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Ice Nucleation Under Climatically Changing Biotic and Abiotic Conditions in Himalayas: A Case Study of Naran, Mansehra District, Pakistan

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ABSTRACT

Water has grave significance in human life and ice nucleation and rain are the two biggest sources of fresh water. In climate changing variables like temperature and other abiotic factors parallel to biotics factors paly vital role in natural process including ice nucleation. In order to have deep insight of ice nucleation process a data of abiotic factors like temperature, pH, wind direction was not only assessed but synchronized with biotics factors by taking example of two commonly spread species (chir and Diar common names) in the study area. In the study, it is revealed that temperature variation impacts ice nucleation process by lowering temperature from -1°C to -10°C. Analyzing temperature data between 2002 to 2022 reveals cycles impacting environmental phenomenon and other climate dynamics. Experimental data shoes inverse relationship with number of frozen drops and temperature. It is observed that bacterial presence in the atmosphere increases probability of ice nucleation. GIS reports indicate snow direct relation with vegetation signifying presence of biotic factors for ice nucleation.

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1. Introduction

In water cycle, ice nucleation is pivotal role to play (Attard et al., 2012). Ice nucleation which is temperature-based process has other obligatory elements like bacterial presence which catalysis ice nucleation especially at warmer temperature but under -1°C (Finkelstein, 2020). Homogeneous (pure water) ice nucleation has potential to start in the range of -39°C or -40°C keeping other variable suitable for ice nucleation, where nearly 65 to 71 molecules are required. The production of energy at -5°C necessitates the participation of over 4000 pure water molecules (Wisniewski & Fuller, 1999). Ice nucleation, a phenomenon revealing behavior below 0°C, relate temperatures with biotic and biotic variability (Wisniewski & Fuller, 1999). The meteorologists and plant pathologists have been investigating evidences of role of biotic factors which unavoidable. This establishes a wonderful and permanent connection of ice nucleation and biotic factors in the form of vegetation which is responsible to provide ideal habitat to microbes needed for ice nucleation and rainfall (Wisniewski & Fuller, 1999). Noteworthy is the fact that all plants, regardless of their health status, harbor bacteria endowed with the capacity to catalyze ice formation, particularly in the temperature range of -3°C to -5°C (Wisniewski & Fuller, 1999). The new climatic trends show potential impacts on plants after change in temperature slight but constant increase. This has potential to change impact rainfall and snowfall. On an average, a leaf of plant can host 10^7 bacteria per sq cm.

Moreover, among the multitude of bacteria, totaling 10^{30}, find their temporary residence on plant surfaces, eventually becoming integral members of atmospheric aerosols leading to

contribute in the environment. Airborne bacterial cells, predominantly originating from plants and soil (Xie, Liu, Shao, Zhang, & Deng, 2020). Abiotic factors including temperature, suspended particulate matter, wind altitude, direction, ultra-violation and pH while biotic factors like bacterial Pseudomonas syringae which has catalyzation for ice nucleation (Kozloff, Schofield, & Lute, 1983; SUZUKI, Ito, FUSHIMI, & KoNDo, 1993; Xie et al., 2020). It was firstly investigated by the French meteorologist Soulage in his study, presence of bacterial cells in ice crystals. The investigation showed a deeper concept about ice nucleation activity, the pathogenic impact of Pseudomonas syringae on plants is and additional aspect to be investigated and kept in mind to take appropriate measures, and their intricate interplay with ice nucleation rates stand as pillars of significance of microbiology and ecological systems in biosphere. The evolving climate trends that reshape atmospheric variables, including precipitation and ice nucleation, constituting a primary water source in Pakistan.

