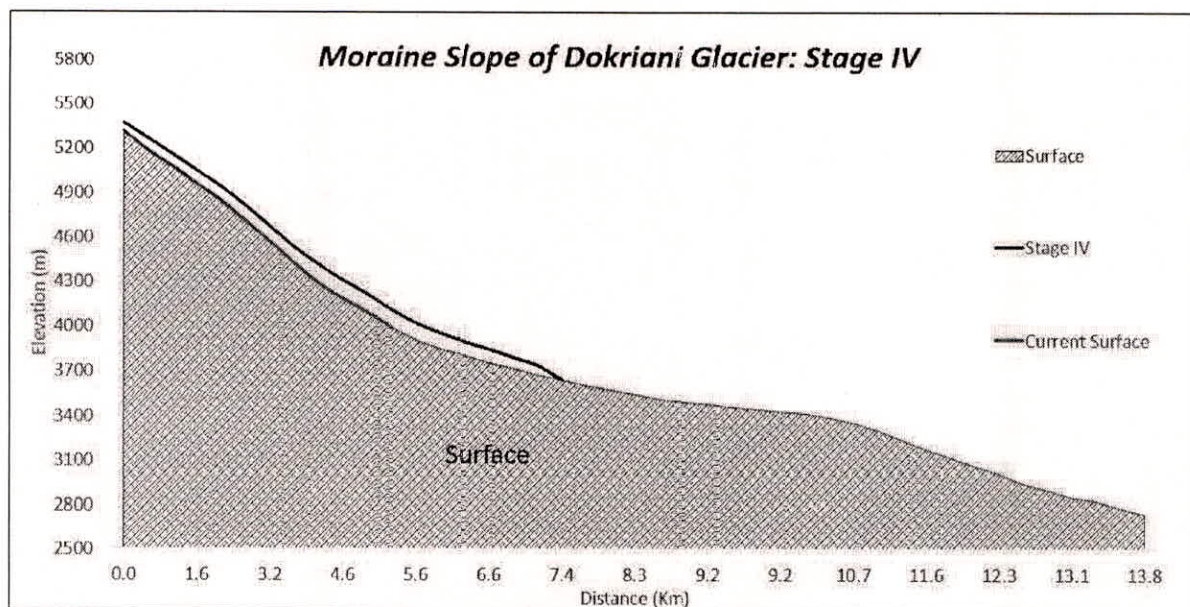
Stage IV

Map 3: Extent of Dokriani Glacier – Stage IV



Source: Own Draft

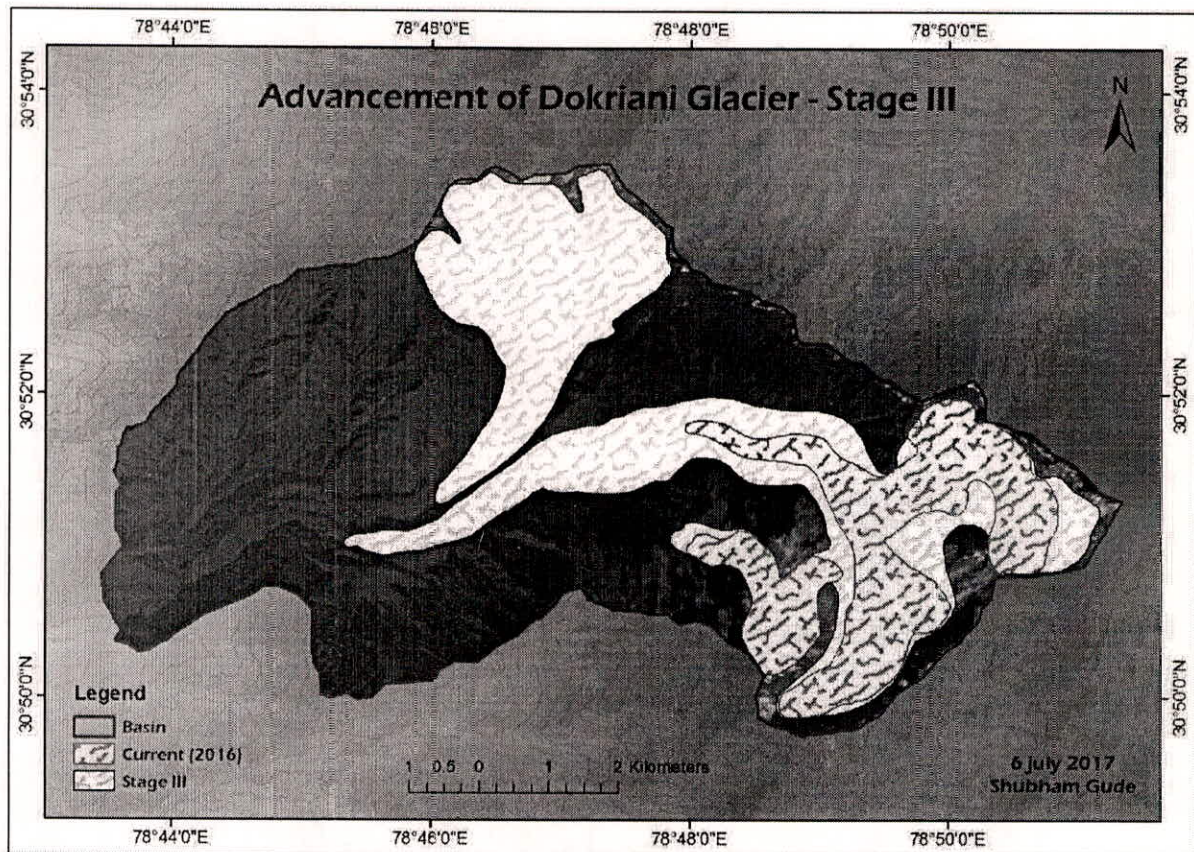
Fig 13: Surface Slope of Dokriani Glacier: Stage IV



Source: Own Draft

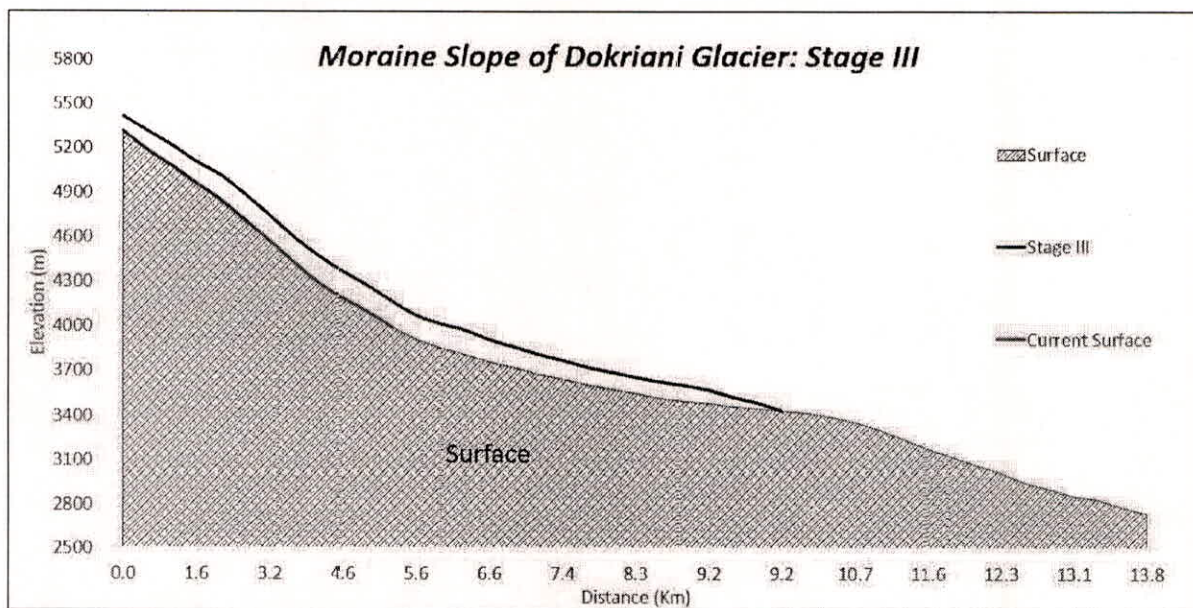
Stage III

Map 4: Extent of Dokriani Glacier – Stage III



Source: Own Draft

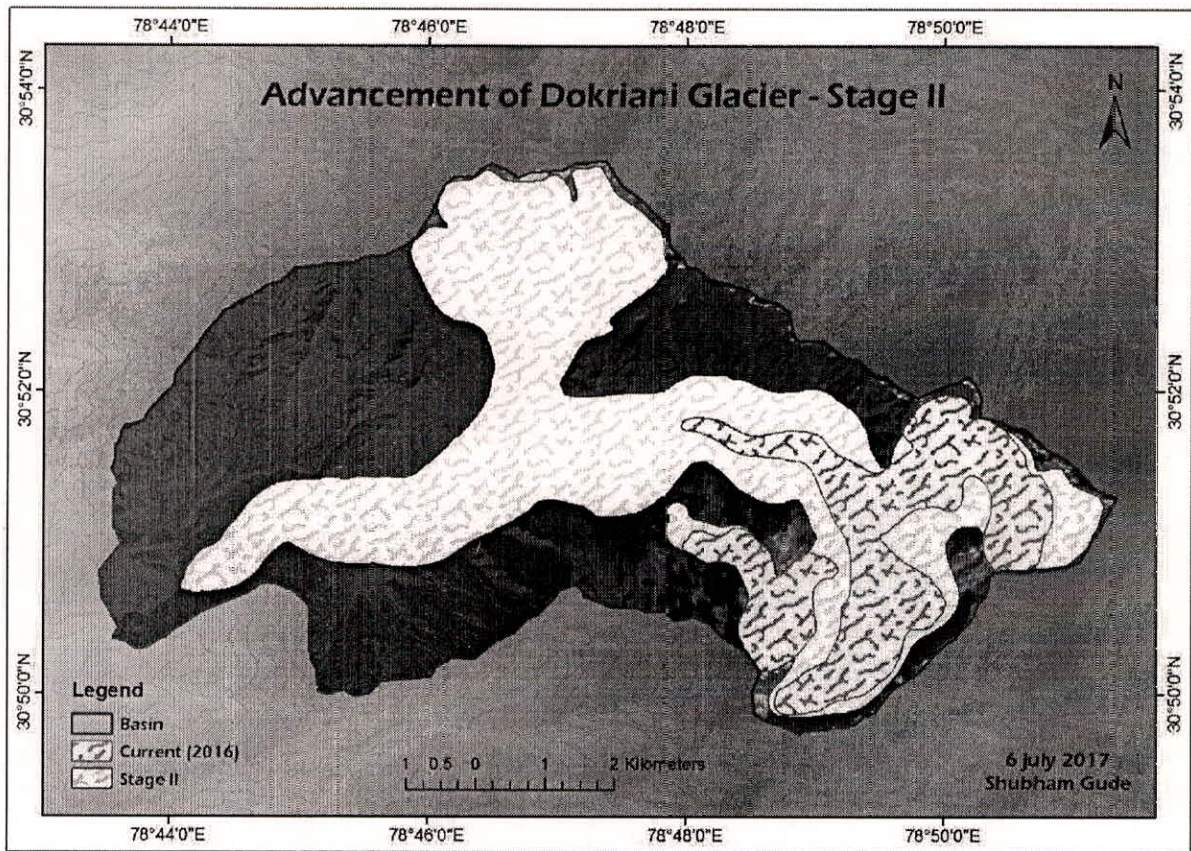
Fig 14: Surface Slope of Dokriani Glacier: Stage III



Source: Own Draft

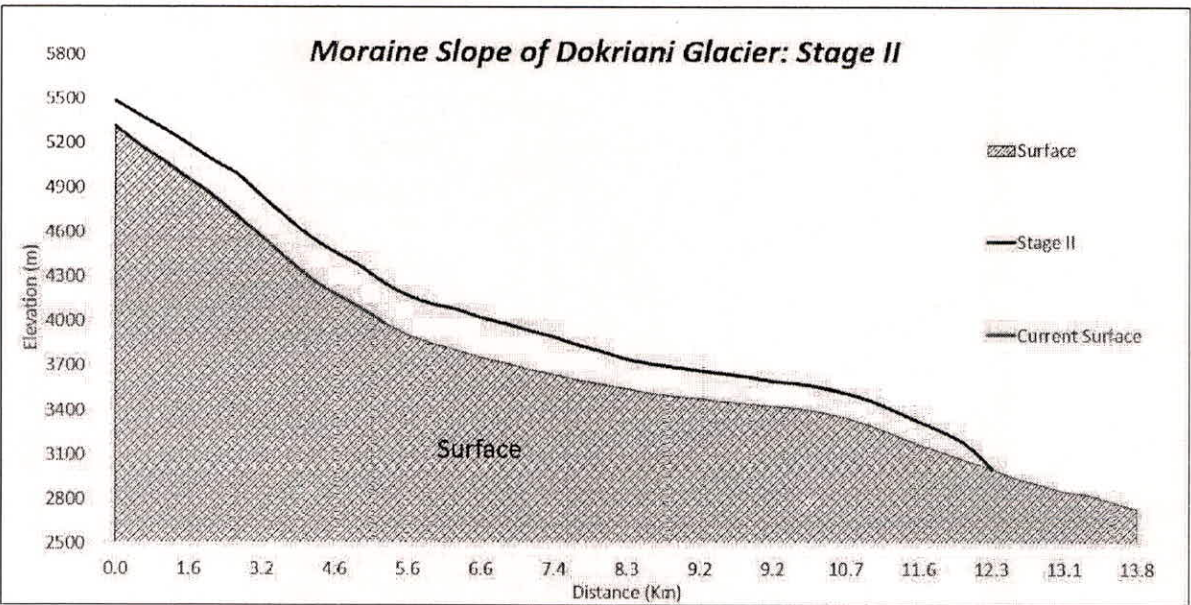
Stage II

Map 5: Extent of Dokriani Glacier – Stage II



Source: Own Draft

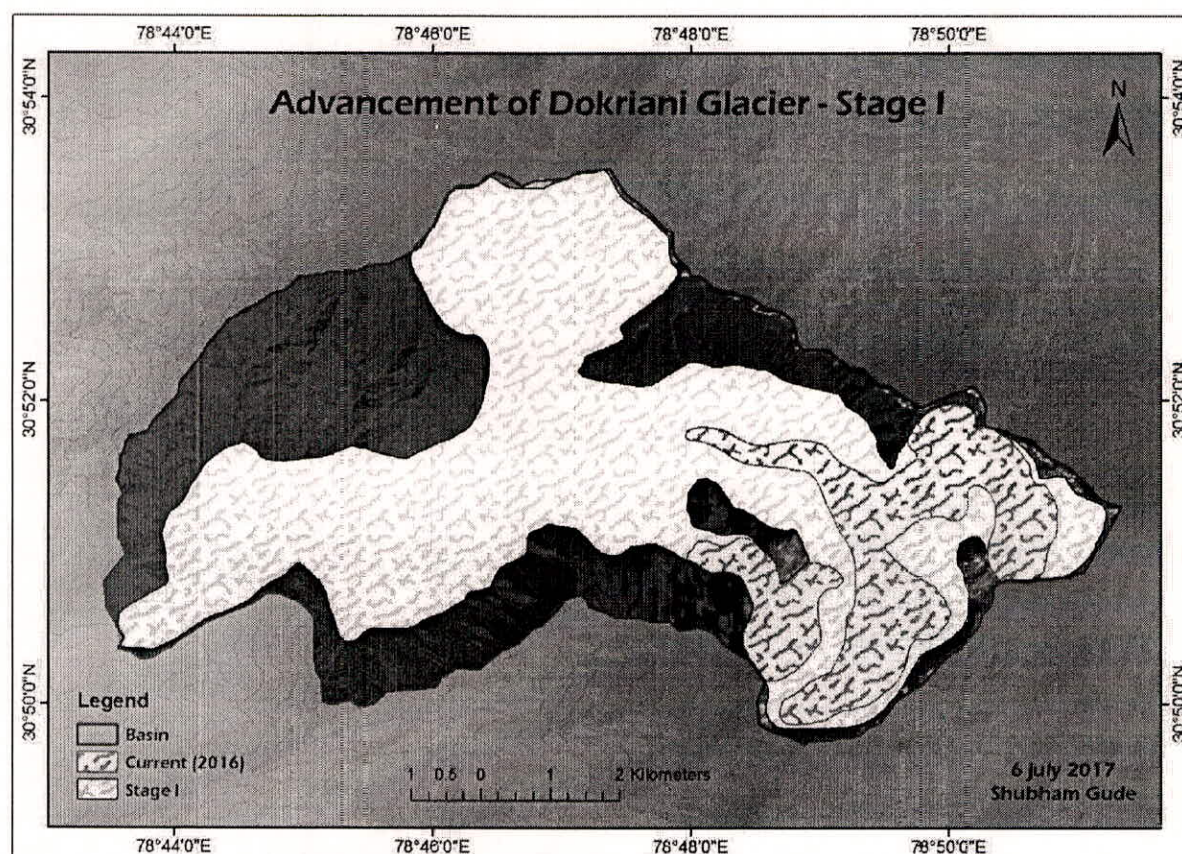
Fig 15: Surface Slope of Dokriani Glacier: Stage II



