Remeasuring Annapurna I: Geospatial Innovation and the Quest for Precision

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ABSTRACT

Mount Annapurna I, the world's tenth-highest peak and a geographic jewel of Nepal, has long captivated scientists, mountaineers, and mapmakers. Despite its significance, the mountain's officially recognized elevation- 8,091 meters—has been derived from legacy survey that vary in accuracy and methodology. In light of recent advances in geodetic science, tectonic shifts, and climate-induced landscape changes, a modern remeasurement of Annapurna I is both timely and necessary. This article explores the historical context of its elevation estimates, the scientific and technological rationale for remeasurement, and the broader geophysical, cartographic, and cultural implications. It argues that a new measurement campaign, leveraging Global Navigation Satellite System (GNSS), satellite gravimetry, and aerial photogrammetry, would enhance national geospatial data infrastructure, support environmental monitoring, and reaffirm Annapurna's place in global geoscientific research.

1. INTRODUCTION

Situated in the North-central region of Nepal, Mount *Annapurna I* is the tenth-highest mountain in the world. (Hutchinson, 2020). *Annapurna I* is the only peak which is above 8000 meters in the 55 kilometers long Annapurna Massif (Shrestha, 2021) which contains 13 peaks above 7000 meters and 16 peaks above 6000 meters (Discovery World Trekking, n.d.). It is also one of the most dangerous mountain because of changing terrain, violent windstorms, and frequent avalanches (Firth et al., 2008). *Annapurna I* was named after hindu goddess of food and nourishment (Nepal Himal Peak Profile, n.d.). The word *Annapurna I*s derived from Sanskrit word where Anna means food and purna means 'filled with'. Therefore, the designation can be interpreted as "The Deity Abundant in Nourishment" or, in simpler terms, as "The Supplier" (Baume, 1978).

Figure 1: Mt. Annapurna I from North Base Camp (Photo: Nima Rinji Sherpa, youngest and fastest climber of all 8,000-meter peaks.)

Although 10th highest in the world and the 8th highest mountain of Nepal, it is one of the most well-known mountains. *Annapurna I* is located within the Annapurna Conservation Area Nepal largest protected region, covering 7929 Km^2 (NTNC, n.d.) one of the regions of Nepal attracting hordes of trekkers from all around the world. Despite its fame among mountaineers for being one of the most dangerous peaks to climb, its precise elevation has long been taken for granted (Prajwalol, 2023). In the face of advancing geodetic technology, increased tectonic activity in the region, and the growing need for accurate geospatial data (KC & Acharya, 2022), re-measuring Annapurna has become a matter of geodetic pride and scientific necessity.

2. EXPEDITIONS IN ANNAPURNA

Maurice Herzog and Louis Lachenal successfully summited Annapurna I on June 3, 1950, marking the first ascent of an 8,000-meter peak (Huey & Eguskitza, 2001). Sherpa climber Ang Tharke was the Guide for this expedition. However, Tharke couldn't make it to the summit because of frostbite at the last camp (Herzog, 1951).

This achievement was a significant milestone in the history of mountaineering. Herzog later wrote a book titled "Annapurna" detailing their expedition, the challenges they faced, and the triumph of reaching the summit. The success on Annapurna I was a remarkable feat in the early exploration of high-altitude peaks.

Sonam Wolang Sherpa made history as the first Nepali to make it to the peak of Annapurna I on October 13, 1977. Till 2022 summer 407 summiteers (some of them repeated scale) have successfully scaled this mountain. (Department of Tourism, 2023, 335)

Annapurna I is notorious as the 'Killer Mountain' due to its challenging ascent (NCESC, n.d.). The Himalaya Database reveals a daunting statistic—1 in 4 climbers attempting to scale the mountain have perished. In the 2021 season, over 50 climbers conquered the peak, bringing joy as, remarkably, no fatalities occurred among the successful ascents that year. (Himalayan Database, 2021). In recent years, the fatality rate has decreased owing to factors such as sophisticated climbing equipment, tools, and accurate weather forecasts.