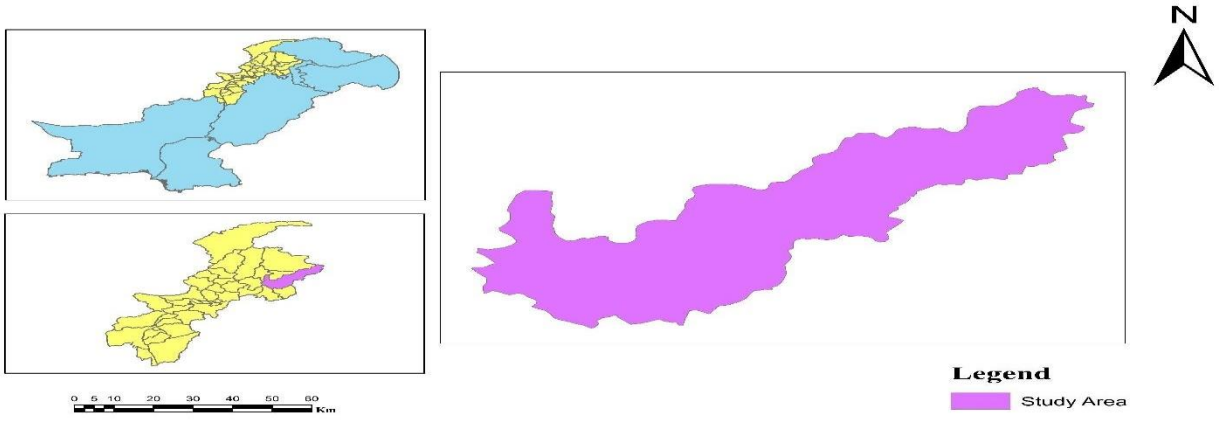
These dynamic changes continued research in atmosphere, indicating the factors that helps in ice nucleation, ensuring smooth water supply not only for agriculture but other domestic uses to have sustainable solutions in the region. The detail investigation of ice nucleation unfolds two distinct factors i. biological ii. non-biological. Recent research shows the formidable impact of biological factors on ice nucleation, leaving impacts on landscapes. In 1990, when aliphatic alcohol monolayers, boasting lattice dimensions of ice, were observed to support ice nucleation (Vali, 1996). Sub-zero temperatures unveil a chapter of plant resilience, as they face the stress of shallow temperatures, warns to dehydrative stress (Attard et al., 2012; Cochet & Widehem, 2000). The present study investigate to inquire the current happenings of ice nucleation and the relation between the Ice nucleation and the temperature and its changing climatic trends in the study area.

2. Material and Methodology

2.1. Study Area

Naran is part of Mansehra District which lies between 35.3247° N latitude and 73.1968° E longitude (Amjad, Kausar, Waqar, & Sarwar, 2019; Awan, 2011). The district's diverse topography contributes to its ecological significance. Preserving the natural environment, managing water resources, and mitigating the impact of natural hazards, given its proximity to earthquake-prone areas, are vital aspects of sustainable development in Mansehra (Ali et al., 2010). The focused area Naran was divided into three points called point 1, point 2 and point 3. Point is Naran city while point 2 is towards Babu Sar, it is nearly 10 km from Naran city. Point 3 which towards Babu sar and is nearly 20Km away from Naran. In this study, plant 1 which Cedrus deodara (common name Diar) and plant 2 which is Pinus roxburghii Sargent (botanical name) (Chir common name) were collected for sampling to identify role of biotics factor in ice nucleation.

Figure 1: Naran, Mansehra



2.2. Data Source

The image of Landsat 8 of year 2014 were acquired from the United State Geological Survey website. The temperature data of the study area were acquired from Pakistan Metrological Department website. Ten samples were taken from each of the following sources: soil, ice meltwater, rivers, streams, and sediments. From April 21 to April 25, 2023, 150 samples (50 samples from each point) were gathered from three designated locations inside

the study region. For more exact and accurate outcomes, this research project's steps were carried out five times.

2.3. Data Analysis

2.3.1. Normalized Difference Snow Index (NDSI)

The Normalized Difference Snow Index were used to calculate the snow area of the Naran District. The NDSI were calculated by the green band and SWIR band. Band 3 represent the green band in the Landsat 8 and Band 6 represent the SWIR band in the Landsat 8. The NDSI were calculated by the equation 1.