Source: Own Draft

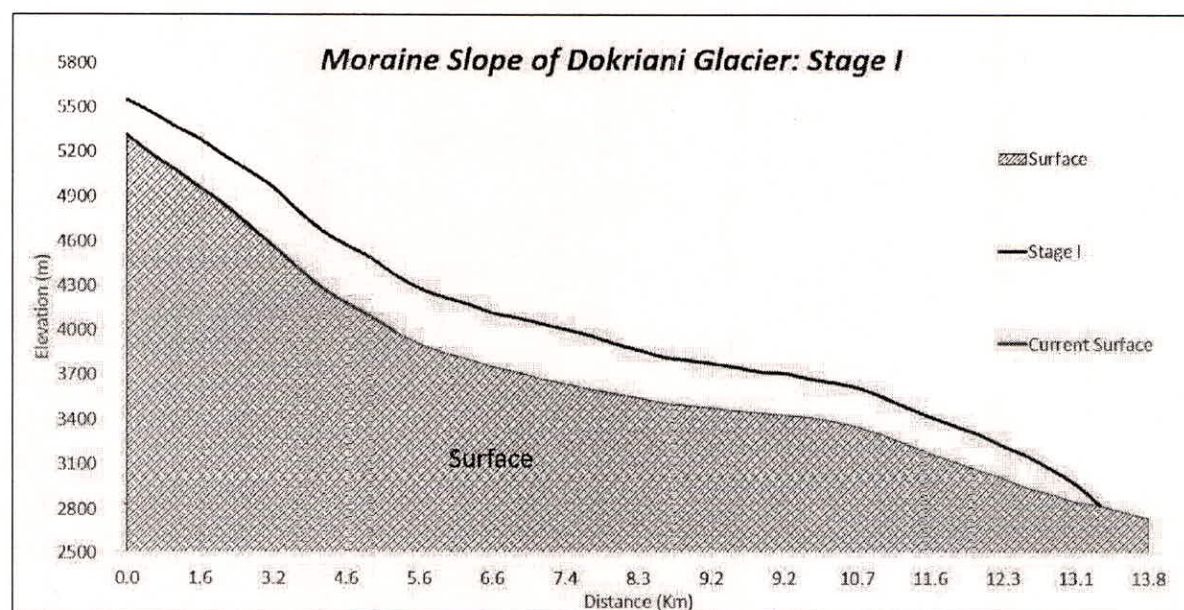
Stage I

Map 6: Extent of Dokriani Glacier – Stage I



Source: Own Draft

Fig 16: Surface Slope of Dokriani Glacier: Stage I

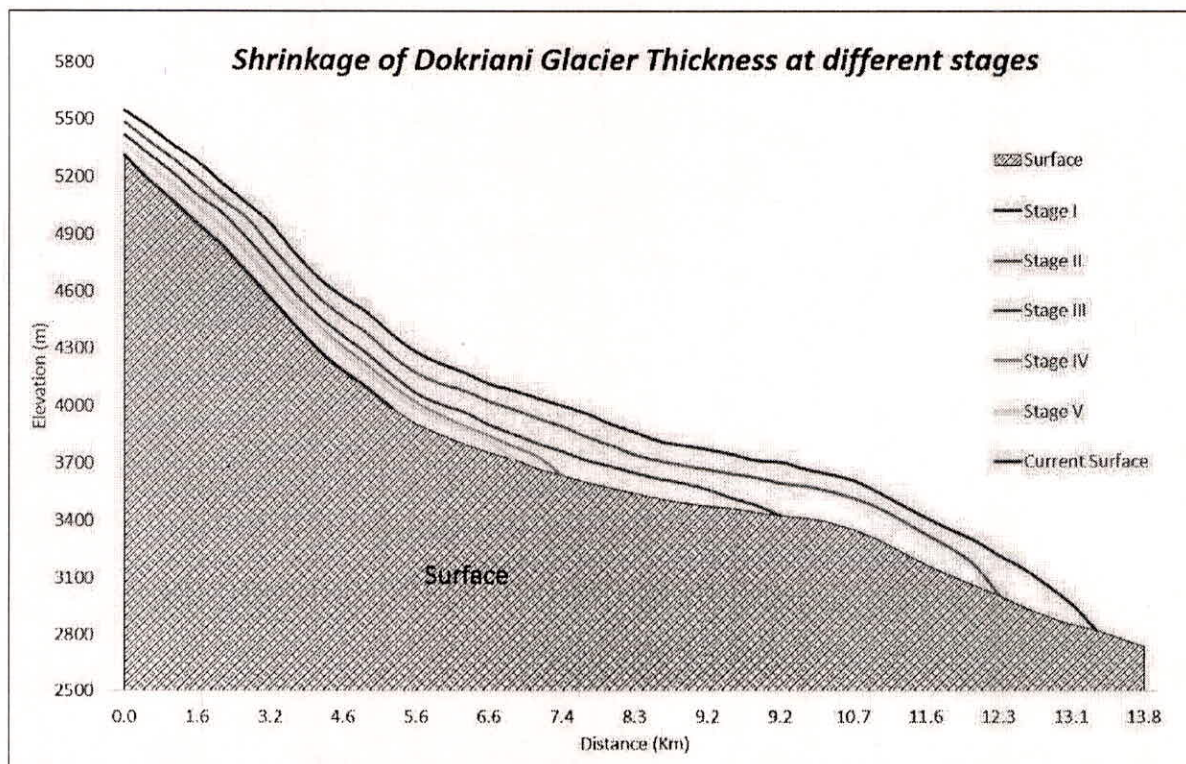


Source: Own Draft

Surface slope

Glacier surface receives heat from various sources but solar radiation has more effect. Change to the slope of the glaciers surface due to climate change will disrupt the equilibrium line. Steep surface slope will increase the erosion while shallow surface slope would increase the rate of deposition. The glacier thickness can be measured using surface slope. Fig 17 shows the surface slope of Dokriani glacier for different advancement stages.

Fig 17: Surface Slope showing shrinkage of Dokriani glacier thickness at different stages

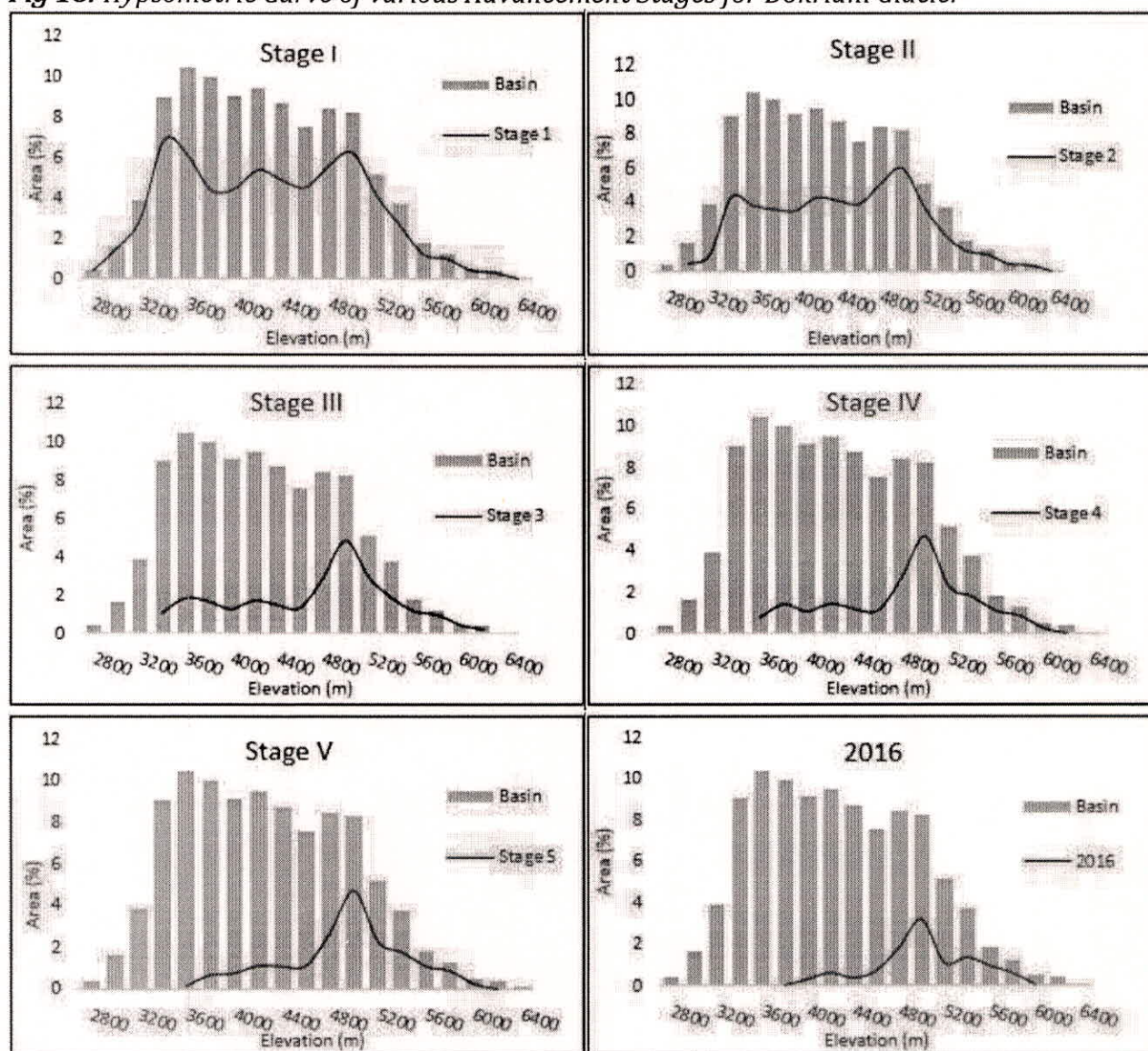


Source: Own Draft

Hypsometric Curve

Hypsometry describes the distribution of elevation of land with respect to sea level within an area of interest, with positive values being above sea level and negative values below sea level. It is distribution of glacier area over its altitudinal range. A graph of cumulative area (0–100%) with altitude can be plotted to show the relative proportion of a region at a specific elevation, known as the hypsometric curve. The elevations may be normalized relative to the range of elevations in the study area (value-minimum)/ (maximum-minimum), and the area under this normalized curve is the hypsometric integral, which by definition lies between 0 and 1. Hypsometric curve is synonym for Area-altitude distribution.

Fig 18: Hypsometric Curve of various Advancement Stages for Dokriani Glacier



Source: Own Draft

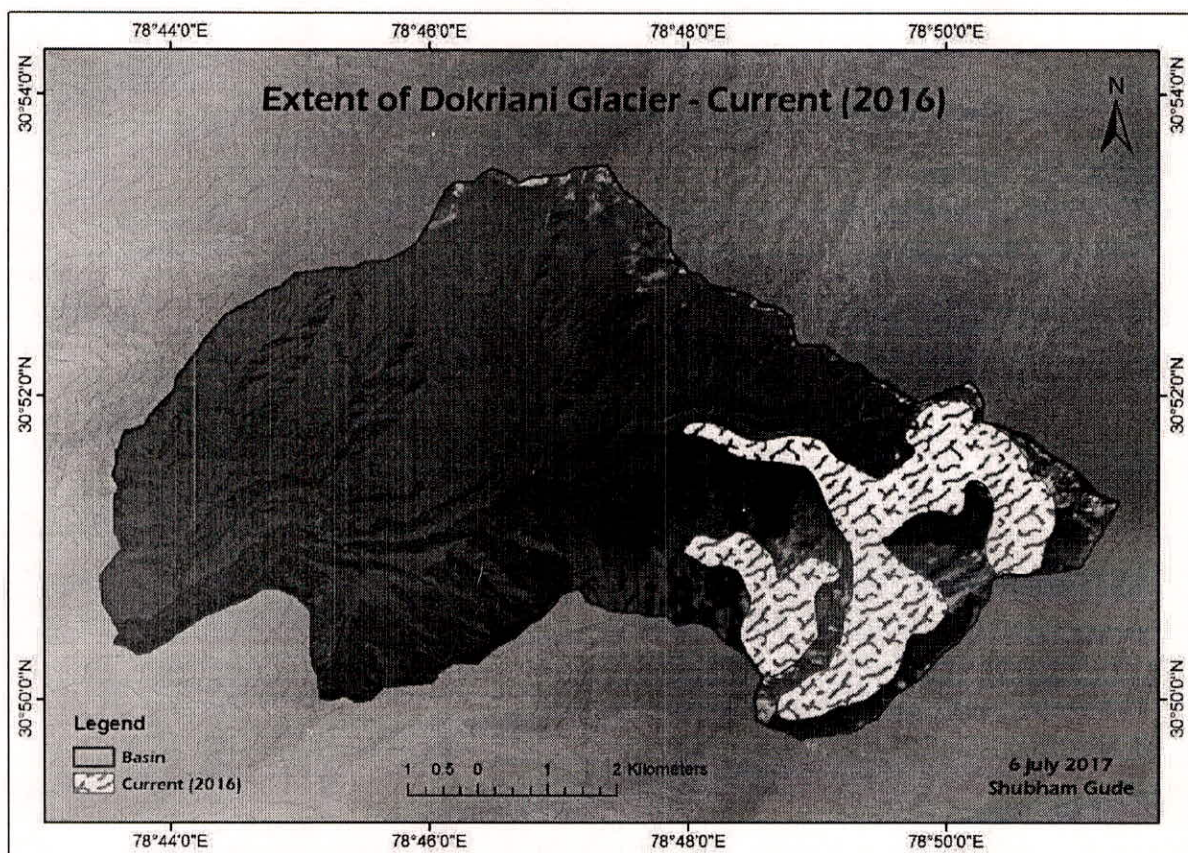
Recent Changes in the Dokriani Glacier from 1995 to 2016

The current (2016) glacier extent is derived from satellite data of 10mt spatial resolution. Along with current extent 1995 extent of Dokriani glacier is digitized using Survey of India Toposheet of scale 1:10000. The differences of glacier in this short span of time from 1995 to 2016 is studied. This 21 year period is an anthropogenic climate change period. Anthropogenic climate change is caused by human activity, as opposed to changes in climate that may have resulted as part of Earth's natural processes. The speed of human induced climate change is happening at a much faster rate than that of earlier periods. The temperature difference between the end of the last ice age and today is 5 degrees Celsius.

Most concerning factor of Anthropogenic climate change is the increase in CO₂ levels. This is due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere), and the CO₂ released by manufacturing industries. Other factors, including land use, ozone depletion, deforestation, are also of concern in the roles they play, both separately and in conjunction with other factors in affecting climate.

Current Extent (2016)

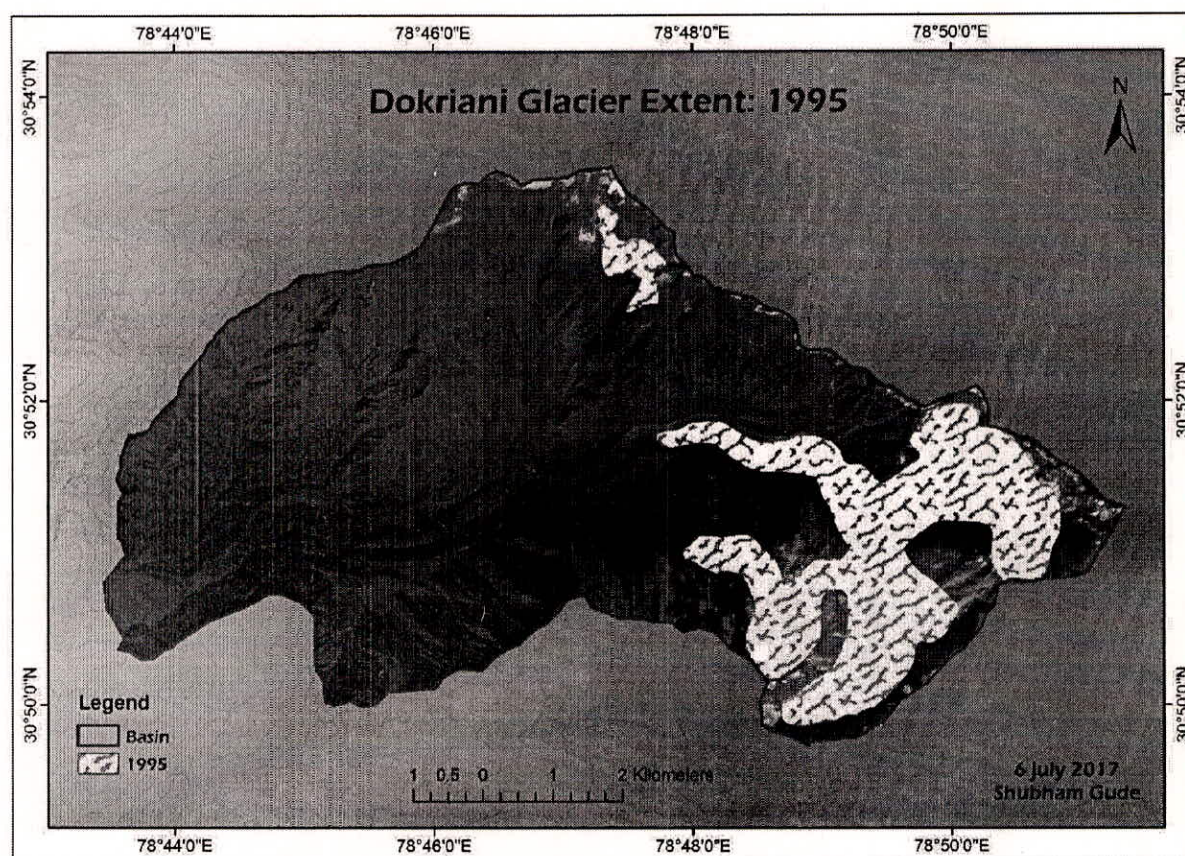
Map 7: Current (2016) Extent of Dokriani Glacier



Source: Own Draft

1995 Extent

Map 8: 1995 Extent of Dokriani Glacier



Source: Own Draft

In 1995, the area of Dokriani glacier was 5.59 Km² and covered 15.9% of total basin area. The total volume of glacier ice was 0.45 Km³. It extended from Headwall altitude of 6400m to the Terminus altitude of 3920. Comparing the changes between 1995 and 2016, the area is reduced by 2.4 Km². The terminus altitude is increased by 104m which indicates that the glacier is receding. Within 21 years the glacier has receded by 400mt. The ELA is shifted from 4756 in 1995 to 4818 in 2016.

