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Method for mass balance

In 2002, International workshop has been organized in Chhota Shigri glacier by the help of International Commission on Snow and Ice (ICSI)-UNESCO HKH-Friend program with objective of monitoring the mass balance of mountain glaciers. During that program we became familiar with mass balance by glaciological method. There are many methods for mass balance measurement but usually under limited economic conditions, mass balance of Chhota Shigri glacier for present study was based on direct glaciological method (Paterson, 1994). This method is less expensive, provides better accuracy and based on in situ measurements. It is also widely accepted throughout the world. Basic principle of this method is to calculate mass balance by evaluating ablation and accumulation. In the ablation area, ablation is determined from stakes inserted in ice down to 10 m (approximately) deep and in the accumulation area; cores are drilled to measure annual net accumulation from snow layering (stratigraphy) and density measurements. A number of individual points the change in surface level (ablation/accumulation) is measured between two same dates in consecutive year. The difference in level (gain or loss), multiplied by near surface density, provide an estimate of the mass balance at that point. The overall specific annual mass balance $B$ is calculated according to:

$$B = \sum b_i \left( \frac{s_i}{S} \right)$$

where, $B$ is overall specific annual mass balance of glacier, $b_i$ is the mass balance of the altitudinal range $i$ of area $s_i$ and $S$ is the total glacier surface.

Since 2003 annual mass balance measurements have been carried out on Chhota Shigri Glacier Part -B at the end of September to beginning of October. The number of ablation stakes has progressively increased from 6 stakes in 2003 between 4600 and 4900m a.m.s.l. along the flow line of the part-B, 9 stakes in 2004 between 4600 and 5200m a.m.s.l. and 13 stakes in 2005 between 4600 and 5200m a.m.s.l. distributed along the B (Fig4.1, 4.2 & 4.3).
Fig. 4.1 Map showing installed stake position in 2003 on the Chhota Shigri glacier, part-B
Fig. 4.2 Map showing installed stake position in 2004 on the Chhota Shigri glacier, part-B
Fig. 4.3 Map showing installed stake position in 2005 on the Chhota Shigri glacier, part-B
One ablation stakes are located on the debris-covered part of the glacier Part-B. In the accumulation area, between 5200 and 5500m a.m.s.l. Recco avalanche reflectors together with blue powder spread out over a 2m² surface are used to mark a reference level easily recognizable the following year while drilling. During the year 2004-2005, accumulation was high, so 2-3 additional accumulation pits were dug on parts B between 4900 and 5500m a.m.s.l. (fig.4.2 & 4.3). In 2006, no accumulation measurements were carried out above 5500m a.m.s.l. due to a dangerous access (crevasses). At 5400m a.m.s.l., the accumulation site is poorly representative due to avalanche occurrence, and blue reference level was never found again during drilling. Ice density is taken constant at 900 kg m⁻³ and snow densities are systematically measured in the field.

**4.1 Procedure to mass balance study**

Following are the steps of mass balance study by Glaciological method.

**4.1.1 Selection of suitable glacier for mass balance investigations:**

Selection of suitable glacier done by investigating the norms necessary for ideal glacier (bench mark glacier), which are set by the International Commission of Snow and Ice (ICSI) the norms are

- The size of glacier is neither too small nor too large; it should be approximately 5km².
- The glaciers must have enough altitude range (approximately 1000m) to detect ELA variability.
- The catchments area of the glaciers must be well defined thus snow feeding to glaciers be clearly well defined. It should not connect to another glaciers and even the accumulation area not border by ice covered steep rock wall.
- The geometry of the glaciers must be simple to eliminate the complication of the fieldwork and analysis. A glacier with one well defined accumulation area and one tongue should be chosen.
- Mechanical processes such as avalanches and calving must be insignificant, its create difficulties in mass balance calculation.
- Glaciers should be free of debris cover or low debris cover.
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- Glaciers surface should be quite uniform and smooth (less crevassed area) to avoid safety problems.
- The access to glacier should be easy and safe to continue smooth working and even safety purposes in any case of injuries or health problems.

In practice all these requirements are hard to meet but they should be considered as guidelines. Chhota Shigri glacier fulfilled the above requirements so it was chosen for the mass balance study.