$$NDSI = (Green - SWIR) / (Green + SWIR) \quad (1)$$

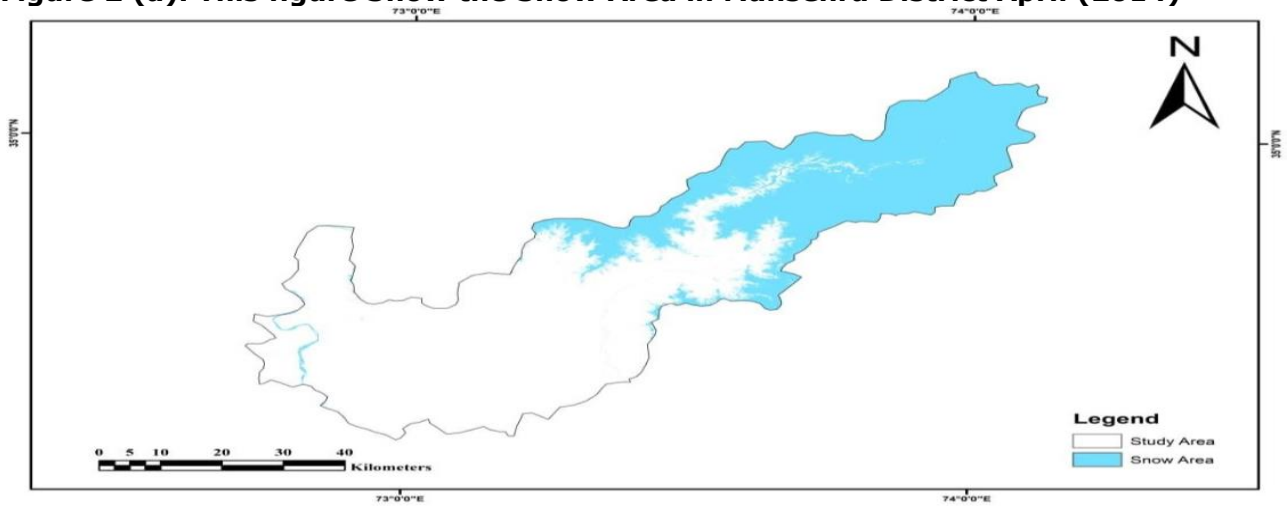
The NDSI used to monitor the Ice nucleation in the different areas and the NDSI gave the better results than the other spectral bands.

3. Results and Discussion

This comprehensive study establishes intricate relationship between temperature dynamics and the crucial phenomenon of ice nucleation. Also shows relation between biotic and abiotic impacts on ice nucleation. The temperature-related insights gained from this study have the potential to inform not only the understanding of ice nucleation processes but also contribute valuable data to climate studies, meteorological analyses, and ecosystem dynamics.

3.1. Results

Figure 2 (a). This figure Show the Snow Area in Mansehra District April (2014)



Mansehra District, like many other northern areas of Pakistan, experiences snowfall during the winter months. Winter in this region typically spans from November to February. The amount of snowfall can vary each year and is influenced by weather patterns. The snow-capped mountains and landscapes in Mansehra District can create picturesque scenes during the winter, attracting tourists and offering a unique experience for locals. The above figure show the snow area and we have also calculated the area of the snowfall which is spread over about 1700 sq.km. This also indicates that ice nucleation or snow is less where human settlement are more and human activity is also increasing with time.