Table 6: Table showing Area, Volume, Water Equivalent, percentage of basin area covered by glacier and distance from current terminus

Glacier Extent	Area (Km ²)	% Basin Area	Volume (Km ³)	Water Equivalent	Distance(km) from snout
2016	5.59	11.09	0.281	0.03	0.00
1995	7.99	15.87	0.456	0.04	0.41

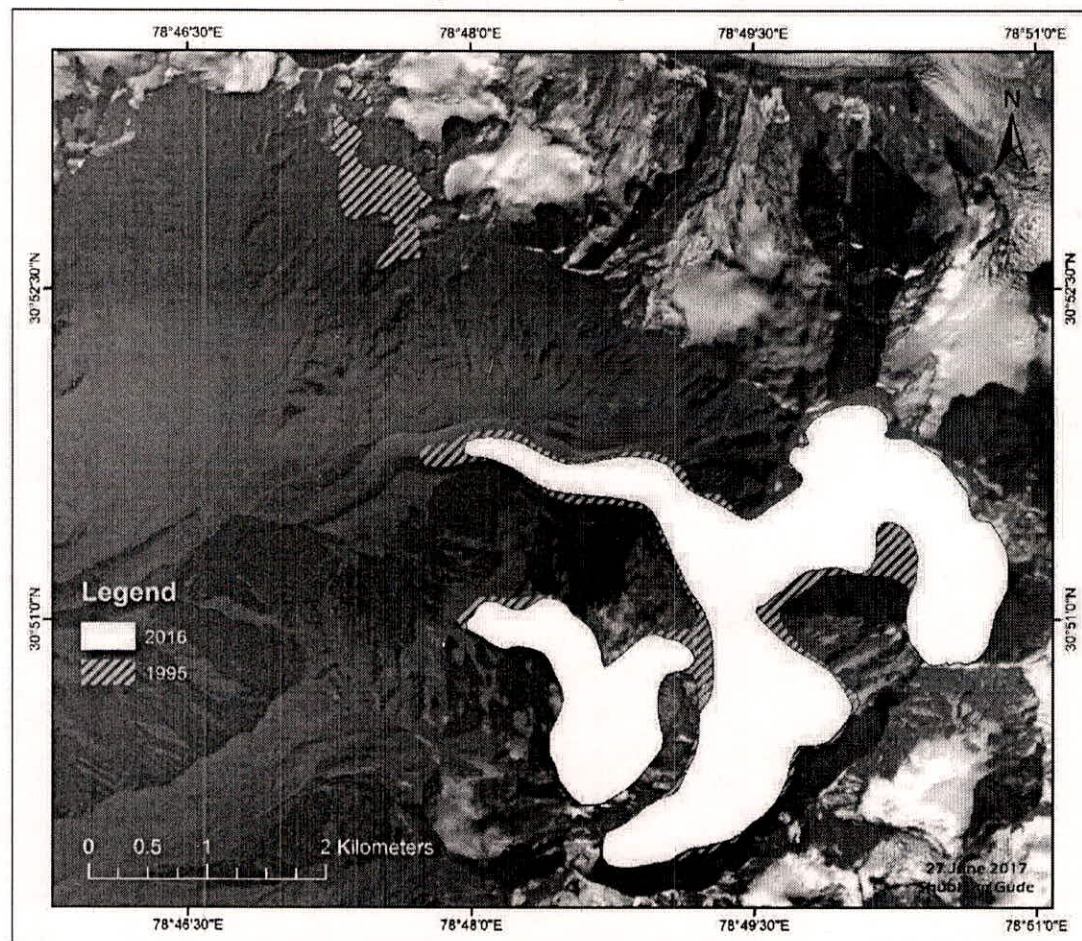
Source: Own Draft

Table 7: Table showing Headwall, terminus and ELA Altitude for all advancement stages

Extent	Headwall (m a. s. l.)	Terminus (m a. s. l.)	ELA (m)
2016	5500	4024	5104
1995	5500	3900	5040

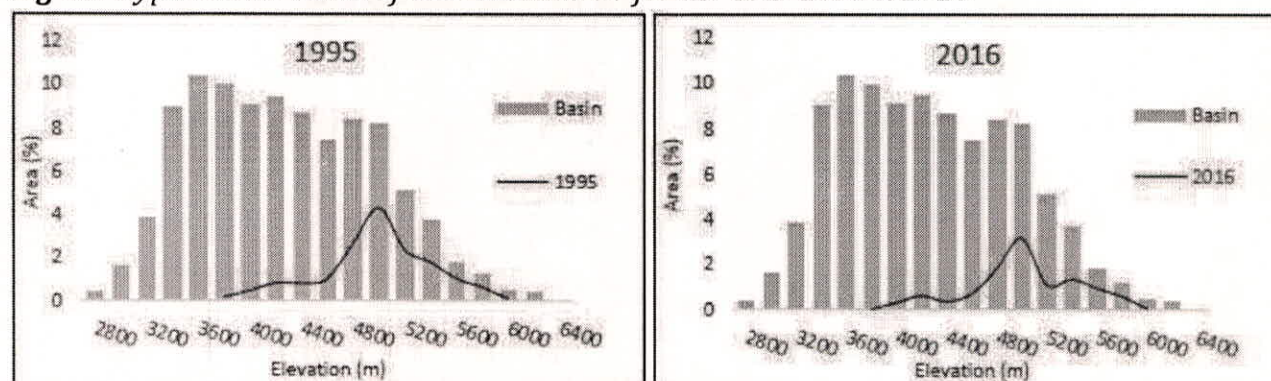
Source: Own Draft

Map 9: Changes in the Dokriani glacier in the past two decades



Source: Own Draft

Fig 18: Hypsometric Curve of Dokriani Glacier for the Year 1995 & 2016

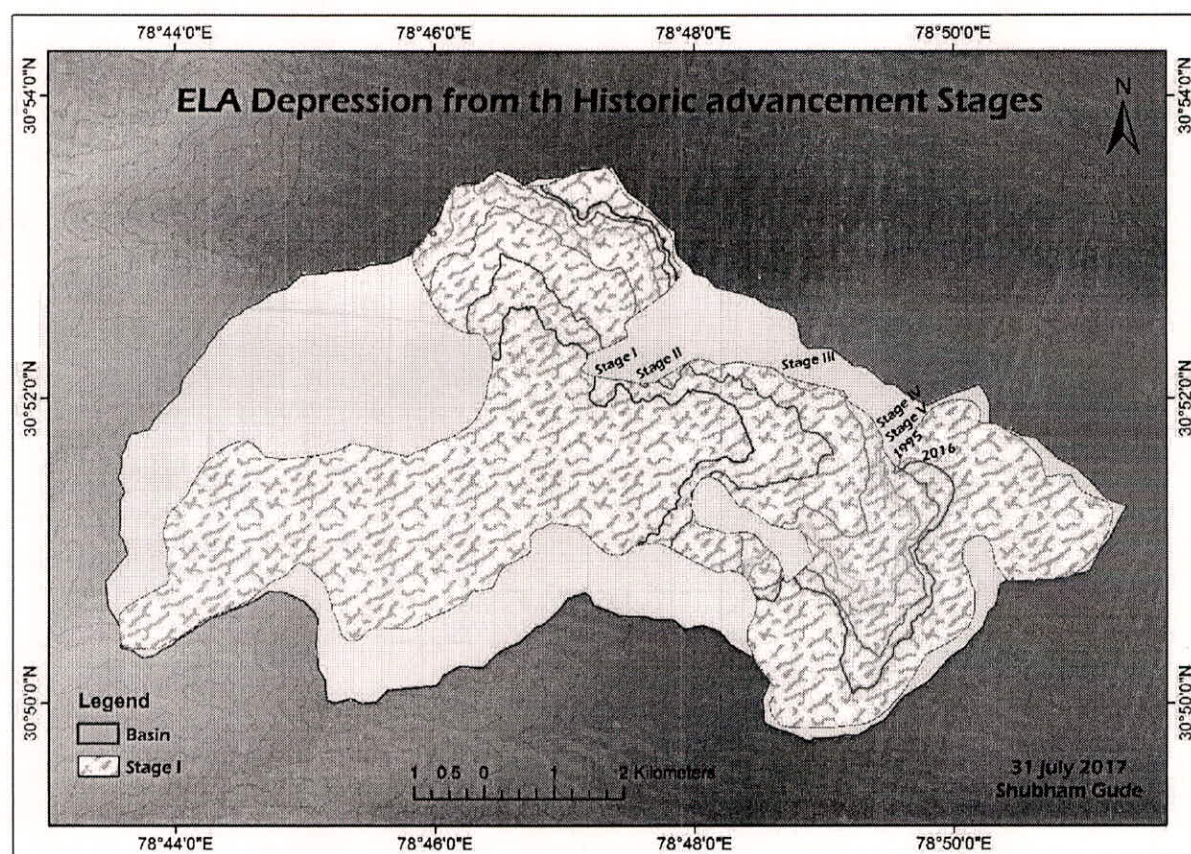


Source: Own Draft

Estimated ELA's for different glacier stages

The equilibrium line altitude (ELA) is the boundary between the ablation area and the accumulation area, the elevation at which mass balance is equal, where accumulation of snow is exactly balanced by ablation over a period of a year. When the annual mass balance of the glacier as a whole is negative the ELA rises, and when the balance is positive, the ELA falls. Variations in the altitude of the equilibrium line on a particular glacier, therefore, can be used as an indicator of climatic fluctuations. *Map 10* shows ELA's constructed for different advancement stages for the Dokriani glacier.

Map 10: Changes in the ELA of Dokriani glacier at different Advancement Stages



Source: Own Draft

Summary

Terminus position or Snout of the glacier is very important in glacier studies. The snout always remains in processes of advancement and retreat. It advances when the Glacier grows or retreats due to increase in melting. Hence snout is the best tool for mapping of glacier extension and for studying changes in glaciers over a period of time. Glaciers fluctuate as response to climate change. In the Historic times the climate change was natural without any human interventions. The climate change was gradual as compared to present trends in climate change. In this study, attempt has been made to reconstruct the glacier spread area in the historic times. Five stages (Stage I, Stage II, Stage III, Stage IV and Stage V) were identified based on historic moraines which are present in the Din Gad catchment. The moraines were identified and studied using high resolution Google earth image. The slope and surface profile of moraines for all advancement stages were constructed using ASTER digital elevation model downloaded from USGS. The glacier extent was mapped using for all the advancement period.

The studies have been done on glacial fluctuations in Garhwal Himalayas and three major glaciation periods were identified, namely the Bhagirathi advancement stage (63000 to 5000 years BP), the Shivling advancement stage (5000 years BP) and the Bhujba advancement stage (300 to 200 years BP) which can be correlated with Little Ice Age (LIA). The three stages out of five in the Din Gad catchment can be correlated with major glaciation periods based on snout altitudes and length from the current glacier terminus. Stage V which is the youngest and the latest can be correlated with Bhujba advancement stage or the Little Ice Age in which the glaciers advanced 1 to 2.2 km beyond present glacier terminus. Stage IV can be correlated with Shivling advancement where the glaciers advanced 1.5 to 3 km beyond present glacier terminus. Stage I can be correlated with the Bhagirathi stage when glaciers advanced up to terminus altitude of 2200 m above sea level. The glacier thickness, Area, Volume, Water equivalent, ELA were calculated for all the advancement periods.

The changes in the Dokriani glacier for the past two decades were analysed. The 1995 glacier extent was constructed using Survey of India Toposheet of Dokriani Glacier. Whereas the current glacier extent was mapped using satellite image of September 2016. The changes between the two were mapped and comparison was made. It was found that the Dokriani Glacier is retreating on a faster rate (approximately 400 m within 21 years) as response to anthropogenic climate change.

The hypsometric curve was prepared for all the glacier extent, showing glacier ice covering percentage of basin area with respect to elevation. Maps and Animations were created for better visual interpretation.

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Project 2

**Hydrological Modelling in a part of
Netravati Basin using SWAT Model**

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Introduction

The integrated watershed management approach has been accepted widely as one of the best technique for natural resource management. However, its application is limited because of the lack of technical knowledge. Water is essential element for livelihood. It is very valuable natural resource and at the same time very difficult to manage. There is no doubt that we as a country have performed quit well in the sector of water resources in the last fifty years which has played a very important role in the progress of the country. Most of the big rivers in the world originate from the mountains areas and are considered important sources of water for the large population of the world.

Hydrological model is a power full technique to management the natural resources. Models are essential tool which can be used to manage the hydrological process and validate the risks and benefits of Land use land cover and soil over various period of time (Spruill, C.A et al. 2000). The main objective of a hydrological model is to extract most of the information for the management of water resources in a sustained manner to improve human welfare and conserve the environment. Create awareness for sustainable use of water, among the users with respect to planning, design and management of the projects under their jurisdiction. A large number of hydrologic model are available for different aspect for water resource management. Geographic Information System (GIS) gives a convenient platform for water resource modelling. A huge number of models are interfaced with GIS. Geoinformatics techniques (Remote Sensing and GIS techniques) will provide useful information on the various problems related with water and land management, up to the date. Remote Sensing is a tool for dealing with spatial and temporal database, with high resolution. Hydrological model can be capable of producing all the specifications of water balance at a high temporal but low spatial resolution. The use of remote sensing data, with distributed hydrological model, provides a new way to obtain spatially distributed time series of input variables, parallel with calibration and validation for the hydrological model.

The application of GIS has been widely used in water resource field. GIS store these data as 'Geodatabase', like satellite data, topographic data, thematic map and others. SWAT is one of the most widely accepted model introduced by United States Department of Agriculture (USDA). It's a physical based, continuous, long term simulation agricultural model.

SWAT Model

SWAT model helps to assessing the stream flow of a river based on climate datasets. SWAT model run on a daily time steps. It is designed to predict the impact of land use land cover and management, sediment, and agricultural chemical yields upon stream flow. This model is process based, calculation wise efficient, and it is able to do continuous simulation over a long term datasets. The major components of this model are weather components, hydrological data, soil and temperature properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, firstly a watershed is being created by the use of a predefined outlet station. The next step is to divide river basin into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneity in land use land cover pattern, management criteria, topographical characteristics, and soil specifications. The HRUs are represented as a percentage of the sub watershed area and may not be contiguous or spatially identified within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub watersheds that are characterized by dominant land use, soil type, and management. SWAT was introduced by the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) primarily at the Grassland, Soil, and Water Research Laboratory in Temple, Texas. The model was schemed for basin-scale applications. SWAT is able to predict water, sediment, and chemical yields in ungauged basins (Gassman et al. 2007). Major components of the SWAT model include weather generation, hydrology, sediment, crop growth, nutrients, and pesticides (Neitsch et al. 2005). The SWAT model, first released in the early 1990s. The very latest version of the SWAT model is SWAT 2012. SWAT can be used in different division like hydrology, groundwater, agricultural management (SWAT theoretical documentation). Physical based input is use in SWAT model namely soil properties, elevation, weather variables. The hydrological cycle (equation no. 1) is simulated by SWAT model based on different weather datasets.

$$1. \quad SW_t = SW_o + \sum_{i=1}^t (R - Q - E - W - G)$$

Where,

SW_t = the final water content

SW_o = the initial soil water content

T = time in days

R = the amount of precipitation on day

Q = the amount of surface runoff

E = the amount of evapotranspiration on day

W = the amount of percolation and bypass existing in the soil profile bottom on day G

G = the amount of ground flow on day

In the water balance equation the hydrological simulation process are shown, as precipitation, surface runoff, evapotranspiration and percolation and return flow. Precipitation and the other weather parameters, in general, provide the various inputs that control the water balance. The daily weather data required for SWAT are precipitation, temperature (maximum and minimum), solar radiation, wind speed, and relative humidity. These data can be observed or generated using a weather generator. The weather generator is used to either generate daily weather data or to fill missing values in the input data.