4.1.2 Ablation measurement:

As mention above, in the ablation area, ablation is determined from stakes inserted in ice down to 10 m (approximately) deep. So firstly we need to select what kind of stake we use for this purpose, second selection of site in the glacier to install the ablation stakes to know the ablation.

4.1.2.1 Selection of ablation stakes to install in the glacier

For ablation greater than 0.5 m/year sectioned stake is needed. In present study we used bamboo stakes due to they are easily available, strong, and resistant to weather; even have low thermal conductivity and low weight. They are also inexpensive.

4.1.2.2 Selection of sites in the glaciers to install the ablation stakes

Statistical analysis from a variety of studies agrees that 10-15 ablation stakes are sufficient to estimate a glacier’s mass balance, independently from the size of the glacier (Fountain and Vecchia, 1999). For small alpine glaciers, stakes are typically placed in a pattern that provides a more or less even distribution of points over the surface (Ostrem and Brugman, 1991). A useful distribution is on a longitudinal axis along the central flow line of the glacier. even many glaciers, ablation stakes are distributed more or less regularly over the ablation area with no particular structure.

Before placing the stakes into the glacier the stakes were numbered using a knife. The stakes which has go to first through drilled hole was marked by one (in roman digit), second one with two (in roman digit), third with three (in roman digit) and so on. We also put stake no. on each stake for e.g. stake no.5 has four stakes section so each section numbered 5 and I.III.IV and so on. Even we locate ring on all same year stakes to identify the same year stakes. These marks were made in order to locate the number of stakes easily while taking the second reading after the ablation season. After marking the stakes the stakes were accordingly tied together properly with metallic wire (Fig 4.4 and Fig 4.5).
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Fig. 4.4 showing tiding of stakes in the field
Fig. 4.5 showing falling of stakes in the field
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Plate 4.1 Stake installed on debris cover area of Chhota Shigri glacier, part-B

Plate 4.2 Installing stakes on upper ablation zone of Chhota Shigri glacier, part-B
4.1.2.3 Drilling to install ablation stakes

To installing the stakes into the glacier bed a light portable steam driven ice drill suitable for drilling holes in ice and firm (Heucke, 1999). So we used this steam drill to install the stakes in present study. The working pressure of this drill is between 0.7-1.7 bars. The boiler capacity is 4.4 litre. Basic principal of working of steam drill is release vapour of water with pressure to melt ice or firm to create hole. Prior to drill, $3/4^{th}$ of the boiler filled with water and connects the hosepipe. The boiler was allowed to heat up until pressure reached up to 2 bars. The drilling pipe was held perpendicular to the snow/ice surface (to avoid the tilting of the hole) and the vapour valve was released slowly. As soon as the vapour was released the drilling pipe started drilling the surface. When desired depth was acquired, the drilling pipe was pulled out. The depth of the holes for the stakes depends on the magnitude of the expected ablation. At last pre connected numbered stakes were put into the holes.

4.1.2.4 Reading of ablation stakes

For net ablation measurement the length of the stakes (L) from the free end to the surface is measured at two successive dates (t1, t2). The depth of snow over ice surface is also measured. The difference between exposed stake length at t1 and t2 dates $L (t2)-L (t1)$ plus difference of snow depth at t1 and t2 dates, gives the net ice ablation at this point.

Following are the steps to take readings

1. Depth of the snow was measured by pre calibrated steel rod. The rod were held perpendicular to snow surface and forced to penetrate into the snow till the ice layer was reached. It gives thickness of the snow at that point. Reading of snow depth was taken 4-5 points around ablation stakes. Average of this reading is used for calculation.
2. Free end to ice was measured by adding the exposed portion of stake and snow depth.
3. Free end to snow measured by only exposed part of the stakes from snow surface.

4.1.3 Accumulation measurements

In the accumulation area cores are drilled to measure annual net accumulation from snow layering (stratigraphy) and density measurements. Same as ablation area firstly we need to select site for digging pits to know the accumulation on that point then we calculate snow density.
4.1.3.1 Selecting of sites for digging pits to identification of previous year layers

Generally 3-4 measuring points are suggested. The location of accumulation measurements must represent a possibly large surrounding area. These points with depth and density measurements are complemented by spatially extensive depth information from probing.