Recent expeditions have increasingly incorporated geodetic instruments such as handheld GNSS receivers and altimeters, though these are often limited in accuracy. What remains missing is a comprehensive, scientifically robust remeasurement campaign that integrates modern surveying techniques with high-altitude logistics. A well-equipped expedition, combining professional mountaineers and geodetic experts, could yield critical data not only for validating Annapurna's current elevation but also for understanding how tectonic and climatic forces continue to reshape this iconic massif.

3. FROM BATTLE TO TRIANGULATION

The British rulers, understanding the importance of safeguarding and expanding their colonies, knew the significance of having a plan. Whether for development or waging wars, a map was deemed essential. This awareness became more pronounced after the East India Company lost three wars with Haider Ali, the King of Mysore, and his son Tipu Sultan between 1767 and 1791 AD. The British, resorting to various conspiracies and diplomatic maneuvers, launched another attack on Mysore in 1798 after exploring different strategies. After a long, bloody battle in 1799, they successfully unfurled the British flag in Mysore (Kochhar, 2013. After the victory over Mysore in 1799, the Britishers reflected on the reasons behind their repeated defeats in previous wars. They concluded that their defeats resulted from waging wars without organized plans. Recognizing the importance of a map, they understood that organized warfare was challenging without one.

For this, in May 1799, Lord Sir Richard Belesli ordered Lieutenant Colonel William Lambton to survey and prepare a map of India. Lambton was also a surveyor and an Army officer injured in the Mysore war. The British also wanted to know how much land they had conquered following the victory over the Mysore war. Following the lord's order, Lambton commenced planning for the map, working on astronomical observation. Lambton came up with a plan within seven months by November, which the lord approved. With this, some basic works of surveys had also been completed by then. He eventually started the geographical and mathematical survey after three years in 1802 AD (Roy, 1986). It was during this survey that it was known that Annapurna I towered over 8000 meters. The record shows that the peak was initially registered in the field book as Peak XXXIX.

4. ANNAPURNA I-THE PEAK XXXIX

On April 10, 1802, the British formally commenced the trigonometrical survey with the measurement of the baseline, spanning 12.1 kilometers along the Madras seashore (present-day Chennai). From 1818, it was officially named the Great Trigonometrical Survey of India (Kumar, 2012). It was headed by Colonel William Lambton. Thanks to this mega-project, many of the highest mountains of Nepal including Sagarmatha (Mt. Everest) were identified as the world's highest peak.

During the British rule, the surveyors of Survey of India conducted trigonometric surveys and mapping the Himalaya from the Chomolhari Himal in Bhutan to Nanda Devi in Garhwal, covering 79 major peaks to determine their positions and elevations (Phillimore, 1958). As the local names of all the Himalayan peaks were not known, they temporarily named them using Roman numerals. Just like the world's highest peak was called peak XV, Annapurna I was referred to as Peak XXXIX in Roman numerals. The calculation of Annapurna I elevation from sea level, performed at the East India Survey Department headquarters in Dehradun, showed it to be 26,492 feet (8,075 meters) tall (Tilman 1951). This standard was established by triangulation stations at eight points near the Nepal-India border. The long distance and the length of the summit range made it harder to accurately pinpoint the exact position. In trigonometric surveys, the precision of height measurement relies on accurately gauging the distance from the observation point to the summit.

It was only known after a very long time that the Peak XXXIX, which the British surveyors had measured, was actually *Annapurna I*. Later, in 1929, the British Survey of India prepared the map of this region in the scale of 1 inch to 4 miles, and that map showed *Annapurna I*'s elevation as 8078 meters. However, in the 1963 map, the peak's elevation is noted as 8,091 meters.

Table 1: Table 1: List of Mountain peak with coordinate and height. Source: Burrard, S. G., & Hayden, H. H. (1908).