For each HRU, Runoff is simulated, then it combined to acquire the total amount of stream flow for the sub-basins, the sub basins are further combines with other sub-basins stream flow to calculate the total stream flow for the whole basin. According to Neitsch et al (2011), the surface runoff can be delineates by using two methods, they are modified SCS curve number method or the Green and Ampt infiltration method. The SCS curve number, which was used in this study, is a function of the soil permeability, land use and the associated moisture condition. The curve number varies non-linearly based on antecedent moisture condition. The basic equation used in the SCS curve number method is given by:

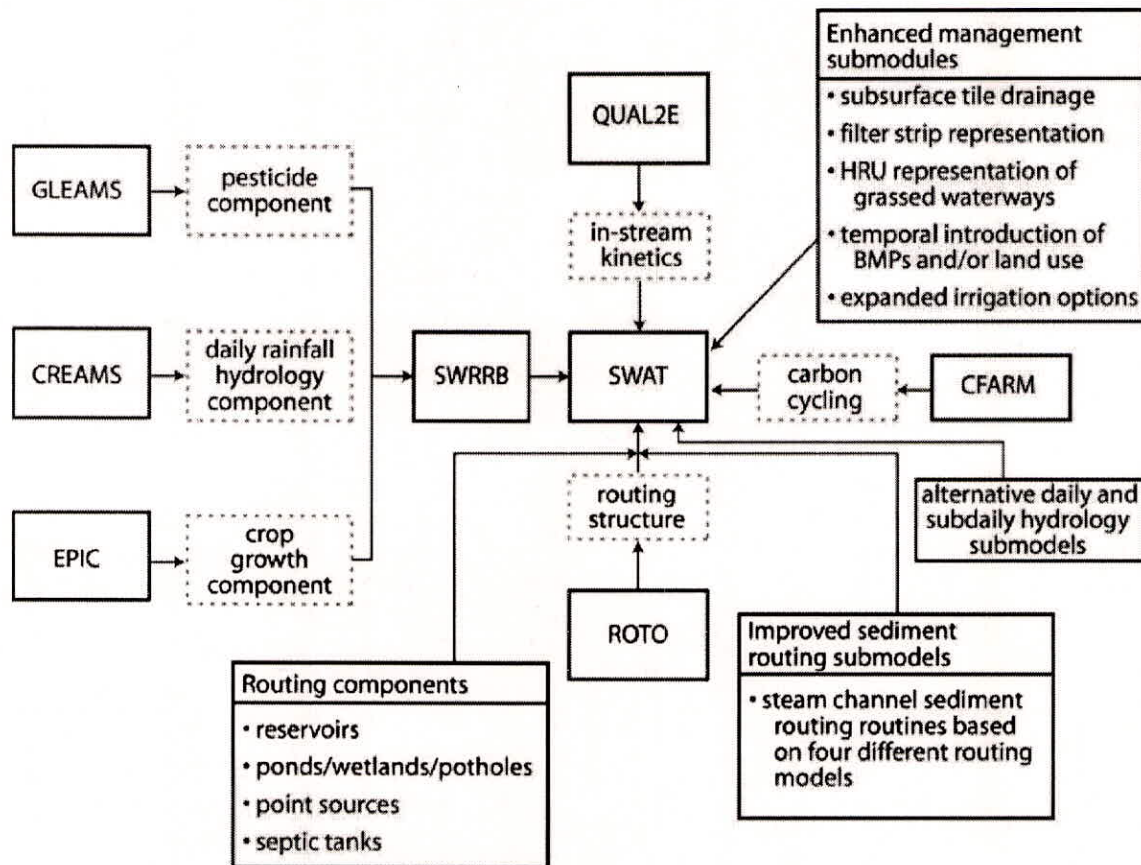
$$Q = \frac{(R - I)^2}{R - I + S}$$

Where,

Q denotes the accumulated surface runoff or rainfall amount (mm), R is the rain depth for the day, I is the initial abstraction, which includes surface storage, interception and infiltration prior to runoff (mm) and S is the retention parameter (mm).

Development of SWAT

SWAT, Soil and Water Assessment Tool emerged mainly from SWRRB and contains features from CREAMS, GLEAMS, EPIC, and ROTO. It was developed to assist water resources managers in predicting and assessing the impact of management on water, sediment and agricultural chemical yields in large ungauged watersheds or river basins. It is a continuous model and operates on a daily time step. Model components include weather, hydrology, erosion/sedimentation, plant growth, soil temperature, nutrients, pesticides, agricultural management, channel routing, and pond/reservoir routing. The model is intended for long term yield predictions and is not capable of detailed single-event flood routing.

Fig 1: Schematic of SWAT development history and model adaptations

Source: SWAT: Model use, calibration, and validation, Philip W. Gassman, Iowa State University, 2012

SWAT CUP

SWAT CALIBRATION UNCERTAINTY PROCEDURES (SWAT-CUP) is a software program for calibration, validation of SWAT model. It was invented by Eawag, Swiss Federal Institute that looks into the prediction of uncertainty of SWAT model. The parameters of the model can be chosen in accordance with the objectives of the study. The results obtained after using different variables and combination of variables among water content. Pressure head and cumulative outflow on the estimation of hydraulic parameters by inverse modelling were investigated in previous study (Abbaspour et al. 1999). GLUE is included in SWAT-CUP which is defined to partly show the possible similarity, PARASOL, and SUFI-2 are the methods to give combined objective functions into a criteria which is globally optimized which uses SCE-UA algorithm.

A soil map is considered in model parameterization, in SWAT-CUP of a watershed model which can be similar soils in different parameters due to difference in climate, land use and soil management. Different calibration programs allow parameters combinations of soil, land use, hydrological group and sub-basin specification which are linked to SWAT (Abbaspour et al. 1999).

X_<parname>.<ext>_<hydrogrp>_<soltext>_<landuse>_<subbsn>

Where, x = indicate the type of change to be applied to the parameter

<Parname> = SWAT parameter name

<ext> = SWAT file extension

<hydrogrp> = Soil hydrological group (A, B, C, D)

<Soltext> = Soil texture

<Landuse> = Land use category

<Subbsn> = sub-basin number

SUFI-2 (Sequential Uncertainty Fitting)

SUFI-2 can be used for calibration of model and uncertainty analysis, it is a multisite and semi-automated global search procedure. In SUFI-2 we take an account of the homogeneity in distribution to demonstrate the uncertainty of input variables. In this model the output uncertainty is quantified by 95% prediction uncertainty, which is calculated at 2.5% and 97.5% levels of cumulative distribution of output variables obtained from the method Latin hypercube sampling. The parameter uncertainty is directly proportional to uncertainty of output. In SUFI-2 p-factor is used for the assessment of uncertainty, r-factor is also a significant method that can be used, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The value of p ranges between 0-100 percent, while the r-factor ranges between 0 to infinity. The exact correspondence to measurement the data is p-factor of 1 and r-factor of 0. The parameter uncertainties are the desired parameter ranges after obtaining satisfactory values of r- factor and p-factor. The most reliable result can be measured by the R² or Nash-Sutcliff coefficient method amongst the observations and the final "best" simulation.

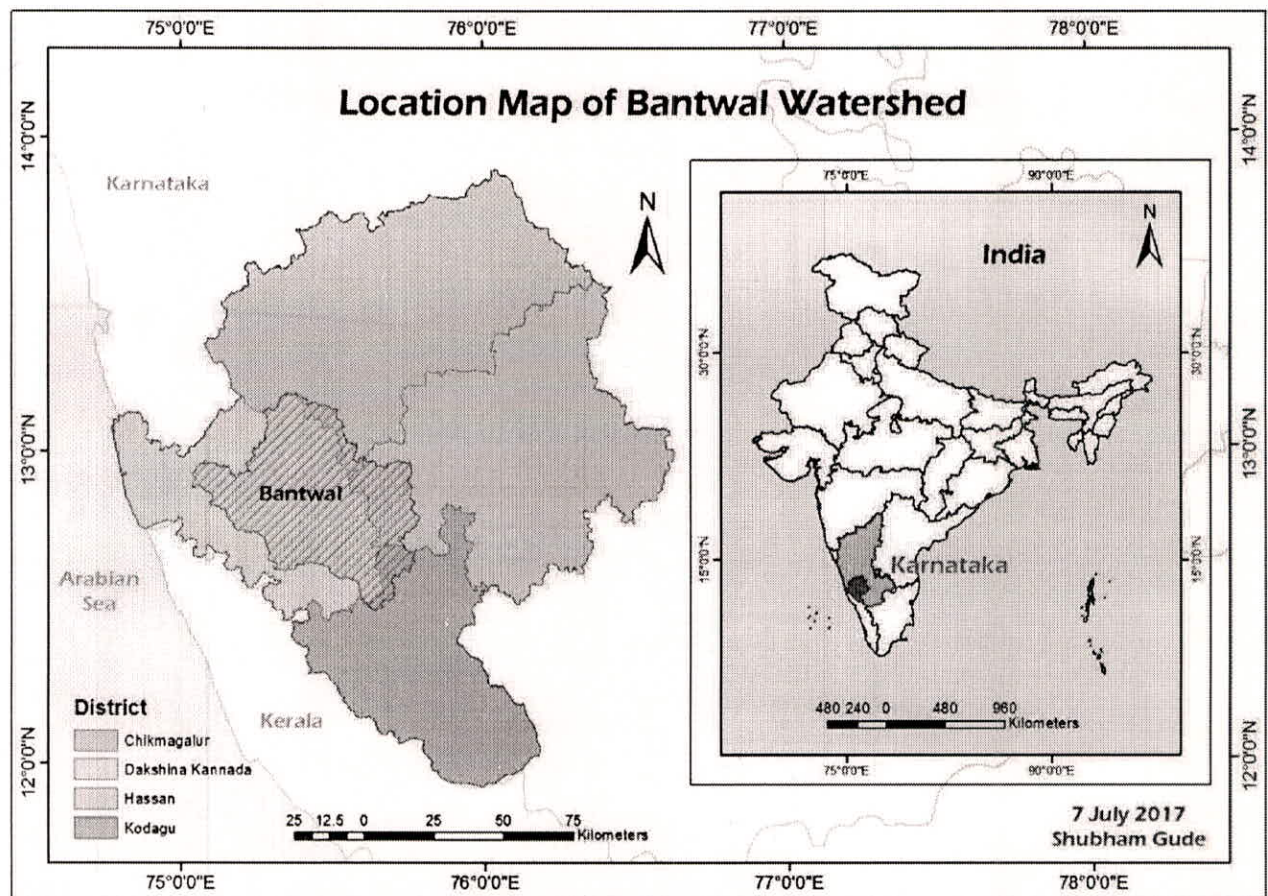
Study Area

The Netravati River is one of the important west-flowing rivers in Karnataka. The geographical location of the Netravati River basin lies between 12°29'11" to 13°11'11" N latitudes and 74°49'08" to 75°47'53" E longitudes. The Netravati River originates in the South of Samse village in the Western Ghats (meaning a mountainous region with thick forest running parallel to the west coast of India) of Karnataka state, India. The altitude varies approximately in the range of 0 – 1,200 m from mean sea level. Total length of the river is about 103 kilometers, which drains an area of about 3,657 km². The river is joined by Mundaja Neriya, Shishla Uppar, and Beltangady nallas from either side. Further, downstream is joined by the Kumaradhara River at Uppinangadi and flows westward in the coastal plains. It joins the Arabian Sea at Mangalore. Average rainfall over the Netravati basin is 3,930 mm. The south-west monsoon period is the coolest part of the year with the mean daily temperature below 20°C. The mean daily temperature during the months from March to May is about 35°C, and the weather is highly humid all

through the year. Humidity exceeds 85% during southwest monsoon (June to September). The Netravati River is mainly used for irrigation and drinking water supply for more than 0.6 million people, petrochemical industries established at the Mangalore city, and religious purposes in places like Dharmastala and Kukkesubramanya throughout the year. If any change in LULC occurs in the Netravati basin would cause changes in the hydrological parameters. This will change the streamflow, which, in turn, affect the water resources distribution in the river basin.

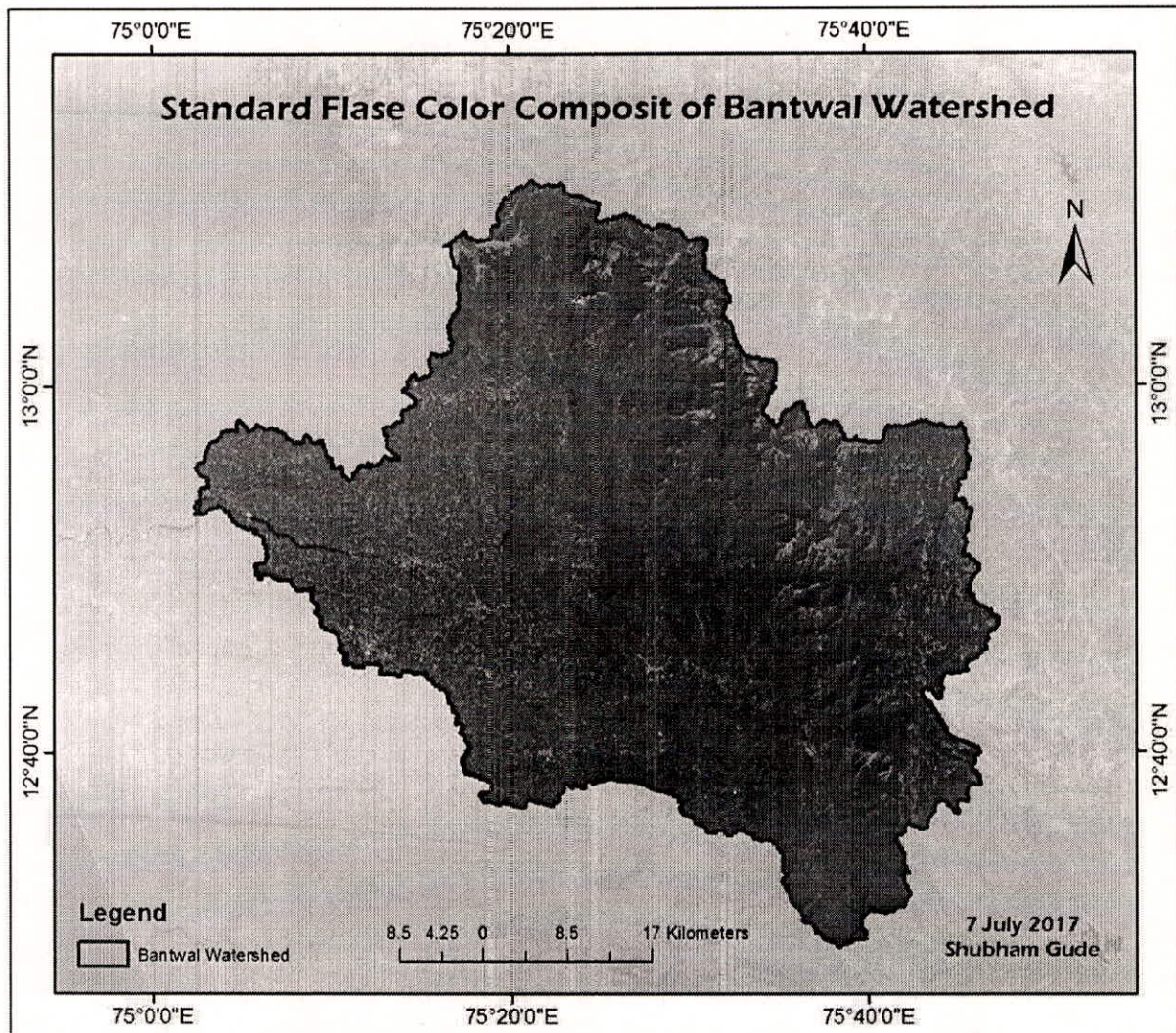
The Netravati River is gauged at Bantwal location from where daily stream discharge data is collected (Latitude: $12^{\circ}52'51''\text{N}$ and Longitude: $75^{\circ}02'27''\text{E}$). The catchment area of Bantwal watershed is 3184SqKm.

Map 1: Location map of Bantwal watershed



Source: Own Draft

Map 2: Standard FCC of Study Area



Source: Own Draft

Software used

Table 1: List of Software used in the project

Sr. No.	Software Used	Description
1	ERDAS IMAGINE 14	LULC Preparation Using Supervised Classification
2	Arc GIS 10.1	DEM Preparation, Co-registration, Map Preparation
3	Arc SWAT 2012	Runoff Estimation
4	Arc SWAT-CUP 2012	Calibration, Validation & Global Sensitivity Analysis
5	Microsoft Office Excel 2013	Data Preparation

Source: Own Draft

Data Source

The area of this study mainly falls in the state of Karnataka, for carrying out the study various types of multispectral, multi temporal and dynamic data was collected. In Netravati basin discharge data is collected at 1 station (Bantwal), which is completely maintained by India WRIS. The satellite imageries, Digital Elevation Model was obtained from the web which is freely available. Meteorological data such Precipitation, Temperature, Relative Humidity, Solar Radiation and Wind, which has been downloaded from global weather database for SWAT. The soil map was prepared by digitization from Toposheet of NBSS & LUP, Nagpur. Source and description of the datasets are showing in Table 2.