Figure 2 (b): Vegetation at Naran, Mansehra

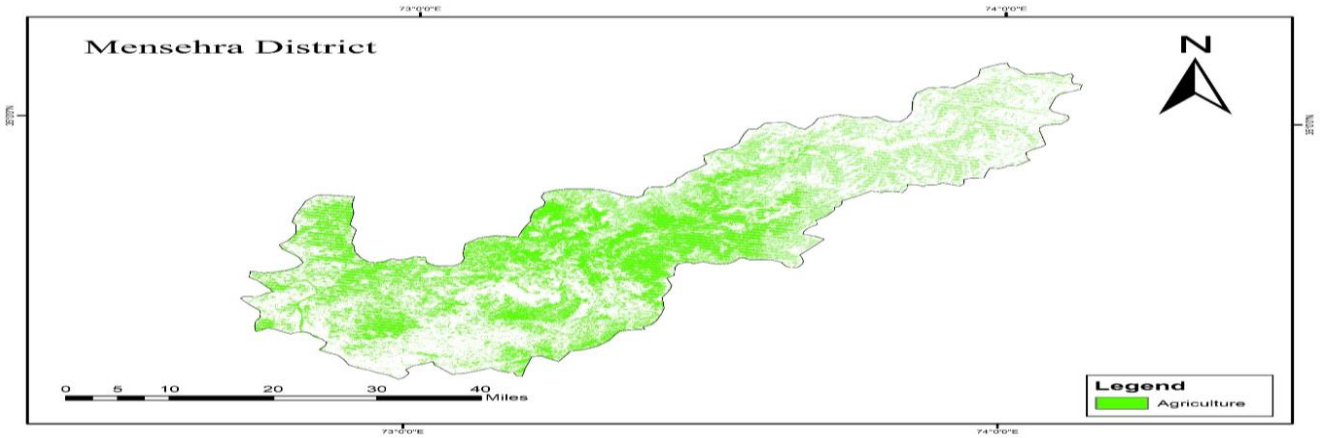
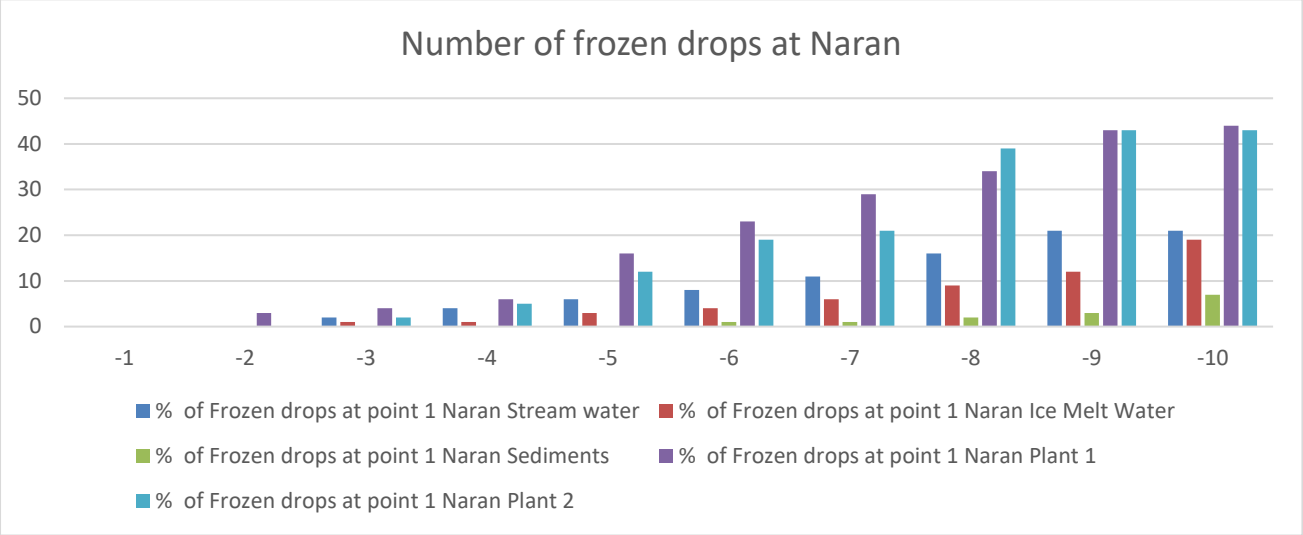


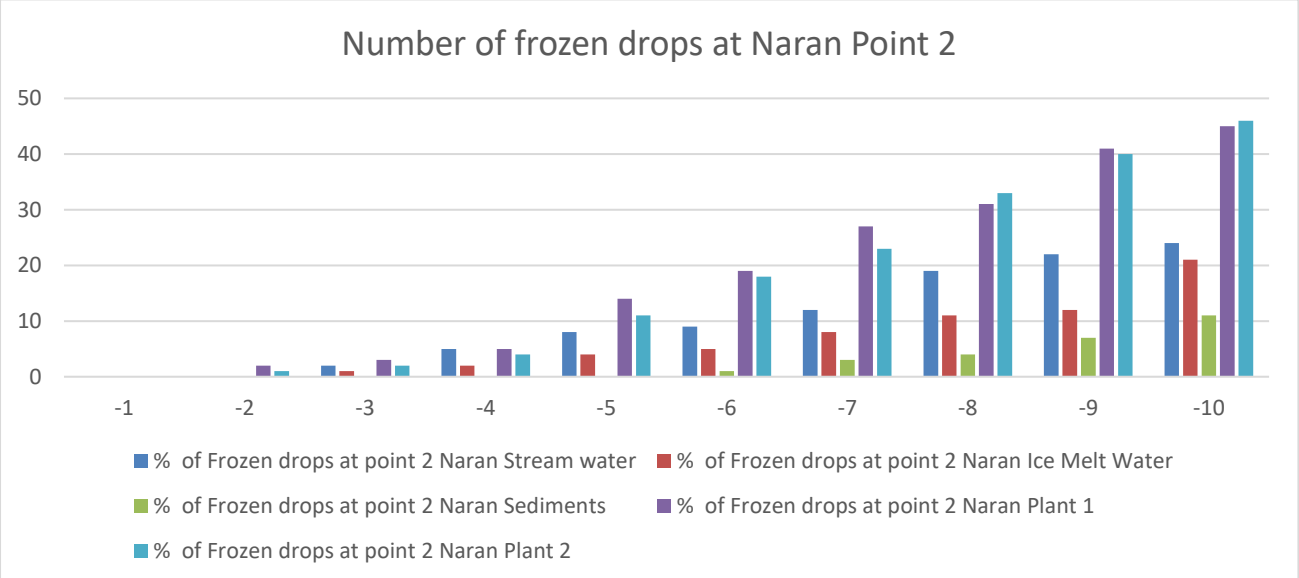
Figure 2b shows area covered by vegetation in the region. This shows vegetation is higher in the central part of the district. Figure 2a shown snow covered area. Snow covered area mostly where vegetation is less. More snowy area where human activity is less and altitude is higher from sea level. Anthropogenic impact is not only on ice nucleation but also on vegetation.