SN	Name of Peak	Ht in feet	Latitude	Longitude	Location
1	T^{45}	26867	28º5'32"	86º36'51"	Nepal Himalaya
2	Dhaulagiri	26795	28º41'48"	86º29'42"	Nepal Himalaya
3	XXX	26658	28º33'0"	84º33'43"	Nepal Himalaya
4	Naga parbat I	26620	35º14'21"	74º35'24"	Punjab Himalaya
5	XXXIX	26492	28º35'44"	84º49'19"	Nepal Himalaya
6	K^{6} or Gasherbrum I	26470	35º43'30"	76º41'48"	Karakoram
12	K^{4} or Gasherbrum II	26360	35º45'31"	76º39'15"	Karakoram
7	Gosainthan	26291	28º21'07"	85º46'55"	Nepal Himalaya
8	K^{3a} or Gasherbrum III	26090	35º45'36"	76º38'33"	Karakoram
9	XXXIV	26041	28º32'5"	84º7'26"	Nepal Himalaya
10	K^{3}or Gasherbrum IV	26000	35º45'38"	76º37'2"	Karakoram

(*The values of longitude are based upon the determination of the difference between Greenwich and Madras Made in 1894-96 and are not those hitherto accepted by Survey of India at that time)

5. PEAK ELEVATION: DILEMMA AND UNCERTAINTY

On July 5, 2023, Nature, the prestigious science journal based in the United Kingdom, published an article titled "Medieval Demise of a Himalayan Giant Summit Induced by Mega-Landslide."

The article asserts that no peak can rise beyond a point where it cannot maintain balance. This challenge to maintain balance often results in occasional slides of large boulders, the splitting of the peak, and erosion of rock. Emphasizing these effects, the author highlights the controversial nature of discussion over the height of peaks.

Likewise, the article suggests that a massive rock explosion caused by an earthquake in 1190 might have resulted in a reduction in the current height of Annapurna compared to the old summit. The article also states that the current peak was formed from the sliding of 23 square kilometers of rock located approximately 8 kilometers above sea level. The article claims that Annapurna, before the earthquake of 1190, was a few hundred meters higher than its current height (Lave et al., 2023)

The fact, as presented here in above mentioned article, prompts the question: was Annapurna higher than Mount Everest a thousand years ago than it is today? No one can say with certainty, but there is room for doubt.

There are grounds to speculate that changes in the form and height of Annapurna may have occurred due to far-reaching consequences brought forth by various mega-earthquakes and seismic activities around the mountain and in lower areas. This is also evident in the topography of Pokhara, its hills, and plains.

Initially, in the 1850s-60s, the Great Trigonometrical Survey (GTS) of India conducted observations near the Nepal-India border as determined by the Sugauli border treaty, concluding that *Annapurna I*'s elevation was above 8,000 meters. However, studies of subsequent surveys, including the GTS surveys and the field maps published by the Survey of India between 1929 to 1960, indicate some inconsistencies regarding the position and height of *Annapurna I.*

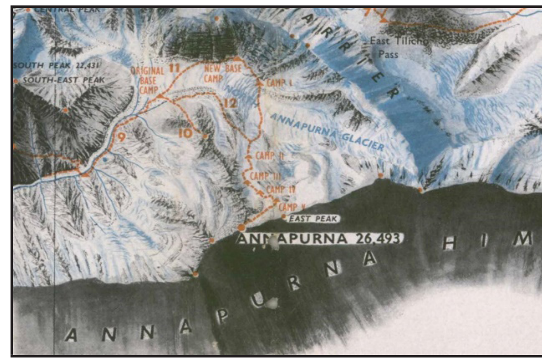

Figure 1: Map covering the Dhaulagiri and Annapurna I was published by France in 1952,

The peaks in the Annapurna Mountain range became the subject of scientific study for the first time around two centuries ago, which was also conducted by the Survey of India under British Empire (Sorkhabi, 2013).