Table 2: List of data used in project and their sources

Data Type	Source	Spatial / Temporal Resolution	Description
Topography	USGS Earth Explorer	30 m	ASTER Digital Elevation Model
	(https://earthexplorer.usgs.gov/)		
Land Use/Land Cover	ESA Copernicus	10 m	Sentinel 2A
	(https://scihub.copernicus.eu/dhus/#/home)		
Soils	National Bureau of Soil Survey & Land Use Planning, Nagpur	1:7000000	Soil Toposheet
	(http://esdac.jrc.ec.europa.eu/resource-type/national-soil-maps-eudasm)		
Weather Data	Global Weather Data for SWAT	Daily	Rainfall, Minimum and Maximum Temperature, Solar Radiation, Relative Humidity, Wind Speed
	(https://globalweather.tamu.edu/)		
Stream Flow Data	India - WRIS	Daily	Daily Stream Flows measured at gauging station
	(http://www.india-wris.nrsc.gov.in/wris.html)		

Source: Own Draft

Aims and Objective

Aim

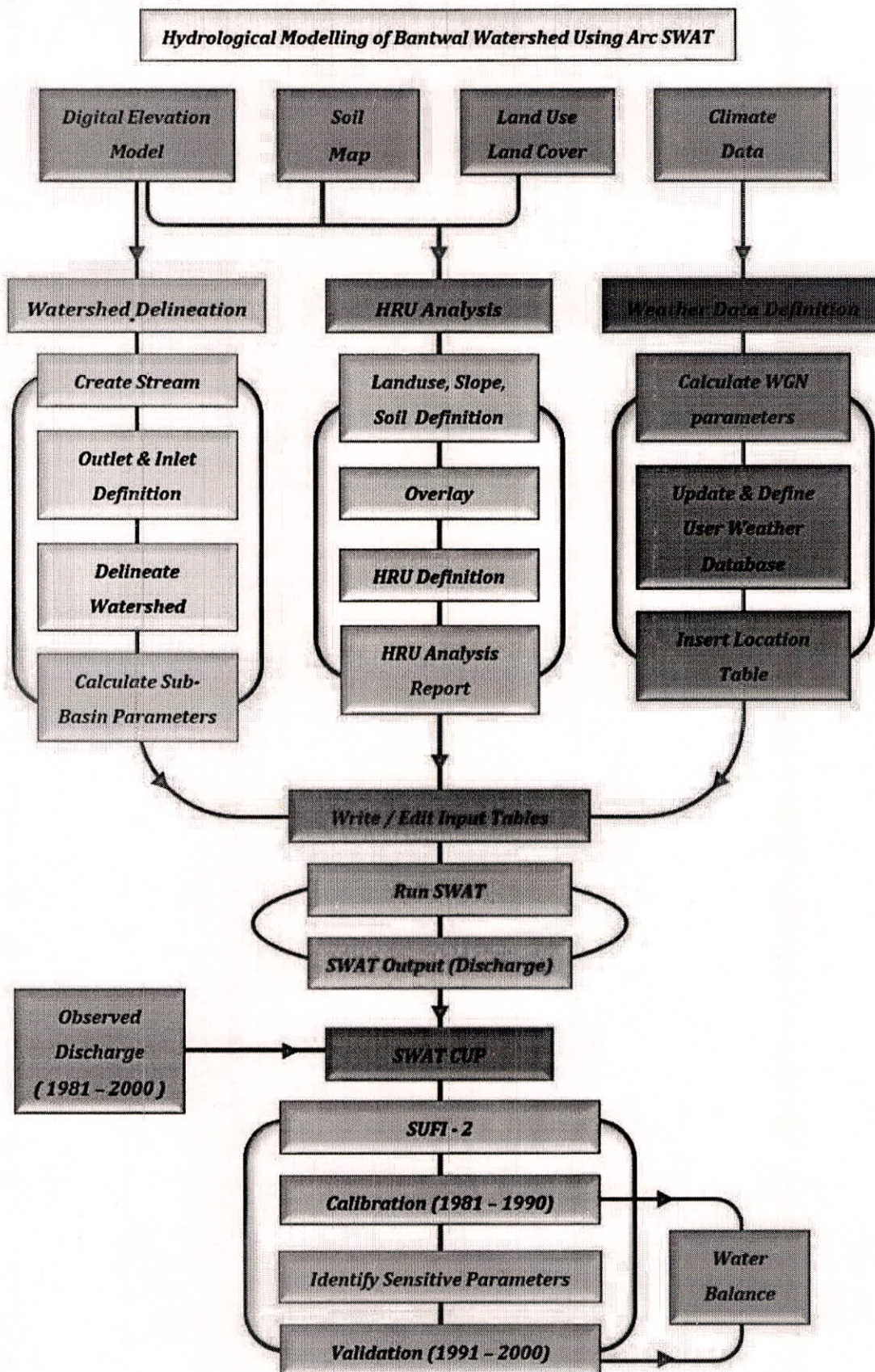
- To Assess the response of basin on stream flow for present land use and climatic conditions

Objective

- To simulate stream flow for Netravati river using Arc SWAT
- To perform Calibration, Validation and Global Sensitivity Analysis on the simulated data using SWAT-CUP
- To estimate water balance for the delineated watershed in Netravati basin

Methodology

Fig 2: Methodology Flow Chart for Arc SWAT



Source: Own Draft

Swat Model Inputs

To perform the model, primary steps are identification and delineation of the hydrological response units (HRUs). From ASTER DEM drainage network was delineated, where analytical technique of the Arc SWAT-2012 GIS interface was used. To calculate an acceptable numbers of HRUs within each sub basins, a perfect combination of land use and soil (5%, 5%, and 10%) were used. To run this process the study area was divided into 6 sub basins and 79 HRUs. These combination establish an acceptable drainage network description as regard to the management of dominant land uses, soil types within every sub basins, and an acceptable numbers of HRUs in each sub basins.

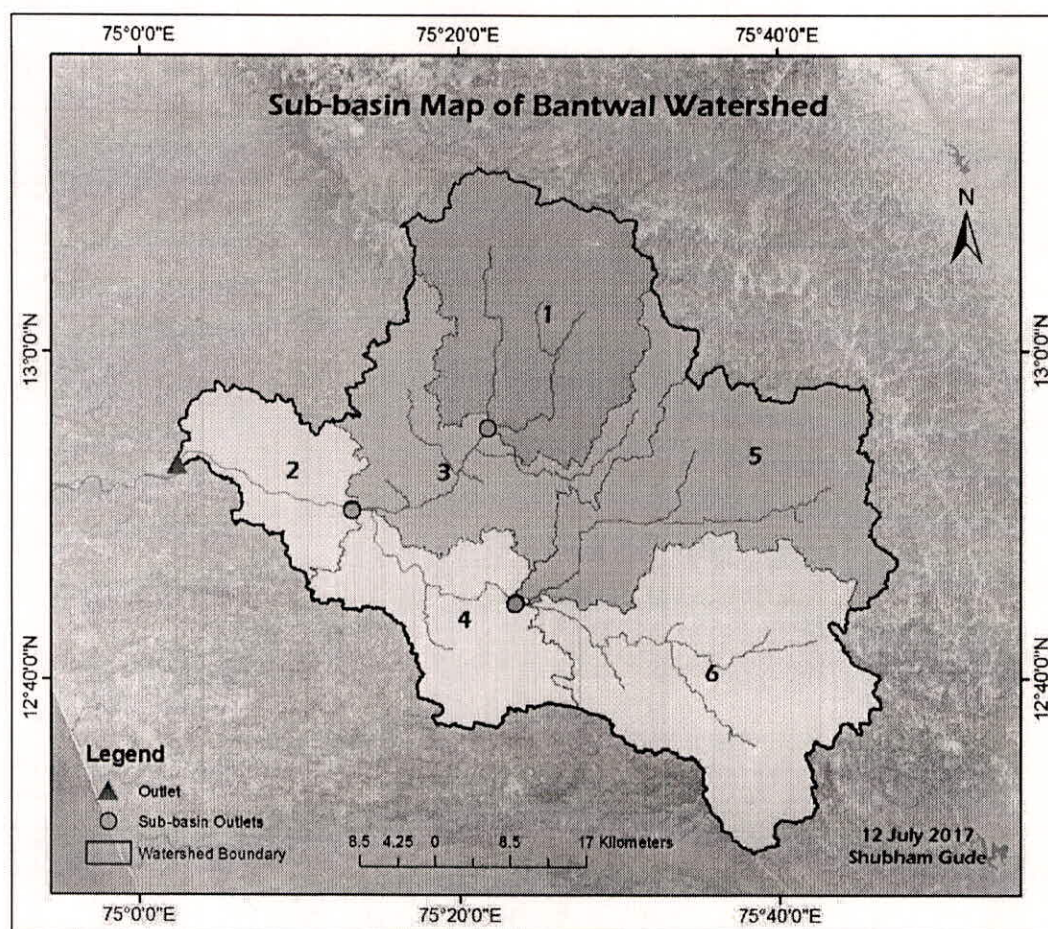
Arc SWAT Model Setup Simulation of Hydrological Process

The model has setup to establish hydrological simulation of any watershed. The following steps has been followed to set up the model.

- SWAT project setup
- Automatic watershed delineation
- Land Use, Soil and Slope characterization (HRUs analysis)
- Climate data definition (Write input tables)
- Editing input information
- SWAT simulation

Automatic Watershed Delineation

Arc SWAT 2012 automatically delineates watershed into sub-watersheds based on DEM and the river's drainage network. The ASTER DEM which is clipped for the area is imported in the model, a mask of polygon was created manually in Arc SWAT (grid format) which was inserted in the model to extract the area of interest. The DEM has to be pre-processed for the determination of the size and number of sub watersheds based on the threshold area. In the study the default threshold value has taken to be 6000 hector which formed 6 sub basins. Once the stream network is delineated, a specific outlet of the study area has to be defined (Bantwal). Based on this outlet point Arc SWAT delineates boundaries of watershed and sub watershed. At last all the geometric parameters of every sub basins and stream reaches are calculated and saved as a vector file (.shp format). The area delineated by the software has been found to be 3203 sq. km.

Map 3: Sub-basin Map of Bantwal watershed

Source: Own Draft

Table 3: Specifications of different Sub-basins

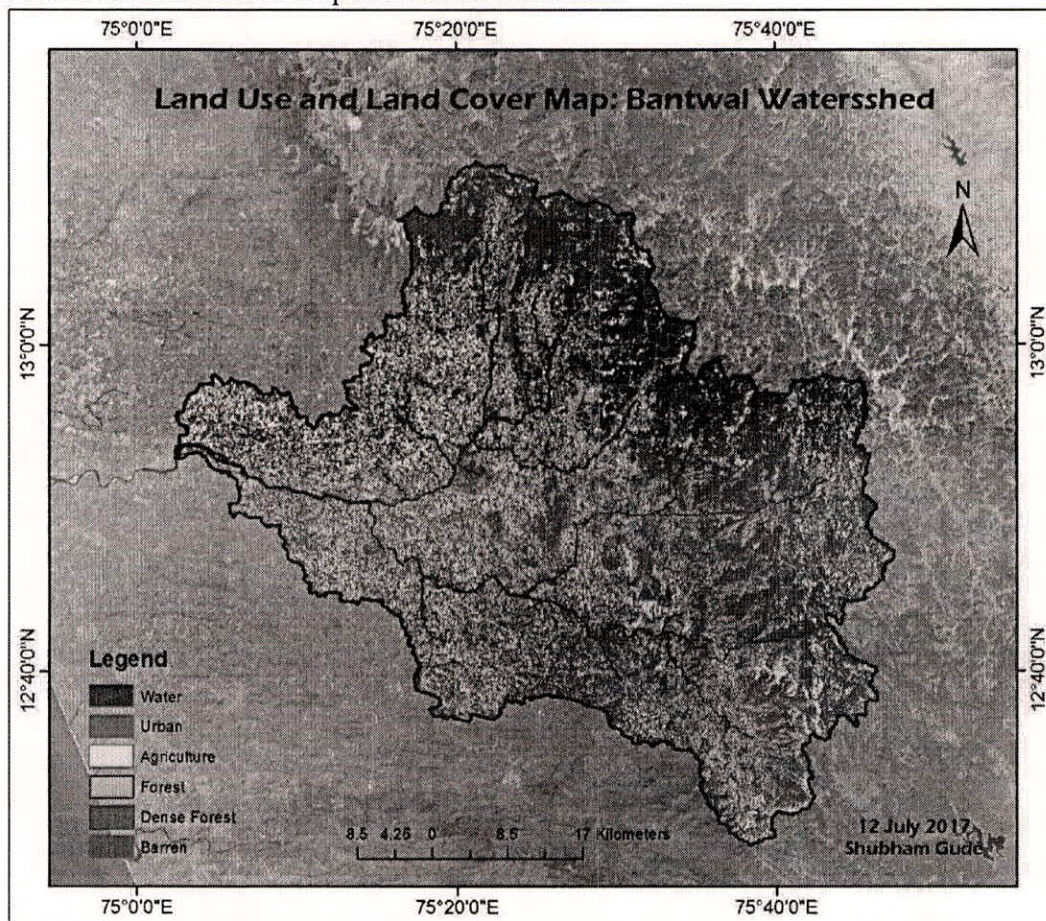
Type	Sub-basin ID	Area Km ²	Area (%)
Sub-basin	1	639.3	19.96
	2	258.2	8.06
	3	505.5	15.78
	4	379.5	11.85
	5	634.1	19.80
	6	786.6	24.56

Source: Own Draft

Land Use and Land Cover Map

It is necessary to prepare a proper LULC (land use land cover) map to perform the model as it is one of the most essential factor effecting the runoff, infiltration, percolation, evapotranspiration, drainage network, soil erosion in a basin. In this study a LULC has been prepared by using remotely sensed satellite data. For this current study, Sentinel 2A data has been used, after downloading the data from ESA Copernicus. For this study supervised classification technique is used. According to spectral reflectance 6 land use land cover classes are made, those are Water, Urban, Agriculture, Forest, Dense Forest and Barren Land.

Map 4: Land use Land cover map of Bantwal watershed



Source: Own Draft

Table 4: Specifications of different land use and land cover

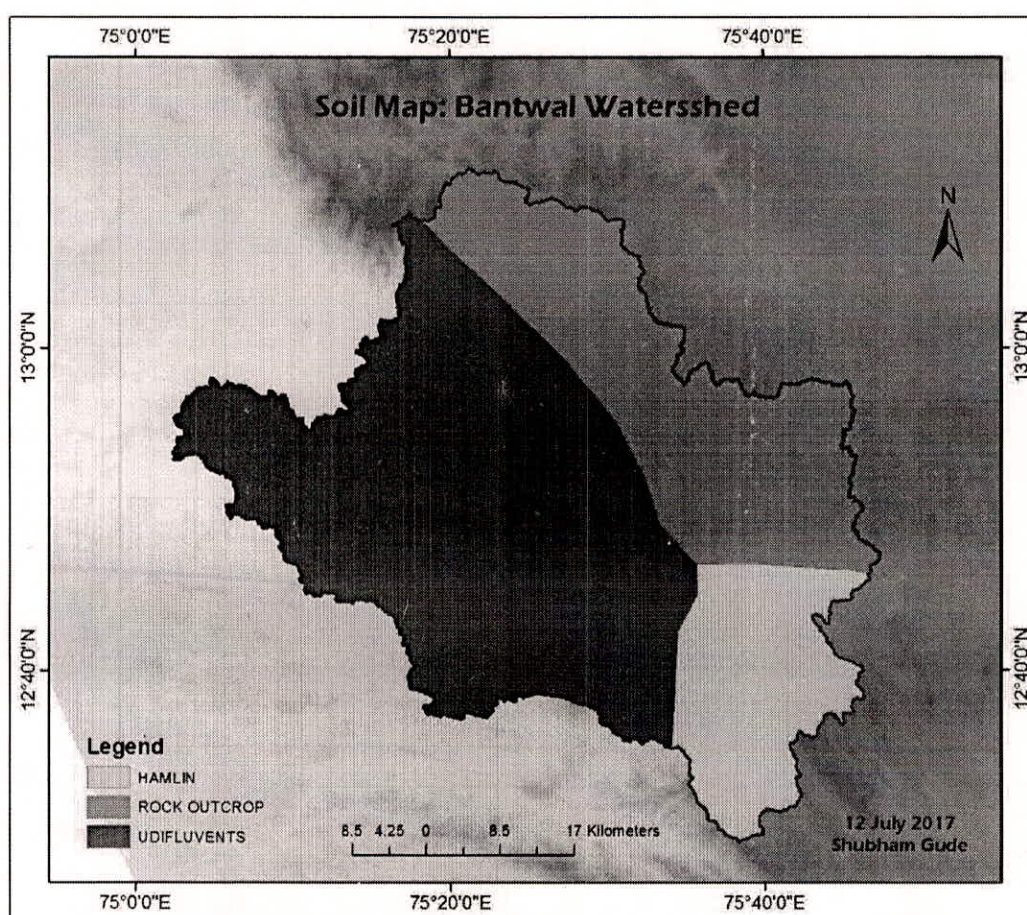
Type	Classes	Reclassified According to SWAT Geodatabase	Area (%)
Land Use/Land Cover	Water	WATR	0.38
	Urban	URBN	1.48
	Agriculture	AGRL	14.88
	Forest	FRST	35.10
	Dense Forest	FRSE	43.78
	Barren	BARR	4.39

Source: Own Draft

Soil Map

For SWAT Model one of the main major input is the physical properties of the soil. It plays a great role for any hydrological modelling. The basic requirement of the model is soil properties like texture, hydraulic conductivity, water availability etc. For this current study soil map has been digitized from National Bureau for Soil Survey & Land Use Planning (NBSS & LUP), Nagpur. According to the soil properties the study area has been classified in to 3 categories namely UDIFLUVENTS, ROCK OUTCROP and HAMLIN.