4.1.3.2. Net accumulation is determined in respect to a previous surface position.

Accumulation stakes was installed with a piece of tape marking the level of the surface prior to accumulation seasons. Markers fixed on stakes are buried by the accumulated snow. It was found by digging a snow pit. This pit was also used for the density measurements. Sometimes the previous year surface might be difficult to distinguish. In such cases dyed dark saw dust sprinkle over a large area around accumulation stakes. When digging a snow pit at the stakes the following year, the saw dust easily distinguished and the previous surface positively identified.

4.1.3.3. Digging of pit

The pit should be dug without disturbing overlying snow cover. The size of the snow pit and its shape depends on the expected depth. The deepest point of the pit should be a square approximately 0.5X0.5 m to provide sufficient room for density measurements and stratigraphy observations. All the walls of pit must be kept perpendicular and continuous to minimise error in accumulation and density measurements.

4.1.3.4. Snow density measurement

Snow samples were collected by means of steel cylinder of 20.5 cm length and 5.64 cm of inner diameter (known length and diameter). While collecting snow samples the steel cylinder was kept slightly outside the periphery of the pit. While taking out samples of snow by the cylinder the snow was neither compressed nor was it allowed to escape in order to avoid the errors in snow density measurement. The extra snow that leaped over the cylinder was carefully scraped off with a shovel. Finally the snow samples were transferred into a pre-weighted plastic bag and weigh it by use of a sensitive spring balance. To avoid the errors in the measurement spring balance was kept away from the direct influence of wind in the field.
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The mass (M) of the snow is given by spring balance reading. The density of the snow was then calculated by use of formula that given below

\[ \rho = \frac{M}{V} \]

Where \( \rho \) is density of snow, \( M \) is weighted mass of snow and \( V \) is volume of cylinder.

4.2 Calculation for mass balance

The overall specific annual mass balance \( B \) is calculated according to:

\[ B = \sum_i \left( \frac{b_i}{s_i} \right) S \]

Where, \( b_i \) is the mass balance of the altitudinal range \( i \) of map area \( s_i \) and \( S \) is the total glacier map area. For each altitudinal range, \( b_i \) is obtained from the corresponding stake readings or net accumulation measurements.

4.3 Demarcation of the stake’s position

To calculate the annual surface velocities of the glacier and even to know the accurate location of each stakes in the glacier we used differential global positioning system (DGPS – Ashtek ProMark II). The accuracy in x, y and z is ±0.3 m except for some stakes of the lower ablation zone where it is ±1 m due to low sky-view factor (narrow valley).

4.4 Installation of automatic weather station (AWS)

To determine the meteorological parameters Automatic weather station (AWS) Model-352 was installed on the Chhota Shigri glacier at 32° 15.7’ N and 77° 31.7’ E having an altitude of 4343m a.m.s.l. The AWS observation was half hourly with an integration time of 10 seconds. Unfortunately this AWS works only one year, during the field of 2nd and 3rd year it was not functioning.

4.5. Discharge measurement

Here discharge is measured by velocity area method.

4.5.1 Selection of site for discharge measurement (discharge site)

Discharge site should be plane (low gradients) and also free from high turbulence water flow.
4.5.2 Cross sectional area measurements

To determine the cross sectional area of the channel at the gauging site, the depth of the channel was observed at the interval of 0.5m or 1.0m by a heavy measuring iron or other metallic rod. The very low temper and high velocity of the flowing water hurdle to take cross-sectional area only two or three. By help of depth of channel data river profile (channel profile) is created at discharge site.

4.5.3 Velocity measurement by float-method

The surface velocity of stream was measured by using wooden floats of the dimension 8X8X2 cm and 10X10X2 cm. The float observation were taken at three place in same line right, central and left in the stream and even repeated twice or thrice to obtain accuracy in the velocity measurement of the flow. During 2003, velocity was measured by current-meter, Swoffer model 3000 (only 6 days) as well as by float method for the same gauge reading. Although by float method we can measure only surface velocity of stream. The surface velocity showed a good agreement for both the methods. However as the current meter developed a malfunction, on the 7th day in 2003, so onward reading of surface velocity is only taken by float method for the same gauge reading. In 2004 and 2005 reading of surface velocity is only taken by float method. Continuous measurement of discharge is not feasible so only three time discharge data are collected here morning, afternoon and evening. At every time water level is measured.