Figure 3: Number of frozen Drops Naran Point 1



The data shows connection of temperature changes with other biotic and abiotic factors in the study area and its ecosystem. The variables taken under discussion in the present study are variation in temperature, ice melt water, sediments, pH and bacterial presence on plant leaves. All said variables are tested to gauge impact on ice nucleation. The graph 3 shows interesting results in about temperature changes and number of freezing drops in different variables taken for the study. At warmer temperature like -2 degree freezing trends is observed only biotic factors. Plant 1 indicates freezing trend followed by other biotic and abiotic factors like ice melt water, stream water and two said plants. Freezing trend increases with comparatively less pace till -5 degree but exponential increase is observed in biotic factors from -5 to -10 degree. As compared to biotic factors a little less trend was observed in abiotic factors but still there was increasing trend in number of drops with lowering temperature.

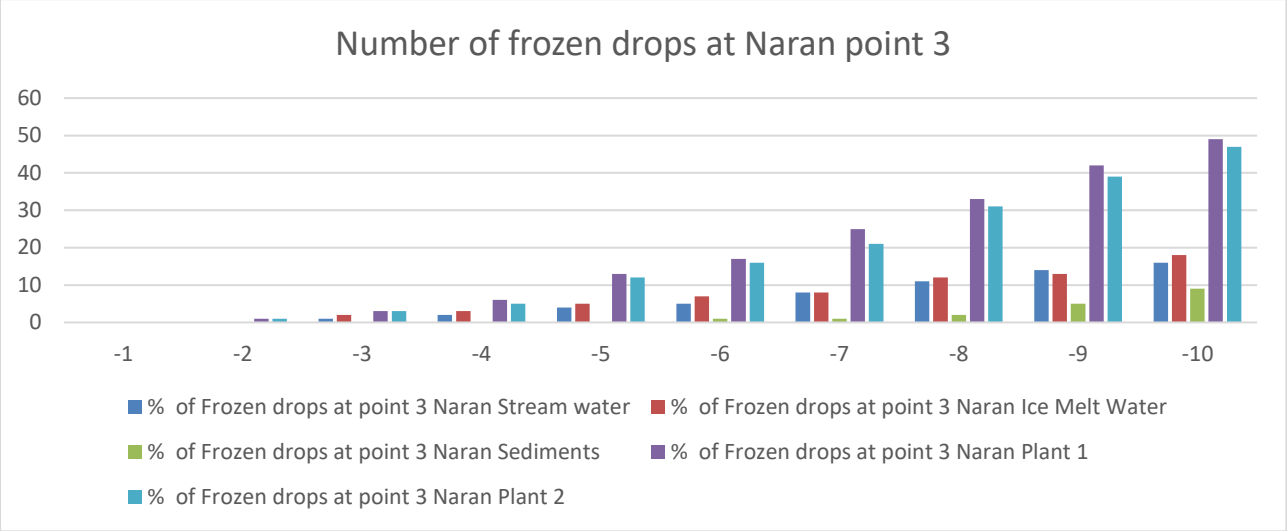
Figure 4: Shows the number of Frozen Drops at Point 2



At point 2 which is 10km from Naran, ice nucleation trend was same like point 1 which Naran city, at comparatively warmer temperature like -2-degree biotic samples showed freezing trends. This is established again that biotic factors start freezing earlier as compared to abiotic factors. The plant leaves having presence of bacterial presence showed freezing

quicker than other samples. With lowering temperature, ice nucleation trend increases in all the samples taken but biotic samples indicate ice nucleation trend higher with 50% number of drops. The least trend was observed in the samples collected from sediment. Sediments pH values and presence of other impurities have impact on number of freezing drops. This proves that presence of other elements in the samples can deeply impact the ice nucleation. To maintain ice nucleation happening at comparatively warmer temperature it is essential to adopt sustainable measures in future by taking care the such sites like Naran.