Map 5: Soil classification map of Bantwal Watershed



Source: Own Draft

Table 5: Soil categories and their characteristics

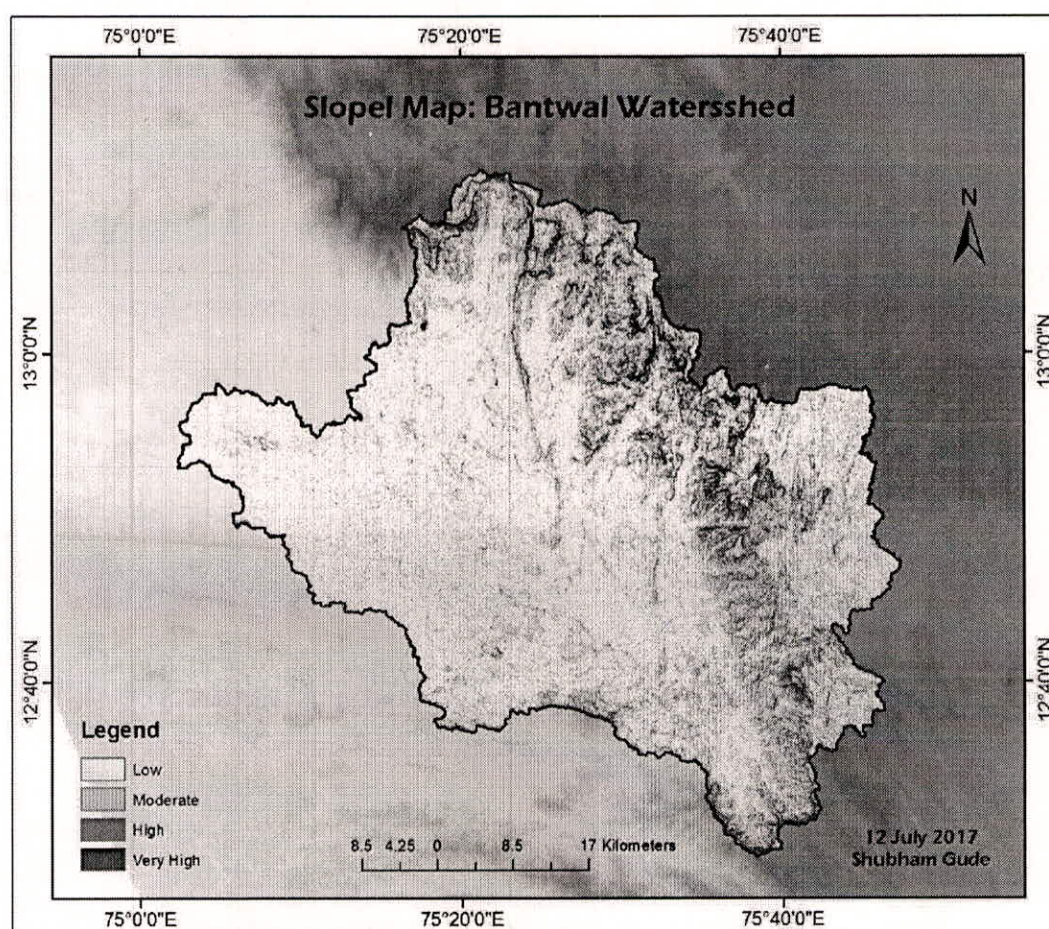
Type	Classes	Reclassified According to SWAT Geodatabase	Area (%)
Soil	UDIFLUVENTS	VFSL	56.71
	ROCK OUTCROP	UWB	28.17
	HAMLIN	SIL-VFSL-VFSL-VFSL	15.12

Source: Own Draft

Slope Map

Slope is one of the important factor affecting surface runoff. SWAT defines slope classes from the DEM which is inserted during automatic watershed delineation process. User have to define the Range and Number of classes depending on the topography of study area. The user can make maximum of five classes in SWAT 2012. For hilly and mountainous region more classes are advisable as compared to relatively flat terrain Bantwal watershed is classified into 4 classes for this study, each ranging from 0 – 25, 25 – 50, 50 – 80 and 80 – 100.

Map 6: Slope classification map of Bantwal watershed



Source: Own Draft

Table 6: Slope categories and their characteristics

Type	Range	Classes	Area (%)
Slope	0 - 25	Low	66.32
	25 - 50	Moderate	28.25
	50 - 80	High	5.21
	80 - 100	Very High	0.22

Source: Own Draft

HRU Definition

The Hydrological Response Unit (HRUs) is basically which divided the whole watershed into different homogeneous unit with respect to land use land cover, soil types and slope criteria at each grid. HRUs are a part of sub basin which produces a unique land use / management / soil attributes. Land use, management and soil may be scattered throughout the study area but for HRUs creation it should be put together in one group. As a thumb rule, a sub basin should have 1-10 HRUs. HRU definition allows users to load land use land cover map, soil map and it also include classification of HRU for different slope classes, which has linked to the SWAT Geodatabase to generate HRUs. The inserted datasets have reclassified according to the given codes. To calculate an acceptable numbers of HRUs of each and every sub basins, a correct combination of land use land cover, slope and soil (5%, 5% and 10%) were used. The associated topographic report regarding HRUs has been generated successfully which described all the statistical parameters for each sub basins like minimum elevation, maximum elevation, standard deviation, percentage of area, percentage of watershed. The land use map as well as soil map have been overlapped by 100% with the delineation of watershed and 79 HRUs were created for the 6 sub basins.

Fig 3: HRU Report

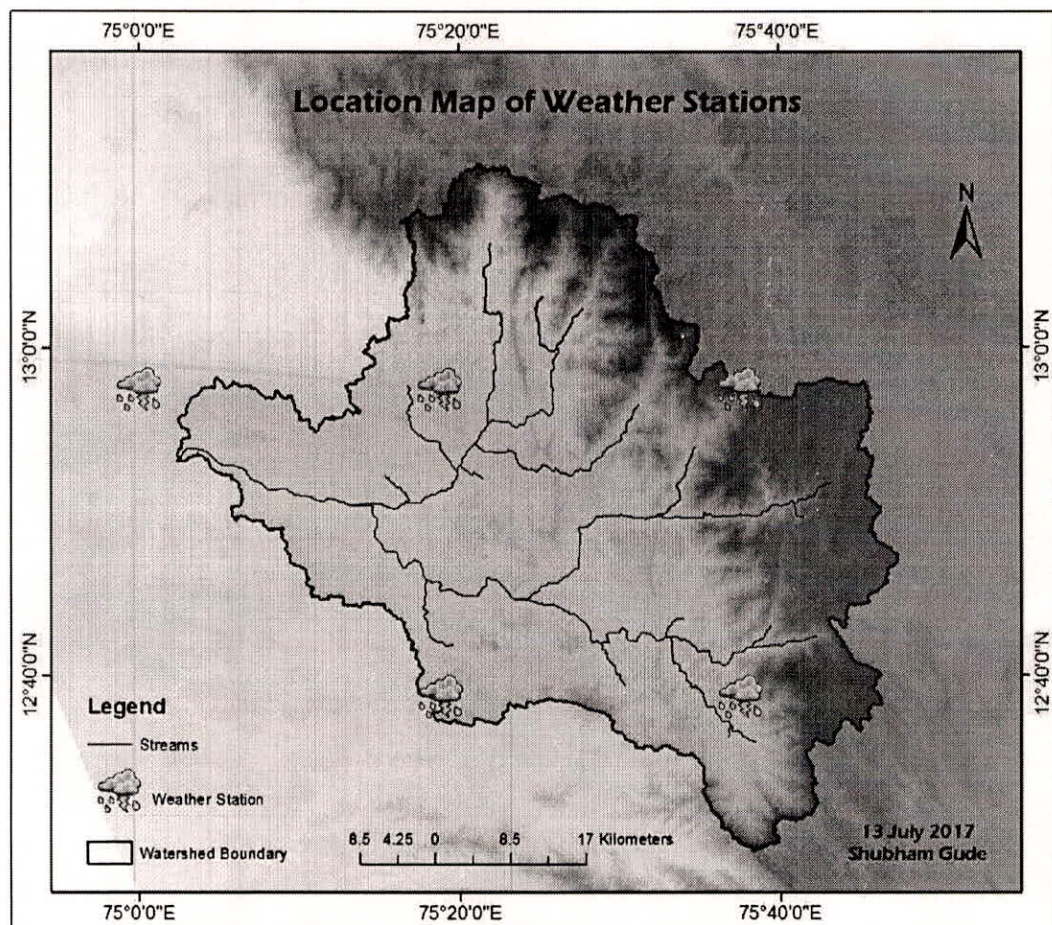
SWAT model simulation Date: 07-13-2017 00:00:00 Time: 00:00:00				
MULTIPLE HRUs LandUse/Soil/Slope OPTION			THRESHOLDS : 5 / 5 / 10 [%]	
Number of HRUs: 79				
Number of Subbasins: 6				
		Area [ha]	Area[acres]	
Watershed		320333.6613	791560.4938	
LANDUSE:		Area [ha]	Area[acres]	%Wat.Area
	Agricultural Land-Generic --> AGRL	49109.3625	121351.6902	15.33
	Forest-Mixed --> FRST	115322.6821	284968.1137	36.00
	Forest-Evergreen --> FRSE	143426.2094	354413.3348	44.77
	Barren --> BARR	12475.4072	30827.3550	3.89
SOILS:				
	ROCK OUTCROP	88200.7804	217948.5384	27.53
	UDIFLUVENTS	183559.8729	453585.6240	57.30
	HAMLIN	48573.0080	120026.3313	15.16
SLOPE:				
	50-80	16675.7089	41206.5105	5.21
	0-25	212441.6069	524953.8328	66.32
	25-50	90500.1630	223630.4278	28.25
	80-9999	716.1825	1769.7228	0.22

Source: Own Draft

Write Input Tables

SWAT requires weather data inputs, those are daily precipitation, maximum/minimum temperature, solar radiation, wind speed and relative humidity. Values for all these climatic parameters may be determined from previous records of observed. Required parameters have been used in SWAT weather input database, with swat supported format and inserted into the model. Five weather stations has been defined across the river basin. The weather generator input file consist of statistical data, needed to create representative daily weather data for every sub basins. It is Ideal to take at least 20 years of recorded data are used to generate parameters for preparing the .wgn file. For this current study 34 years of data has used. These statistics has been generated using WGN EXCEL MACRO downloaded from SWAT website.

Map 7: Location Map of weather stations used in the project



Source: Own Draft

The weather generated input file consists of several parameters like TITLE (the first line of the .wgn file is used for user comments), WLATITUDE (latitude of weather stations used to calculate statistical parameters), WLONGITUDE (longitude of the weather stations), WELEV (elevation of the weather stations), RAIN_YRS (the number of years of

rainfall, if no value is input for RAIN_YRS, SWAT will set 10, by default), TMPMX (average or mean daily maximum air temperature), TMPMN (average or mean daily minimum temperature), TMPSTDMX (standard deviation for daily maximum air temperature), TMPSTD MN (standard deviation for daily minimum air temperature), PCPMM (average or mean total monthly precipitation), PCPSTD (standard deviation for daily precipitation in month), PCPSKW (skew coefficient for daily precipitation in month), PR_W (probability of a wet day following a wet day in the month), PCPD (average number of days of precipitation in month), RAINHHMX (maximum 0.5 hour rainfall in entire period of record for month), SOLARAV (average daily solar radiation for month), DEWPT (average daily dew point temperature for each month or relative humidity can be input), WNDAY (average daily wind speed in month).

Edit SWAT Input

The modeller can edit the database file in the model. The climate data like precipitation, relative humidity, solar radiation, wind speed, temperature and location of meteorological data file were used as inputs for running the SWAT model. The required files were developed as per the format given in the input/output documentation of SWAT 2012.

SWAT Simulation

Once all the weather parameters are inserted in the model, run the model for desired period. The output of the model like HRU, RCH, and SUB was generated on the Daily basis. User can specify the warm up period for the model. The simulated discharge and its associated reports were generated successfully.

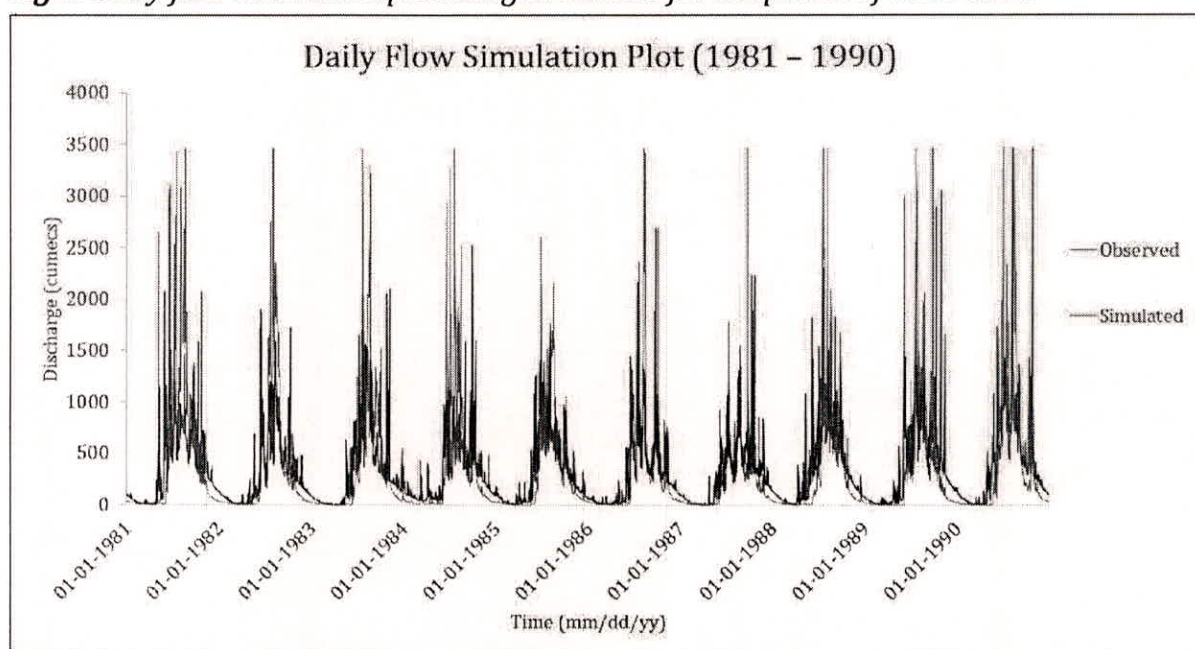
SWAT CUP Model (Sufi-2)

SWAT-CUP was used for calibration and validation purpose. After SWAT simulation SWAT-CUP (2012) was used to calibrate and validate the data using SUFI-2 algorithm. In the SWAT-CUP, observed stream flow and SWAT simulated data (1981 -1990 for calibration) was imported to run the model, both datasets were prepared as per the required format in the SWAT-CUP. Data for the first two years (1979-1981) were conserved as 'warm-up' period for model initialization. Same methods were followed for model validation (1991-2000). The model iteration was 500 for both calibration and validation. The statistics (PBIAS, R^2 , NSE, p-value, t-test) for calibration was evaluated for the period of 1981-1990.

Results and Discussion

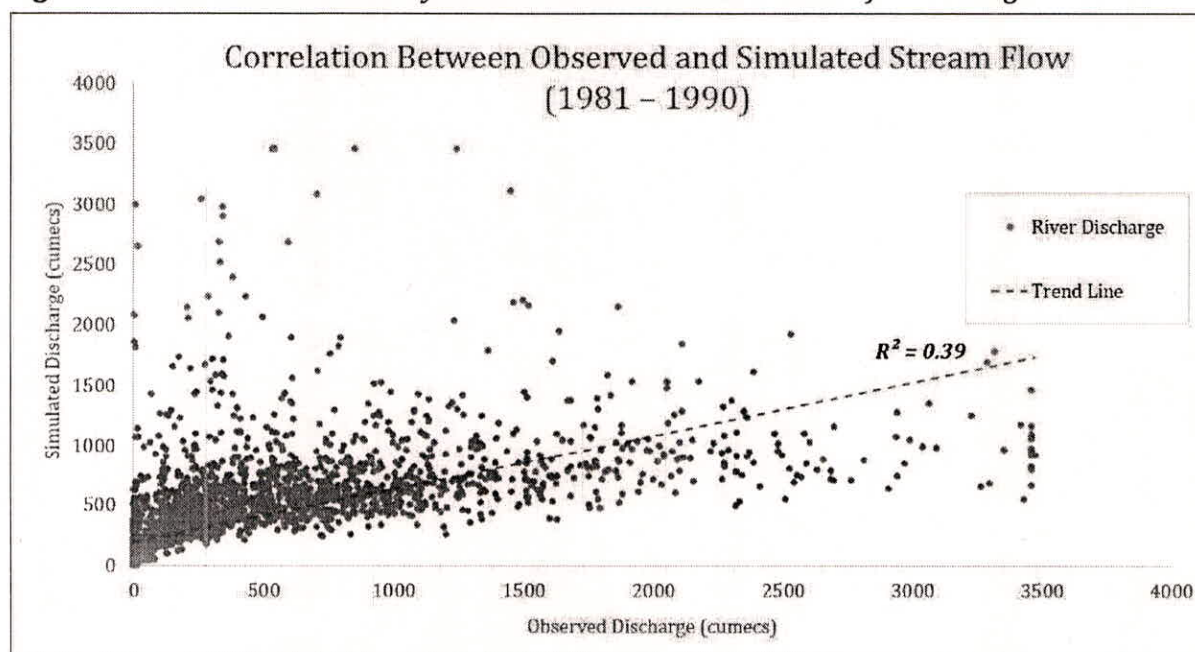
According to the objectives of this study, daily stream flow was simulated using Arc SWAT. Various input datasets have been prepared from various sources according to requirement of mode. The simulation was done for 10 years (1981 – 1990), in which 2 year has been cropped as a “warm-up period”. The time series of observed and simulated discharge value have been compared graphically on the daily basis. The coefficient of determination (R^2) was 0.39 for simulated data.