4.6 Computation of discharge

The discharge is computed by product of cross-sectional area and average velocity of the flow.

\[ Q_t = A \times V_t \]

where \( Q_t \) is discharge at time \( t \), \( A \) is cross-sectional area and \( V_t \) is velocity of stream at time \( t \).

Chemistry for snow, ice and meltwater

For hydrochemical study the systematic sampling of surface snow surface ice and meltwater was done during 2003, 2004, and 2005 from the Chhota shigri glacier. Samples were collected from different points of glacier. The sampling location was given in figure (fig.4.6, 4.7 & 4.8). Sampling and analytical procedures for snow, ice and melting water are discussed as following:
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4.7 Sampling Methods
Snow and ice samples: Snow and ice samples were collected in polythene bags and after melting transferred into cleaned polythene bottles. Prior to each fieldwork polythene bottles were washed in the laboratory with dilute HCL and rinsed twice –thrice with distilled water.

Melt water samples: water samples also collected into cleaned polythene bottles. At the sampling sites bottles were rinsed with melt water before collection of water samples. About 250ml water samples were collected from each sites. Sampling was done for three successive year 2003, 2004 and 2005 to study the variation of solute load and chemistry.

4.8 Analytical Methods
Separation of suspended sediments
Suspended sediments were separated from the water samples in the laboratory by using 0.45 micro millipore membrane filters of 47mm diameter. Vacuum pump was used for accelerate the filtration. Weight of sediments calculated by subtracting the weight of filter papers which were taken before filtration into weight of filter papers which were taken after filtration. Before taking the weight of sediment on the filter paper, it was kept for one week in desiccators to remove moisture from the sediment. Volume of the samples was measured by glass measuring cylinder. Total suspended matter was calculated for one litre water samples from the volume of filtered water and the weight of the sediment.

pH
pH of all samples were measured by Consort microcomputer(P-307) ion meter. Before measuring the pH of samples the electrode was immersed for 10 hours in 0.1N HCl to make it stable. After rinsing the electrode with distilled water the instrument was calibrated with buffer solutions of pH 4.0 and 9.2. The samples were stirred well during measurement for homogeneity.

Electrical Conductivity (EC)
Electrical conductivity (EC) was measured by using Pentex EC meter. It measured EC by a cell consisting of two platinum electrodes to which an alternative potential is applied. The corresponding is proportional to conductivity of the ionic solution in which the cell is applied. For EC measurement the instrument was calibrated and set for 0.01 KCL standard. The conductivity was measured in µS/cm (micro siemens per centimetre) for all samples.
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Bicarbonate

Bicarbonate was determined by following potentiometric titration method. Standards of HCO₃ were prepared for required concentration from chemical salt NaHCO₃. 50 ml of each standard and samples were titrated against 0.006 N HCl, pH 4.5 is taken as the end point of the reaction. A graph was plotted for standard concentrations against the volume of HCl consumed. The concentration of the samples was determined from the graph plotted for standards.

Chloride

Chloride ion concentration was measured by the mercury (II) thiocynate method (Florence and Ferrar 1970). The method involves the reaction of chloride with mercury(II) thiocynate to form chloromercurate(II) complex ion, with the liberation of thiocynate ions, which then react with iron (III) to give the light red colour. 20 ml of each standard and samples were pipetted out into a 25ml volumetric flask. 2ml of iron(III)nitratre regent (prepared by dissolving 15.1 gm of Fe(NO₃)3.9H₂O in 45 ml of 72% perchloric acid and diluted to 100ml with distilled water) and 2ml of mercury thiocynate (saturated solution in ethanol) was added and total volume made to 25ml with distilled water. After mixing well, solution poured into the absorbance cell of the spectrophotometer and reading was taken against a regent blank at 460nm after 5 minute and the chloride concentration was estimated by comparing reading with calibration curve prepared by carrying chloride standard through the entire procedure.