Figure 5: Shows the Frozen Drops Point 3



The graph above shows that plant 1 and plant 2 samples showed ice nucleation at warmer temperature like -2-degrees. Abiotic at such temperature does not show presence of ice nucleation. As temperature decreases, ice nucleation trend increases both in biotic and abiotic factors but biotic factors have exponential increase in number of frozen drops while abiotic factors have less trend but not zero. The least trend in abiotic at point 3 is sediments. This trend of number of frozen drops is even less than number of frozen drops at point 2. Presence of some potential environmental factors are playing role in decreasing number of frozen drops at point 3 which is 20 km away from Naran city.

Figure 6: Shows the mean Temperature Mansehra District (Temperature 2002-2022)

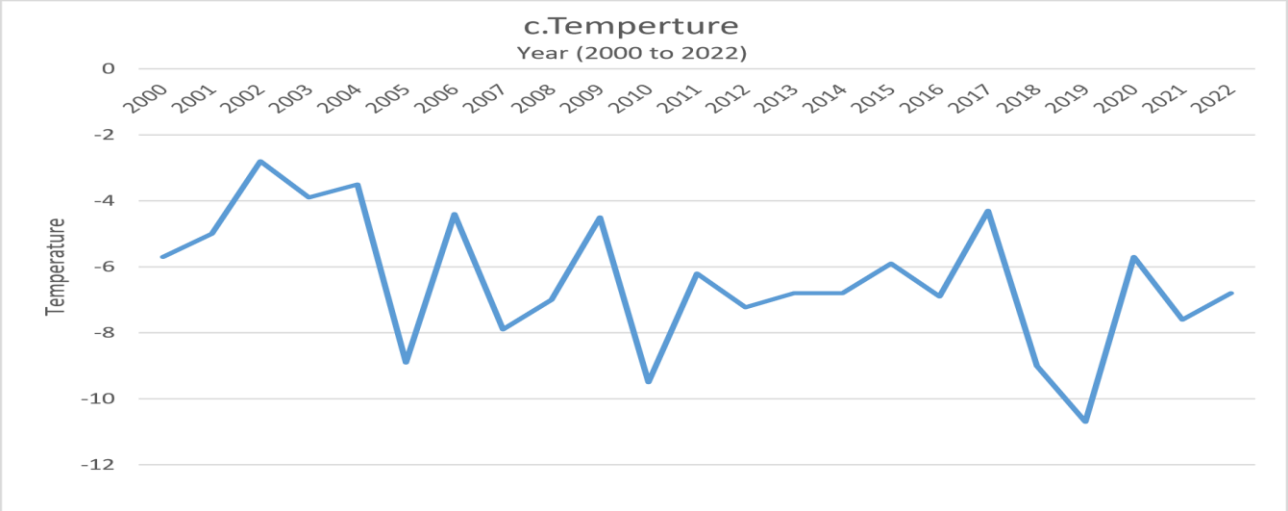


Figure 6 highlights specific years, such as 2006, 2011, and 2019, where the temperatures reach notable extremes of -8.5°C, -9°C, and -10.4°C, respectively. These instances of extremely low temperatures could have significant implications for local ecosystems, including potential impacts on vegetation, water bodies, and wildlife. Monitoring such extreme events is essential for assessing the vulnerability of the study area to temperature extremes. The temporal patterns of temperature depicted in the figure underscore the dynamic nature of the study area's climate. Year-to-year variations contribute to the overall

climate resilience, as ecosystems adapt to these fluctuations. However, understanding the drivers behind these temperature shifts is crucial for predicting long-term climate trends and their potential impacts on the environment. The data shown in the graph above is taken from one of the nearest weather stations situated at Skardu.

3.2. Correlation of Ice Nucleation and Temperature

The practical applications of these findings are profound to understand ice nucleation, particularly weather predictions. Armed with a nuanced comprehension of the temperature-frozen drop relationship, meteorologists can make more informed and precise forecasts, especially when it comes to frozen precipitation events during the winter months. for icy conditions on roads, and emergency responders can be more proactive in addressing challenges posed by frozen precipitation.