Fig 4: Daily flow Simulation plot using Arc SWAT for the period of 1981-1990



Source: Own Draft

Fig 5: Correlation between daily observed and simulated stream flow during 1981-1990



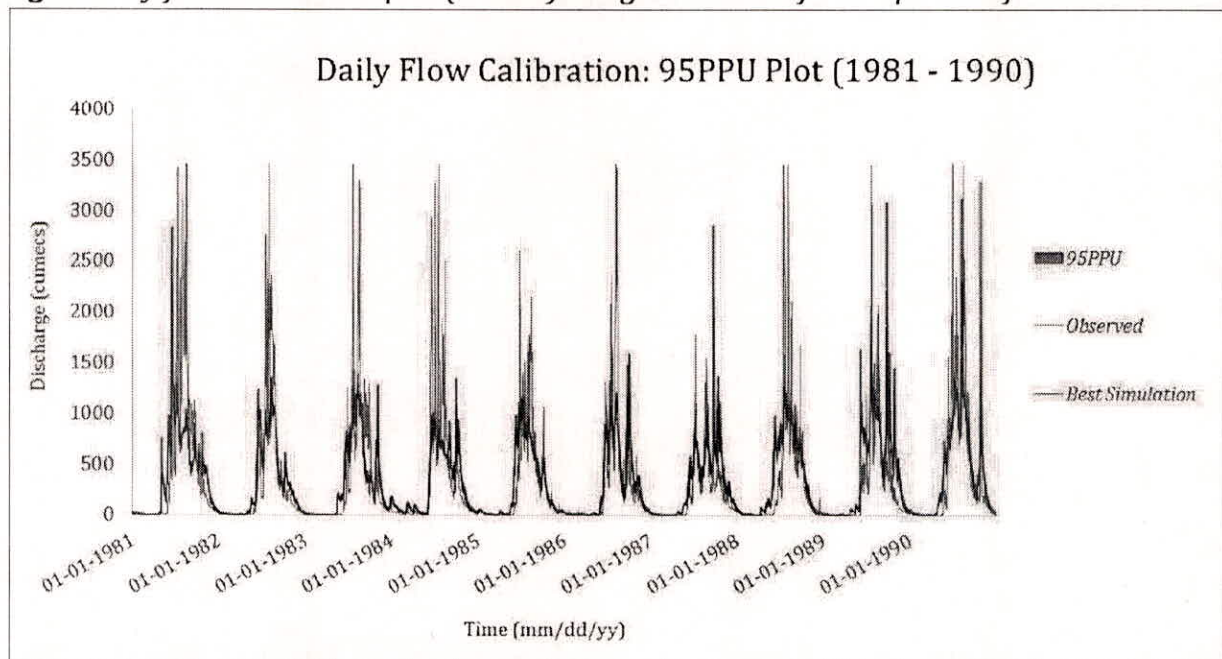
Source: Own Draft

Model Calibration

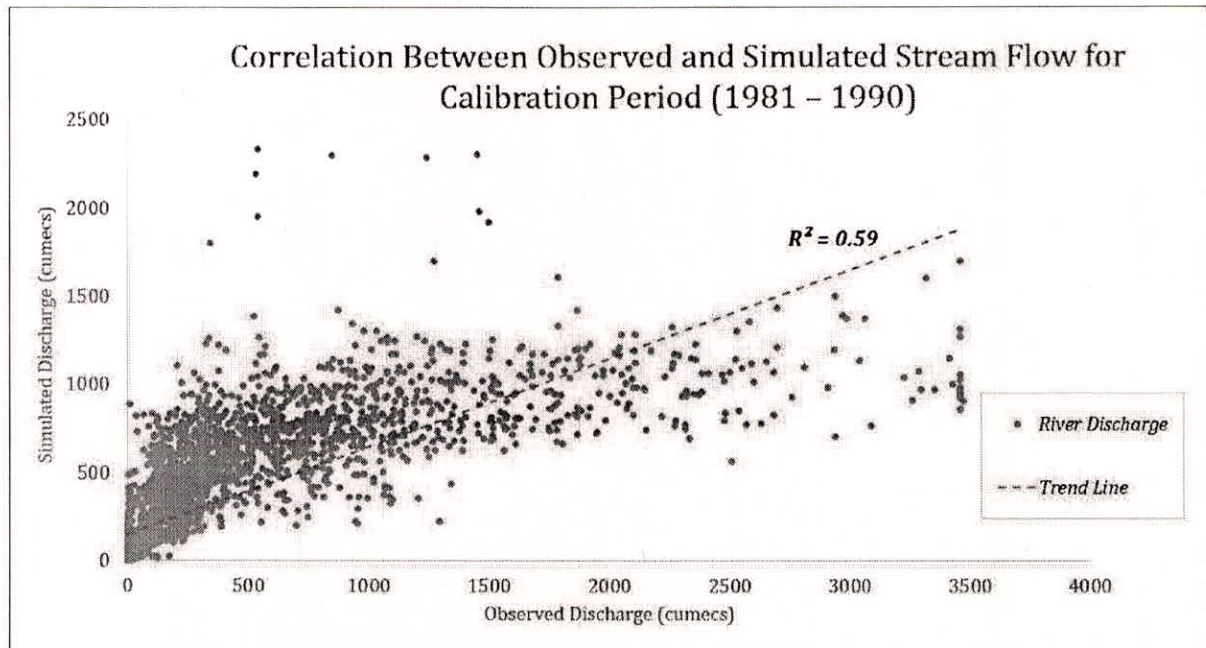
Calibration and Validation of SWAT model are two essential process in this hydrological modelling. After achieving the objective function for calibration, validation of the model was followed. In the current study the Arc SWAT model has simulated on daily basis for the year of 1981 to 1990. The calibration was performed for the same year using discharge data recorded at the outlet of the study area which is Bantwal. The model has calibrated based on several parameters like available water content (AWC) and soil evaporation compensation factor (ESCO) and some others. The details of these parameters are given in *Table 9*. Many simulations have been conducted till the time the best simulated flow was obtained. In order to check the efficiency of the model, the simulated and observed discharge value have been compared with coefficient of determination (R^2) and Nash & Sutcliffe efficiency index (NSE).

The time series of observed and simulated discharge value have been compared graphically on the daily basis. The calibration period denoted the coefficient of determination (R^2) of 0.59 for daily results. On the other side Nash & Sutcliffe has been found 0.57.

Fig 6: Daily flow calibration plot (SUFI-2) using SWAT-CUP for the period of 1981-1990



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Fig 7: Correlation between Observed and Simulated Stream Flow for Calibration Period

Source: Own Draft

Model Validation

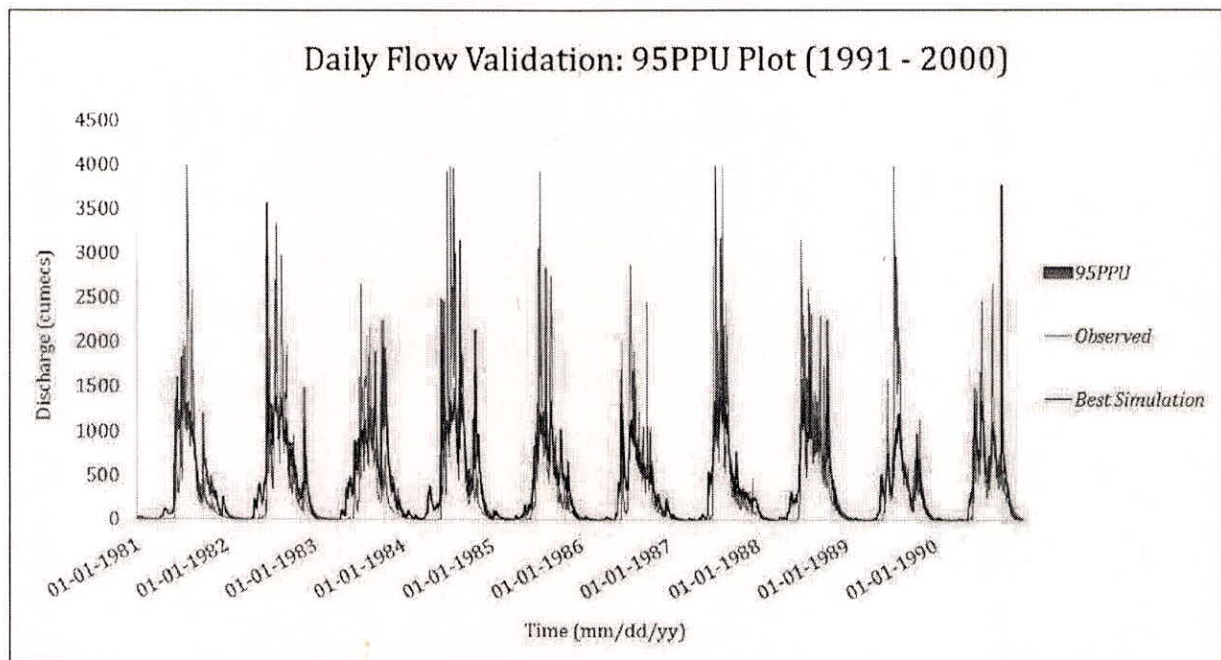
After completing calibration, the model was validated for the daily surface runoff from 1991 to 2000. Validation process is similar to calibration procedure. The model parameters values are assigned according to output of calibration. For the current study 500 iteration were carried out. The time series of observed and simulated discharge value have been compared graphically on the daily basis. The calibration period denoted the coefficient of determination (R^2) of 0.60 for daily results. On the other side Nash & Sutcliffe has been found 0.59.

Table 7: Model Evaluation Statistics of 95PPU plot (SUFI – 2)

Model Stage	Evaluation Statistics		
	R^2	p - factor	r - factor
SWAT Simulation (1981-1990)	0.39	-	-
Calibration (1981-1990)	0.59	0.33	0.09
Validation (1991-2000)	0.60	0.30	0.10

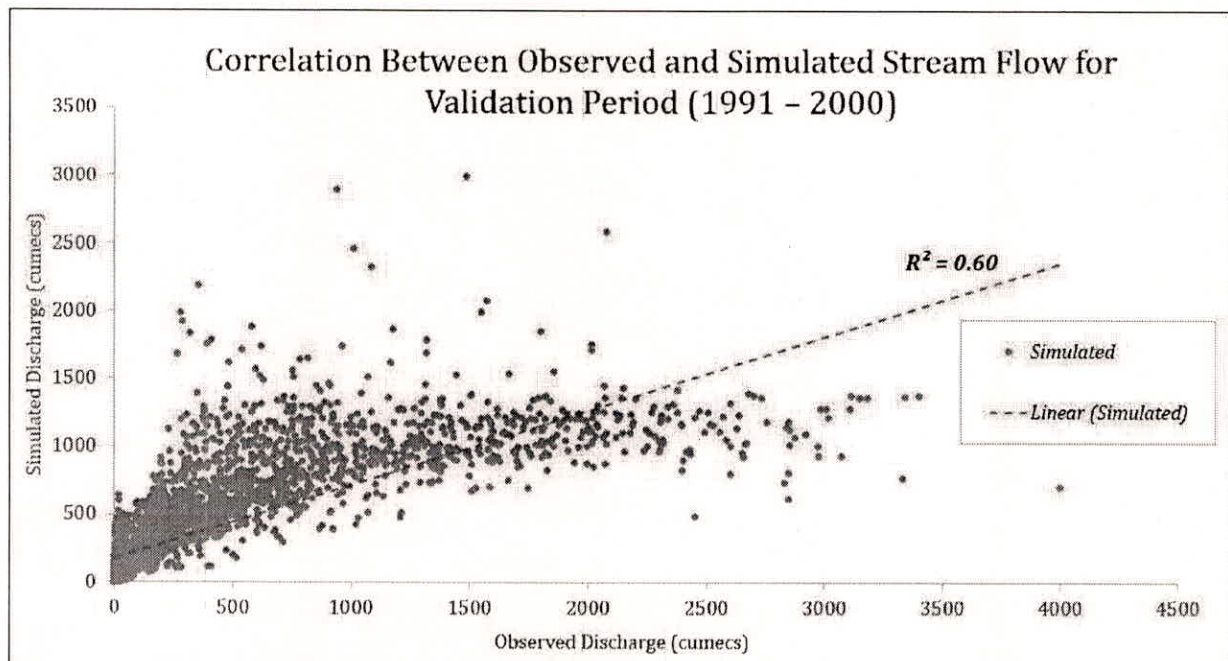
Source: Own Draft

Fig 8: Daily flow Validation plot (SUFI-2) using SWAT-CUP for the period of 1991-2000



Source: Own Draft

Fig 9: Correlation between Observed and Simulated Stream Flow for Validation Period



Source: Own Draft

Global Sensitivity Analysis

Before applying the validation technique, a sensitivity analysis was performed in order to find the most suitable model parameters. In SWAT-CUP, SUFI-2 method has been selected for the current study for parameter optimization to find out the key parameters that effect the runoff during calibration. Global sensitivity analysis has been done to determine the sensitive parameters in the study. Two statistical tests have been measured to find out the sensitivity of the selected parameters namely P-value and t-Stat. The P - value measures the sensitivity of a parameter, on the other side t - Stat gives a measure of significance of sensitivity. The parameters were used to rank according to their sensitivity which influence of stream flow. The parameters are differ from one basin to another basin based on their geomorphology, therefore cannot accept any generalization status for model calibration (Gyamfi et al. 2015). The most sensitive parameters listed in *Table 11*. The SUFI-2 algorithm is in built within the SWAT calibration and SWAT-CUP environment. In SUFI-2 the goodness of calibration is measured on the basis of closeness of the P - value towards 0. 500 to 600 iteration is necessary to get the best threshold of the parameter in the simulation result (Singh et al, 2013). In the study however the efficiency has been measured including several statistical techniques likewise Nash-Sutcliffe (NSE) [Equation number 1], the coefficient of determination (R^2) [Equation number 2], percent bias (PBIAS) [Equation number 3], and RMSE observation standard deviation ratio (RSR) [Equation number 4] have been used to justify the efficiency of the model.

$$1. \quad NSE = 1 - \frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - Y^{obs, mean})^2}$$

$$2. \quad R^2 = \left[\frac{\sum_{i=1}^n (O_i - S_i)(S_i - \bar{S})}{\left(\sum_{i=1}^n (O_i - \bar{O})^2 \right)^{0.5} \left(\sum_{i=1}^n (S_i - \bar{S})^2 \right)^{0.5}} \right]^2$$

$$3. \quad PBIAS = \frac{\sum_{i=1}^n (O_i - S_i) \times 100}{\sum_{i=1}^n O_i}$$

$$4. \quad RSR = \frac{\sqrt{\sum_{i=1}^n (O_i - S_i)^2}}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

Where O_i = observed variable, S_i = simulated variable, $\bar{O}$ = mean of observed variable. $\bar{S}$ = mean of simulated variable, n = number of observation in the model.

The result of sensitivity analysis of parameter using SUFI-2 method is shown in Table x. For this current study 14 parameters have been used, 7 were found to be more sensitive to the stream flow depended on its t-Stat and p-value ($p < 0.00$). Sensitivity of a parameter is calculated based on the P - value, and significance of the parameter's sensitivity analysis is measured by t - Stat. A parameter with larger t-stats and smaller p-value considered as most sensitive parameter on the specific variable.

The sensitivity of a parameter has been ranked based on the SCS runoff curve number (CN2) on the stream flow. The sensitivity of a parameter varies with respect to land use and soil properties of the specific area. The other relative sensitive parameters ranges from 0.00 to 0.85 according to p-value, the parameters are CN2 (SCS runoff curve number), SOIL_K (Saturated hydraulic conductivity), RCHRG_DP (Deep aquifer percolation fraction), CH_K2 (Manning's n value for the main channel), ALPHA_BF (Base flow alpha factor or recession constant), ESCO (Soil evaporation compensation factor), GW_DELAY (Groundwater delay), SOL_AWC (Available soil water capacity), GW_REVAP (Groundwater "revap" coefficient), GWQMN (Threshold depths of water in the shallow aquifer required for return flow to occur), and REVAPMN (Threshold depths of water in the shallow aquifer required for "revap" to occur).