Sulphate

Sulphate concentration was measured by turbidimetric method (APHA 1985). The method is based on the principle that SO₄ is precipitated in an acetic medium with barium chloride (BaCl₂), so as to form barium sulphate crystal of uniform size. Light absorbance barium sulphate suspension is measured by UV/VIS spectrophotometer at 420 nm and the concentration is determined by comparing the reading with standard curve. 100ml of standard and samples were measured in a volumetric flask and 20ml of buffer solution (prepared by dissolving 30 gm of MgCl₂.6H₂O, 5gm of sodium acetate, 1gm of potassium nitrate and 0.111 gm of sodium sulphate and 20ml of acetic acid in 500 ml of distilled water and then the total volume was made up to 1000ml) was added and mixed with the help of magnetic stirrer. While stirring a spoonful of BaCl₂ crystal was added. This was stirred for 60 seconds with constant speed. After the stirring period, solution was poured into the absorbance cell of the photometer and absorbance reading was taken at 420nm after 5 minutes. Sulphate concentration was determined by comparing reading with calibration curve prepared by carrying sulphate standard through the entire procedure.
Fig. 4.6: Sampling location of surface snow, surface ice in 2003
Fig. 4.7: Sampling location of surface snow, surface ice and meltwater in 2004
Fig. 4.8: Sampling location of surface snow, surface ice and meltwater in 2005
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Dissolve Silica

The dissolve silica was determined by molybdsilicate method (APHA 1985). 20 ml of each standard and samples were pipette out into a 100 ml volumetric flask and 10 ml of ammonium molybdate solution (prepared by dissolving 2 gm of ammonium molybdate in 10 ml distilled water and 6 ml of concentrated HCl and volume was made to 100 ml) and 15 ml of reducing agent (prepared by mixing 100 ml of metol sulphite solution, 60 ml 10% oxalic acid and 120 ml of 25% H₂SO₄ and the volume was made up to 300 ml) were added. The samples were stirred well and kept for three hours to complete the reaction. The optical density was measured for standard and water samples at 812 nm by using UV/VIS spectrophotometer.

Phosphate

Phosphate was determined by the ascorbic acid method (APHA 1985). Phosphate standard solution of different concentration was prepared from the potassium di-hydrogen phosphate (KH₂PO₄). 40 ml of each standard and samples were pipette out into a 50 ml volumetric flask and 5 ml of molybdate antimony solution and 2 ml of ascorbic acid solution was added and mixed well. The mixture was diluted to 50 ml and absorbance was measured at 640 nm using UV/VIS spectrophotometer. Molybdate solution was prepared by dissolving 4.8 gm of ammonium molybdate and 0.1 gm of sodium antimony titrate in 400 ml of 4 N sulphuric acid and making the total volume to 500 ml; with the same acid. Ascorbic acid was prepared by dissolving 2 gm of ascorbic acid in 100 ml water.

Nitrate

Nitrate concentration in water samples was determined by brucine-sulphanilic acid method. The method is based on the reaction of the nitrate ion with brucine sulphate 13 N H₂SO₄ solutions at a temperature of 100 degree centigrade. The colour of resulting complex is measured at 410 nm. 10 ml of standard and samples were pipetted out into a 50 ml tube. 10 ml of 13 N H₂SO₄ solution was added to each tube with swirling and allowed tubes to come to thermal equilibrium the cold bath 0.5 ml brucine-sulphanilic regent (prepared by dissolving 1.0 gm brucine sulphate and 0.1 gm sulphanilic acid in 70 ml hot distilled water, 0.3 ml of HCl was added to this solution and volume made to 100 ml with distilled water) was added to each tube and mixed thoroughly. The tube rack was then kept in water bath at 100°C for 25
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minutes. After that tubes were removed from the water bath and allowed to reach room temperature and the absorbance was measured at 410 nm against regent blank.

Ca$^{2+}$, Mg$^{2+}$, Na$^+$ and K$^+$

The content of major cations calcium, magnesium, sodium and potassium was determined on GBC 906 atomic spectrophotometer (AAS). Calcium and magnesium concentration was determined in absorbance mode and sodium and potassium in emission mode.