Figure 7: Shows the Correlation between Temperature and Frozen Point 1
Point 1

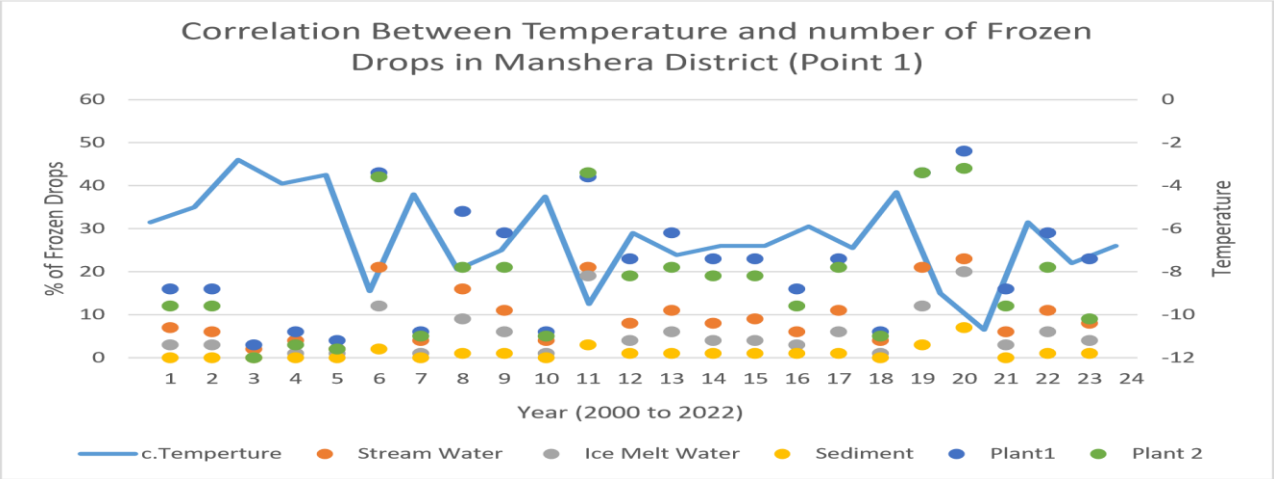
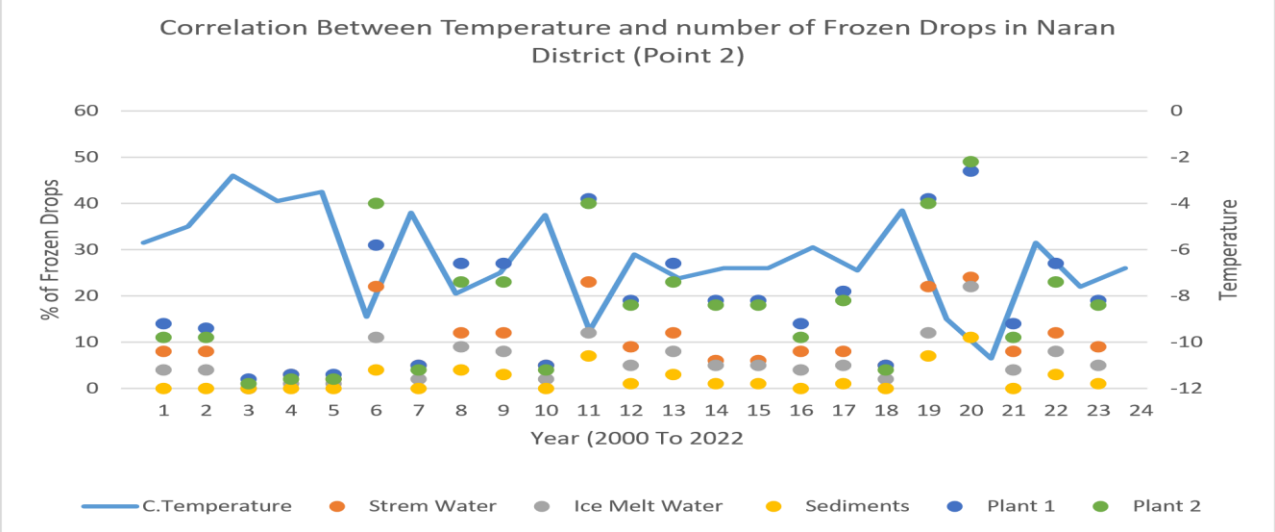
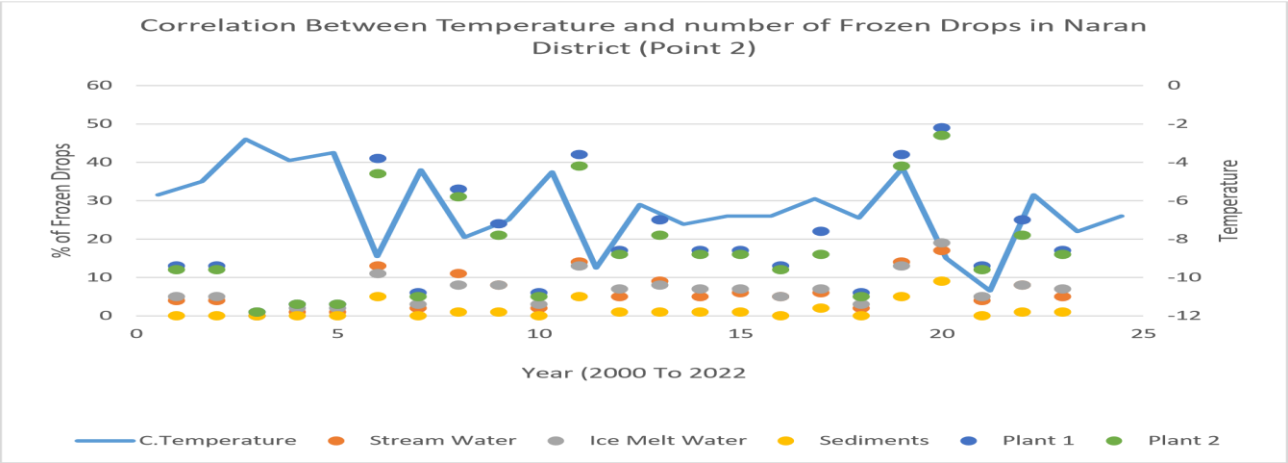