Table 8: Statistical evaluation during calibration and validation period

Model Stage	Evaluation Statistics			
	NSE	R ²	PBIAS (%)	RSR
Calibration (1981 - 1990)	0.57	0.59	6	0.68
Validation (1991 - 2000)	0.59	0.60	-3.1	0.64

Source: Own Draft

Table 9: List of Parameters used in SWAT Model for Parameterization

Parameters	Description	Units
Parameters governing surface water response		
CN2	SCS runoff curve number	none
ESCO	Soil evaporation compensation factor	none
SOL_AWC	Available soil water capacity	mm/mm
SOL_K	Saturated hydraulic conductivity	mm/h
CANMX	Maximum canopy storage	none
SURLAG	Surface runoff lag time	none

Parameters governing surface water response		
GW_REVAP	Groundwater "revap" coefficient	none
REVAPMN	Threshold depths of water in the shallow aquifer required for "revap" to occur	mm
GWQMN	Threshold depths of water in the shallow aquifer required for return flow to occur	mm
GW_DELAY	Groundwater delay	days
ALPHA_BF	Base flow alpha factor or recession constant	days
RCHRG_DP	Deep aquifer percolation fraction	none
Parameters governing surface basin response		
CH_K2	Effective hydraulic conductivity in main channel alluvium	mm/h
CH_N2	Manning's "n" value for the main channel	none

Source: Own Draft

Table 10: Eleven most sensitive parameters used in calibration of SWAT model

Parameter Name	Fitted Value	Max Value	Min Value
R_CN2.mgt	-0.585701	-0.382372	-0.595282
V_ALPHA_BF.gw	0.476534	0.600000	0.435159
V_GW_DELAY.gw	12.076519	20.010794	11.025205
V_SURLAG.bsn	15.666898	16.262394	9.417607
V_CH_K2.rte	67.007690	70.162003	64.458000
V_ESCO.hru	0.470753	0.502596	0.167404
V_GWQMN.gw	0.984317	1.707199	0.568802
V_REVAPMN.gw	438.211975	468.513916	405.516113
R_SOL_K().sol	-0.448186	-0.248839	-0.642029
V_CANMX.hru	83.237923	91.340958	74.971191
V_CH_N2.rte	0.297060	0.442854	0.254246
R_SOL_AWC().sol	0.292470	0.400000	0.275400
V_RCHRG_DP.gw	0.002028	0.026975	0.000005
V_GW_REVAP.gw	0.116921	0.138836	0.009164

Source: Own Draft

P - value and t - Stat

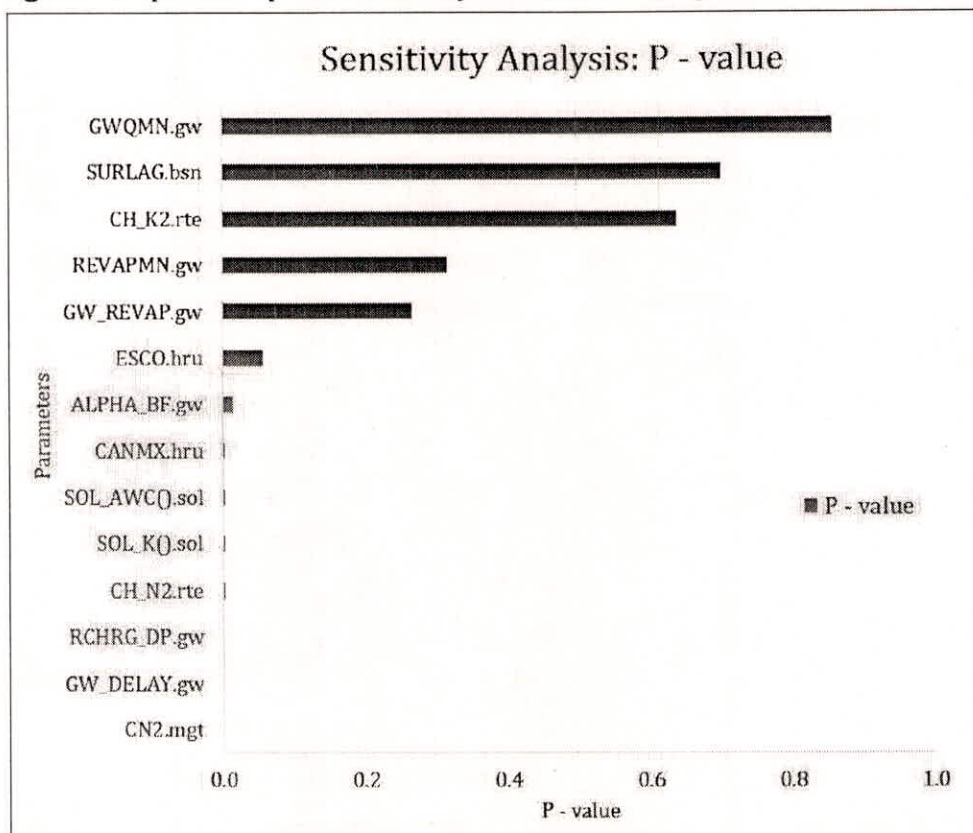
The *P* - value is defined as the probability, under the null hypothesis of obtaining a result equal to or more extreme than what was actually observed. *P* - value closer to zero means that parameters are more sensitive. Smaller the *P* - value, the larger the significance. A *t* - Statistics is commonly used to determine whether the mean of a population significantly differs from the mean of another population. The *t* - Stat measures the size of the difference relative to the variation in your sample data. It can be either positive as well as negative.

Table 11: Sensitivity ranking of parameters for modelling stream flow in Bantwal Watershed

Parameter	Sensitivity Ranking	t-Stat	P-Value
CN2.mgt	1	-54.081367322	0.000000000
GW_DELAY.gw	2	-45.750916620	0.000000000
RCHRG_DP.gw	3	-9.020525302	0.000000000
CH_N2.rte	4	4.252301858	0.000025392
SOL_K().sol	5	3.918123455	0.000102060
SOL_AWC().sol	6	3.853486371	0.000132103
CANMX.hru	7	3.035257226	0.002532464
ALPHA_BF.gw	8	-2.464822528	0.014053592
ESCO.hru	9	-1.916354559	0.055907416
GW_REVAP.gw	10	1.113756478	0.265935326
REVAPMN.gw	11	-1.005043198	0.315377208
CH_K2.rte	12	0.470415919	0.638269365
SURLAG.bsn	13	0.383714561	0.701358171
GWQMN.gw	14	0.179574274	0.857561801

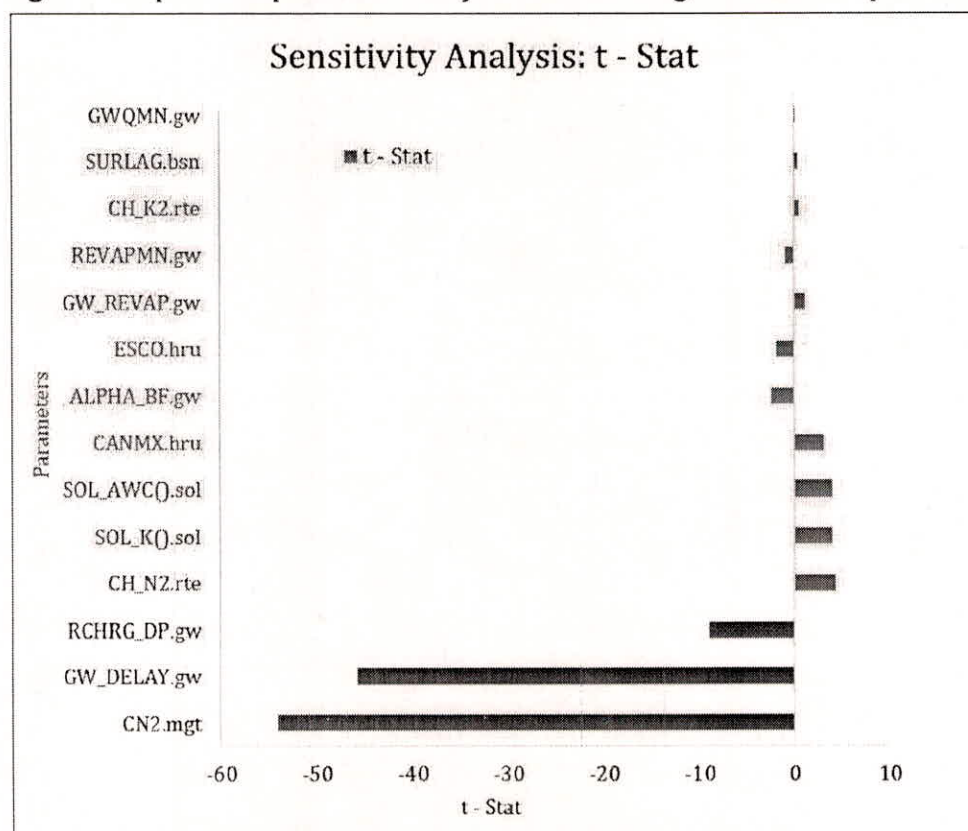
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Fig 10: Graphical representation of P - value showing the sensitive parameters



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Fig 11: Graphical representation of t - Stat showing the sensitive parameters



Source: Own Draft

Estimation of water balance for Bantwal watershed

By using Arc SWAT, mean annual water balance for the study area has been simulated for the year of 1981 to 2000. The water balance components for calibration and validation period are shown in *Table 12*.

The process of SWAT simulation is depend on water balance equation $SW_t = SW_o + \sum_{i=1}^N (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$. Where SW_t is the final soil water content (mm H₂O), SW_o is the initial soil water content (mm H₂O), t time in days, R_{day} amount of precipitation on day i (mm H₂O), Q_{surf} the amount of surface runoff on day i (mm H₂O), E_a the amount of evapotranspiration on day i (mm H₂O), W_{seep} the amount of percolation and bypass existing in the soil profile bottom on day i (mm H₂O), and Q_{gw} is the amount of return flow on day i (mm H₂O). The Bantwal watershed receives 3933.4 mm precipitation annually out of this 232.4 mm takes place in evapotranspiration process. The water budget component and their ratio are shown in *Table 13*.

Table 12: Annual water balance for the Bantwal watershed

Annual Basin	Calibration (1981 – 1990)	Validation (1991 – 2000)
PRECIP	3613.90 mm	4252.90 mm
SURFACE RUNOFF Q	55.19 mm	75.77 mm
LATERAL SOIL Q	1172.95 mm	1388.07 mm
GROUNDWATER (SHALAQ) Q	1817.52 mm	2152.12 mm
DEEP AQ RECHARGE	29.25 mm	34.78 mm
TOTAL AQ RECHARGE	1846.76 mm	2186.71 mm
TOTAL WATER YLD	3074.74 mm	3650.74 mm
PERCOLATION OUT OF SOIL	1846.75 mm	2186.29 mm
ET	539.30 mm	603.60 mm
PET	1265.90 mm	1280.60 mm

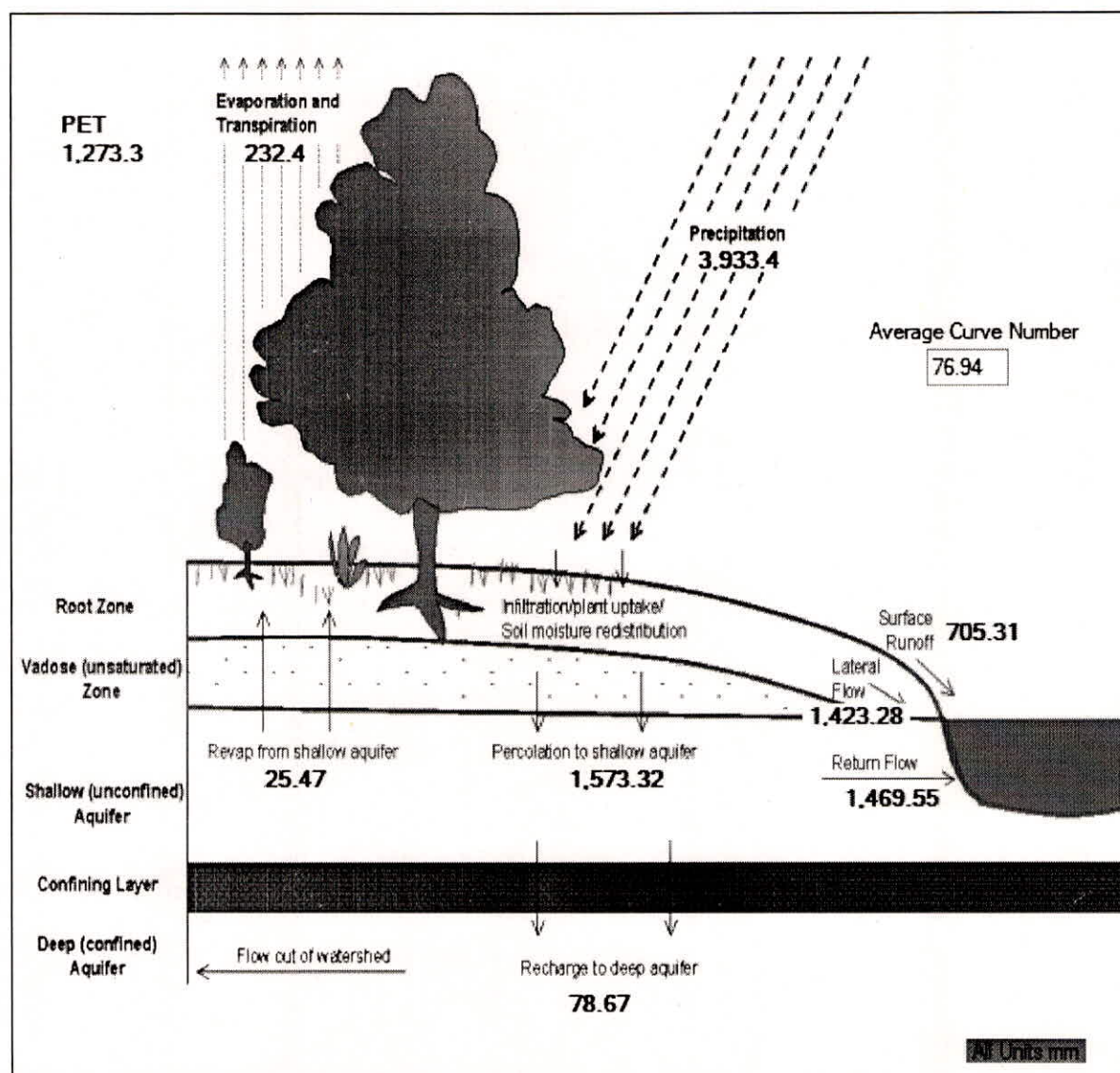
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Table 13: hydrological water balance ratio

Hydrological water balance ratio	
Stream flow/precipitation	0.91
Base flow/total flow	0.8
Surface run-off/total flow	0.2
Percolation/precipitation	0.4
Deep recharge/precipitation	0.02
ET/precipitation	0.06

Source: Own Draft

Fig 12: Pictorial diagram of water balance by SWAT Check (1981 – 2000)



Source: Own Draft

Summary

The stream flow for the Netravati River from Bantwal was simulated using Arc SWAT 2012. The inputs data were collected from different sources. The data was prepared using software's like Arc GIS, ERDAS and Microsoft Excel. The watershed was delineated from DEM using automatic watershed delineator. Inlet/Outlet were defined and six sub basins were created. Landuse, slope, and soil classification map was used to create hydrological response units. HRU is spatially uniform area in terms of soils, land use, and topography. The daily water budget in each HRU is computed based on daily precipitation, runoff, Evapotranspiration, percolation, and return flow from the subsurface and ground water flow. Based on the present Landuse and Climatic conditions, river discharge was simulated for the year 1979 to 1990 from which, two years were considered as warm-up period. For simulation output the coefficient of determination (R^2) was used for performance evaluation. R^2 of 0.39 was obtained from initial simulation of 10 years.

Calibration was performed for the same year using SUFI-2 in SWAT CUP. SUFI-2 is one of the procedures in SWAT-CUP which is effective but need more iterations as well as modification of the parameter ranges for better results. These methods are flexible allowing users to adopt different measures and objective functions. SUFI-2 methods have been used in the present study. The sensitive parameters were found after performing various iterations. The most sensitive parameters for the simulation having P-value close to 0.0 of stream flow includes CN2, GW_DELAY, RCHRG_DP, CH_N2, SOL_K, SOL_AWC, CANMX, ALPHA_BF and ESCO.

SWAT model has been calibrated and validated to examine its applicability for simulating daily basis data. For this study the model set up has been arranged for 22 years (1979-2000), the first 2 years were considered as the warm up period of the model. Out of these 28 years, 1 years (1981-1990) were used for calibration and next 10 years (1991-2000) for validation of model. As a simulation output the coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) were used for performance evaluation. For calibration period, R^2 of 0.59 and NSE of 0.57 and for validation period, R^2 of 0.60 and NSE of 0.59 were achieved. It shows that model performance was good. As per water balance study, Precipitation, surface runoff, evapotranspiration and various other variables were calculated for the calibration as well as validation period (Fig 12). However, the results of water balance study could be improved by improving the quality of the input data.

SWAT model can be used for various purposes which can simulate the response of basin in a given circumstances. River Basin is a complex system and is difficult to simulate because of uncertainties. SWAT model uses empirical formulas along with spatial datasets to reduce errors in simulating basin response and is widely accepted.

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Learnings

- **Work experience**

Working environment is one factor that affects the most in any workplace. The working environment in the National Institute of Hydrology is good. The working time for employees was 9am to 6pm. I got the opportunity to work in Remote Sensing and Geoinformatics laboratory. It was a working environment where all researchers were busy on their respective projects. We get to learn from the experiences shared by the researchers, scientists. There were workshops going on various topics which we could attend. All employees were friendly and helpful. If there was any problem, scientists were helpful. Problems will arise in any project, but we should try to solve and give our best before asking for help.

- **Academic and scientific experience**

I was interested in learning about Glaciers from past few years. During this internship period, I got the opportunity to work under the scientist who was expert in glaciology. This field was totally new to me and had to learn a lot. Though due to lack of time the field work was not possible, I learnt about basics of glaciers, geomorphology of glaciated regions, behavior of glaciers to climate change, etc. There was enough reading material to gain the domain knowledge. Along with study of glaciers, I also got to learn about Soil and Water Assessment Tool (SWAT). SWAT model is used to simulate various things in the basin. I used swat to simulate runoff of river (River Discharge). The main thing in research is the skill of reasoning. If we change our way of thinking, many questions will arise in our minds. While trying to solve those questions, we come across many new things to learn. This is a good institute for any students who want to learn.

- **Social and cultural experience**

Roorkee is a small town and is developing gradually. The people in Roorkee are good and helpful. It is mainly developing because of IIT. The environment inside and outside IIT is totally different. The place is safe and peaceful in terms of living conditions. The neighborhood was good and people were friendly and helpful. Most of the people living here are Hindus and are very religious. Haridwar and Rishikesh are two religious places nearby Roorkee.