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Seasonal Distribution of Zygnemataceae and Mesotaenaceae Families of Algae at Site Joga of the Narmada River, Harda, MP, India

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ABSTRACT

The seasonal variation in algal growth was analy zed to understand the influence of environmental factors such as temperature, water turbulence, and nutrient availability on freshwater ecosystems. The study revealed that algal abundance was lowest during the monsoon season due to heavy rainfall, increased water currents, and nutrient dilution, with the lowest recorded values in June (30% abundance). Post-monsoon conditions facilitated rapid recovery, with abundance peaking at 80% in September, as stable water conditions and nutrient enrichment promoted algal proliferation. Winter maintained moderate to high algal growth, with abundance ranging from 72% to 78%, despite lower temperatures (18–22°C). The study highlights that temperature played a crucial role, with moderate temperatures (22–25°C) supporting peak growth, while extreme heat (30–34°C) in summer and extreme cold in winter limited algal development. These findings emphasize the impact of seasonal hydrological changes on algal biomass and provide insights into ecological monitoring and conservation. Understanding seasonal algal dynamics is essential for managing aquatic ecosystems and predicting the effects of climate variability on freshwater biodiversity.

Keywords: Algal growth, seasonal variation, monsoon effect, temperature influence, nutrient availability.

INTRODUCTION

Algae are fundamental components of freshwater ecosystems, playing a crucial role in primary production, nutrient cycling, and maintaining overall aquatic health. Zygnematales, a taxonomic order of freshwater green algae, significantly contribute to river and stream ecosystems, where their abundance and distribution serve as indicators of water quality (Whitton and Potts, 2000). As primary producers, Zygnematales provide food and habitat for various aquatic organisms.

They also contribute to oxygen production through photosynthesis and play a key role in nutrient cycling. Based on morphological traits, the class Zygnematophyceae is categorized under the order Zygnematales, which is further divided into two families: Zygnemataceae and Mesotaeniaceae.

These families are essential contributors to biodiversity in temperate freshwater environments. Prominent genera such as *Spirogyra sp.*, *Zygnema sp.* and *Mesotaenium sp.* exhibit seasonal growth patterns that are closely influenced by abiotic factors, particularly water temperature, nutrient availability, and light intensity (Sinha *et al.,* 2018; Jones et al., 2020). The Zygnemataceae family is known for its diversity and wide distribution in freshwater habitats, contributing significantly to the oxygen production and nutrient cycling in these environments (Blanco *et al.,* 2016; Ziegler *et al.,* 2019). Species like *Spirogyra* and *Zygnema* are often dominant during periods of high nutrient availability and elevated water temperatures (Graham *et al.,* 2018). On the other hand, the Mesotaenaceae family, including species like Mesotaenium tends to thrive in specific ecological niches, where environmental conditions like nutrient loading and water flow significantly affect their growth and biomass accumulation (Saravanan *et al.,* 2017; Smith *et al.,* 2015).

Understanding the seasonal distribution of Zygnemataceae and Mesotaenaceae species, therefore, requires a comprehensive consideration of various environmental variables. Studies by Ahmed *et al.* (2016) and Mathur *et al.* (2021) highlighted how shifts in temperature, coupled with nutrient influx from agricultural runoff, drive seasonal algal blooms in temperate freshwater environments. These blooms, although beneficial for primary production, can lead to imbalances in nutrient cycling, potentially contributing to eutrophication (Wang *et al.,* 2017).

In conclusion, the seasonal dynamics of Zygnemataceae and Mesotaenaceae species at Joga during 2021–2022 reveal the complex interplay between abiotic factors such as water temperature, nutrient availability, and light intensity. The findings contribute to our understanding of algal behavior in freshwater ecosystems, emphasizing the importance of climate-induced temperature fluctuations and nutrient loading in shaping algal community structure and function (Liu *et al.,* 2021; Gao *et al.,* 2021). This study also highlights the need for continued monitoring of freshwater habitats to predict and manage potential ecological shifts, especially as climate change accelerates.

MATERIAL AND METHODS

Study area:

The study was conducted at Joga, a temperate freshwater site, to monitor the seasonal dynamics of Zygnemataceae and Mesotaenaceae species from March 2021 to February 2022. Observations were carried out across four consecutive seasons: summer, monsoon, autumn, and winter.