Figure 8: Shows the Correlation between Temperature and Frozen Point 2
Point 2



In the graph shown above I indicates correlation of temperature variation from 2000 to 2022 and number of frozen drops taken from stream water, ice melt water, sediments and two plants. Land surface temperature variation and number of frozen drops are inversely proportional to each other. In further observations, biotic factors have higher number of frozen drops than abiotic factors. Among abiotic factors, ice melt water and sediments samples showed less ice nucleation trends.

Figure 9: Shows the Correlation between Temperature and Frozen Point 3
Point 3



As point 3 which is nearly 20km away from Naran city and comparatively less human activities are observed. Looking at the correlation among the factors like plants, abiotic factors like sediments, ice melt water and stream water, similar pattern is observed like point 1 and point 2. Biotic factors have higher trends of ice nucleation than abiotic factors. This establishes that its urgent to understand and control environmental variability in the region for sustainable future of ice nucleation.

4. Conclusion

The dataset from three designated points within the stream ecosystem illustrates the resilience of the aquatic environment to temperature fluctuations. Despite variations, the ecosystem demonstrates stability, showcasing adaptability to changing temperatures. This resilience is critical for predicting the long-term impacts of climate change on biodiversity and ecosystems. While the primary focus is on ice nucleation, the study's implications extend to climate studies, meteorological analyses, and ecosystem dynamics. The insights achieved could inform our understanding of climate-ecosystem interactions, contributing valuable data for conservation and management strategies especially in the mountains. As climate trends evolve, evidenced by observed changing temperature patterns, there is a clear call for continued research. This study serves as a foundation, urging scientists to delve deeper into the ever-evolving dynamics of temperature and its environmental impacts. In the grand narrative of ice nucleation, where temperature guides and plants silently influence, this research adds a significant section to our understanding. As we navigate the intricate choreography of frozen drops, this study resonates, encouraging further exploration of all mysteries of our environment and adaptation to the changing rhythms of our climate in connection with ice nucleation. It is further added that abiotic factors at point 2 and point 3 have least freezing trend due to some unknown fact which must be identified in other research.

4.1. Recommendation

1. The study area is famous resort for tourists especially in summer which brings numerous factors to be investigated for sustainability.
2. Study area could be declared as a National Park, this will make sure to take appropriate measures for sustainability.
3. Research center could be established at Naran which would be responsible for take care climatic changes and their impacts.
4. At Naran, Weather station must be installed to take systematic data recordings of environmental changes.
5. There is need to investigate ice nucleation and altitude from sea level.

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