The Survey of India prepared the map of the region for the first time in 1929 AD. The map mentioned 26,504 feet (8,078 meters) as the height of *Annapurna I*. As per the map, the peak was three meters taller than the height mentioned in the GTS survey.

Figure 2: The first topographical map of this region in 1929, based on a 1925/26 field survey, with a scale of 1 inch equal to 4 miles prepared the Survey of India prepared.

It can be seen that the elevation is different from the ones calculated by the Great Trigonometrical Survey. It can be understood that the field observation was an effort for greater accuracy in their data. Before making the map, the Survey of India had secretly sent their surveyors to various places in Nepal for field verification (Pradhananga, 2007), as Nepal is officially close to foreigner before 1950 (Adhikari, 2018)

Some books written on peaks above 8000 meters have also discussed the confusion and uncertainty on the part of the Survey of India regarding the exact height of Annapurna because the viewpoint for the triangulation survey was prone to errors due to distance and the need to cover a long mountain range for observation. 'To the Third Pole,' by Dyhrenfurth (1955), a book published in London in 1955, has delved into this issue. The book, translated from German to English, notes 8078 meters (26504 feet) as the height of *Annapurna I*. Here is an excerpt from Chapter Six of the book which states:

"The official readings of 26,811 feet (8172 metres) For Dhaulagiri and 26,504 feet (8078 metres) for Annapurna, are minima which probably need adjusting upwards by 130 to 170 feet." (Dyhrenfurth,1955)

The Survey of India, based on aerial surveys between December 1957 to June 1958 and subsequent ground verification (1959-60), published a map in 1963. On map sheet number 62 p/14, a point broadly identified as 'Annapurna Himal' is noted at 26545 feet (8091 meters). However, the map makes no mention of Annapurna I (Survey of India, 1963).

The map published by Nepal, following field verification in 2001, also lists the height of Annapurna I as 8091 meters. It is evident that Nepal's survey, considering the similarity in elevation and location details to our original map, may have derived the height from the Survey of India's map, even though the latter does not explicitly mention the name.

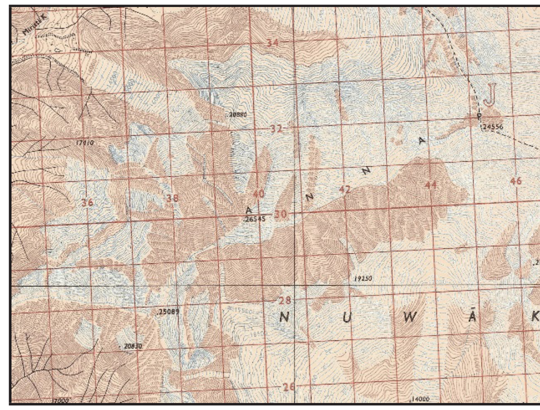

Figure 3: Map published by Survey of India in 1963 with the scale of 1 inch equal to 1 mile

In 2014, a specialized aircraft from the German Space Agency (DLR) was employed to create a digital elevation model and GIS map of the Annapurna range, covering area of radius 6 to 8 km. The primary objective was to assess the parameters of their newly developed three-dimensional aerial camera system, known as MACS (Modular Airborne Camera System).

The aim of DLR was to check the various parameters of the MACS aerial photogrammetric camera and to create different GIS products like a topographic map which can be helpful to study different topographical phenomena of the region like the study of landslide susceptibility as the region is most prone to landslide (KC, 2018).

Figure 4: Summit of Annapurna I (left) and Machhapuchhre (right,) in front DLR motorized glider with special 3D camera,

Some unofficial sources claim that the summit of Annapurna I stands at a height of 8097.47 meters, calculated from aerial photos taken from the special airplane, which needs further verification.

The base map of Nepal was prepared based on Indian topographical map series (Baidar et al., 2023). Except Mt Everest, the Survey Department has not conducted direct field observation to determine the elevations of any prominent mountains. Observing variations in the heights of Annapurna I over time, it's now crucial for us to conduct a detailed scientific study. This emphasizes the importance of accurately measuring the heights of all peaks, especially those exceeding 8,000 meters.

6. WHY REMEASUREMENT

The Annapurna region, despite being a popular Himalaya tourist destination, remains relatively underexplored in terms of comprehensive scientific research.

The Annapurna region, despite being a well-known destination for trekkers and climbers, remains relatively underexplored from a scientific research perspective. While numerous national and international institutions focus on accurately measuring the peak of Sagarmatha and surroundings, there is a notable lack of interest in measuring Annapurna I (Manandhar, 2017).

The region is famous for its stunning scenery and many tourists and scientists visit the region and are curious about the height of this peak. Conducting GNSS measurements not only provides accurate geo information and height but also significantly contributes to various Earth science research endeavors (Abdelazeem et al., 2024).

Annapurna range has large glaciers that are melting due to climate change which can cause the region prone to avalanches and landslides (Khadka et al., 2023). Geospatial and geodetic data collected from the Annapurna region are invaluable for research on tectonic activity and geohazards, as they provide critical insights into the region's structural evolution and seismic hazards (Bilham et al., 1997).

Past measurements relied on traditional surveying. Now there has been huge technical improvement in precision surveying. Using modern methods like GNSS improves the precision of measurement. GNSS gives precise position and ellipsoidal height. With the advancement in gravity measurement techniques from satellite, airborne and terrestrial, we now have access to high resolution and accurate gravity data which can be used to refine elevation with respect to mean sea level by creating geoid model. The accurate height measurement resolves the doubt in inconsistent previous measurements (Bolkas et al., 2016). This project not only determines the orthometric height of the peak but also contributes to enhancing the geodetic network in Nepal's Mid-Himalaya region around Pokhara City (Oli, 2007).

7. TECHNOLOGICAL METHODOLOGY

Height determination integrates precise ground GNSS surveys and applying corrections and geoid models for accurate elevation data. (Dangol et al., 2021). The proposed methodological framework should include the following components:

7.1 Review of Existing Horizontal and Vertical Control Networks and Gravity Data.

The proposed activity includes

- Densifying the existing network using modern GNSS and leveling instruments for both horizontal and vertical control points, as well as gravity points.
- Updating coordinates and evaluate shifts from tectonic activity, especially post-2015 Gorkha earthquake.

7.2 Establishment of CORS and GNSS Observation

Continuous Operating Reference Stations (CORS) station can be established and used as stable base station. These stations can provide a precise and stable reference framework for GNSS observations necessary for accurate coordinate determination.

7.3 Precise Levelling and Gravity Survey

The primary objective of this task is to establish accurate vertical control and define a precise local geoid model. Key activities include:

- Conducting precise leveling to transfer orthometric heights from existing leveling benchmarks to the CORS stations and perform trigonometric leveling using CORS as base station to provide independent validation.
- Carrying out dense and uniformly distributed relative gravity observations using relative gravimeter. The observations can be tied to the nearest absolute gravity station.
- Conducting GNSS observations at leveling benchmarks and gravity stations to for geoid determination.

7.4 Summit Observation

At least two surveyors will deploy high-precision GNSS instruments along with Ground Penetrating Radar (GPR) devices at the summit. An adequate number of reference stations will be established around the Annapurna Massif to ensure accurate summit positioning.

7.5 Data Processing Validation and Height Determination

CORS and GNSS data can be processed incorporating data from International GNSS Service (IGS) stations. The final precise height will be published following the completion of data processing.

Surface Gravity data can be processed and combined with airborne gravity data, Digital Terrain Model, and the Global Gravity Models (GGMs). Incorporating the latest GGM will further enhance the accuracy of the geoid model.

7.6 Photogrammetry and 3D Modeling

To know more details about summit morphology and to provide secondary reference for height estimation, 3D modelling can be conducted using aircraft or UAV.

8. COLLABORATORS AND STAKEHOLDERS

The success of re-measuring Mount Annapurna requires a **multi-disciplinary, cross-institutional partnership** involving expertise in **geodesy, remote sensing, climate science, mountaineering, and local government**. Key collaborators and stakeholders might be :

- Department of Tourism, the National Mountain Administration Agency of Nepal under Ministry of Culture, tourism and Civil Aviation.
- Ministry of Forest and Environment of Nepal.
- National/ international universities and research institutes.
- Space agencies (NASA, ESA, DLR)
- International Development Partners, given that Annapurna I was first climbed by a French expedition, there’s an interesting historical link that could be leveraged. The *Agence Française de Développement* (AFD) or other international development agencies might have interest in supporting scientific and cultural projects in Nepal. Also, we should collaborate with German Aerospace Centre (DLR), as they conducted aerial survey over Annapurna massif in 2014.

- Gandaki Providence
- Mountaineering and expedition agencies.
- Survey Equipment and Technology Providers such as Trimble, Leica, Geosystem,

9. EXPECTED OUTCOMES

Re-measuring Annapurna using state-of-the-art geodetic and remote sensing techniques will result in multiple scientific, cartographic, and societal benefits. The key expected outcomes include:

- **Accurate, Up-to-Date Elevation of the summit of Annapurna I**
- strengthening the geodetic network of the region.
- Scientific Insights into Tectonic and Climatic Processes,
- Improved National and Global Mapping Infrastructure,
- Capacity Building and Research Collaboration
- Long-Term Monitoring Framework
- Public Awareness and Educational Outreach.

10. OPPORTUNITIES AND CHALLENGES

Nepal's Survey Department measured Sagarmatha using its own resources, producing number of skilled geodesists. They gained experience with handy tools, and the department can complete this project efficiently. However, to materialize the idea, one of the important aspects is funding.

Opportunity and challenges are two sides of a coin. With every opportunity comes challenges. The most important and daunting challenge of this mission is to climb one of the technically challenging peaks, conduct summit observation, and gather accurate data. Other challenges include raising ample resources for the expedition, obtaining necessary gears and technological devices, managing the expenses required for manpower for ground survey, and addressing possible technical difficulties of working in harsh geographical areas.

It would be a matter of pride for the Survey department to measure Annapurna I, the first eight-thousand peak to be scaled—with its own human resources based on its own data.

11. CONCLUSION

Nepal is home to eight peaks towering above 8000 meters, which attract a significant number of foreign tourists every year. Among them, Annapurna I stands as an unparalleled gem in the realm of global mountaineering. While other countries in Asia also have mountains, Nepal’s peaks remain unmatched in their breathtaking beauty. Nepal’s mountains are not just natural wonders—they are cultural, economic, and geographic assets. Therefore, it is imperative to tell the world about these mountains, advertise their majestic beauty and explore various unknown and unexplored facts related to them.

Annapurna I is a mountain full of mysteries and suspense. Many world-renowned climbers come to Annapurna to climb the peak and seek glory. The peak also holds several environmental and religious importance. Despite its fame, Annapurna remains understudied in comparison to Everest and other Himalaya giants. Re-measuring Annapurna I is not just about correcting numbers—it's about deepening our understanding of Himalaya geology, climate impacts, and geohazards. Successful remeasurement not only gives precise height but the initiative contributes to broader geoscientific goals. It will refine regional geoid model, quantify crustal deformation, and bolster hazard assessment across Nepal’s central Himalaya. Ultimately, this work underscores the critical role of high-precision geodesy in supporting national development strategies and advancing global Earth observation efforts and inspiring future research in the region.

The study presents a comprehensive framework for the remeasurement of *Mount* Annapurna I, building upon the methodological precedent established during the recent Sagarmatha height measurement campaign completed in 2020. This study integrates cutting-edge geospatial technologies, such as GNSS, gravity observations, and precise leveling to improve the accuracy of topographic data in tectonically active regions.

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