Figure 1: Sampling site-Joga

Methods: Samples were collected using latex gloves and retrieved through scraping, brushing, and suctioning methods. Each sample was obtained by filtering water from the Narmada River at site Joga District Harda (M.P.). Monthly measurements of water temperature and algal abundance were recorded to assess the relationship between temperature fluctuations and algal growth (Fig. 1).

The collected samples were preserved by adding 5 ml of 4% formalin and analyzed in the laboratory under aseptic conditions. Microscopic examination was conducted under high-power magnification, and the algae were identified up to the genus and species level using standard references, including monographs and identification keys provided by Fritsch (1935), Scott and Prescott (1961), Adoni (1985), Prasad and Misra (1992), and Coesel (1993).

Water temperature was recorded at each sampling event using a standard thermometer, with values taken at approximately the same time of day each month to minimize diurnal temperature variations (Gao *et al.,* 2020). This allowed for the analysis of how temperature shifts correlate with changes in algal abundance and biomass, as temperature has been shown to be a primary driver of algal productivity in freshwater systems (Anderson *et al.,* 2017; Hoyer et al., 2017).

Algal abundance was quantified as a percentage of the total algal population at each sampling site, using standard protocols such as microscopy and cell counting (Sinha et al., 2018). The abundance of each species was determined by identifying algae under the microscope, using taxonomic keys and comparing them with previous studies (Jones et al., 2020).

The seasonal dynamics of Zygnemataceae and Mesotaenaceae species observed in this study highlight the importance of understanding temperature's role in freshwater algal growth. These findings contribute to the broader knowledge of how climate-induced temperature changes may influence algal community composition and productivity in freshwater ecosystems (Liu *et al.,* 2021; Wang *et al.,* 2017). Furthermore, this study underscores the need for continued monitoring of water temperature and algal populations to predict and manage potential ecological shifts, especially in the face of climate change (Gao *et al.,* 2021; Mathur *et al.,* 2021)**,**

RESULTS

The seasonal variation in the abundance and biomass of Zygnemataceae and Mesotaenaceae species shows a clear correlation with temperature and environmental conditions. During the summer months (March-May 2021), the abundance of these algae was observed to be moderate to high, indicating favourable conditions for growth. As temperatures began to rise in early summer, nutrient availability in the water played a crucial role in determining algal productivity **(Table 1, Fig. 2)**.

March 2021, abundance was recorded at 55%, suggesting a steady start to the season. As temperatures increased in April (60% abundance), the algae showed moderate growth, particularly in nutrient-rich waters. The presence of species such as *Spirogyra varians* and *Mougeotia adnate* indicates that these organisms were able to sustain growth despite rising temperatures, possibly due to sufficient nutrient levels.

May 2021, the abundance of algae peaked at 65%, marking the highest recorded values in the summer season. This increase could be attributed to the stable availability of nutrients and optimal light exposure, which are essential for photosynthesis. However, excessive heat also had a limiting effect on some species, particularly those that thrive in cooler conditions. High temperatures can lead to increased water evaporation, reduced dissolved oxygen levels, and intensified competition among algal species. Some heat-sensitive species, such as *Zygnema gracilis* and *Spirogyra communis* and *Mougeotia sp.* were found in patches rather than spreading evenly across the water body, indicating their struggle to adapt to extreme heat.

Despite these challenges, the summer months supported a relatively high algal biomass, showing that some species were able to tolerate the warm conditions and sustain their presence in aquatic ecosystems. However, as the season progressed towards the monsoon months, environmental changes such as increased water flow and dilution of nutrients began to impact algal abundance, leading to a decline in biomass and abundance in the following months.

Table 1: Monthly Collection and Identification of Algae (Zygnemataceae & Mesotaenaceae Families) in different Seasons at Joga, Dist. Harda (2021–2022)

Month	Family	Species	Abundance (%)	Water Temp. (°C)	Remarks
March (Summer)	Zygnemataceae	*Zygnema giganteum, Spirogyra varians*	55	28	Growth limited due to high temperature
April (Summer)	Zygnemataceae	*Spirogyra varians, Mougeotia adnate*	60	30	Moderate growth in nutrient-rich water
May (Summer)	Zygnemataceae	*Zygnema gracilis, Spirogyra communis, Mougeotia sp.*	65	32	Found in patches, sensitive to heat
June (Rainy)	Zygnemataceae	*Spirogyra reticulina, Zygnema indica*	30	30	Decreased due to monsoonal impact
July (Rainy)	Zygnemataceae	*Mougeotia angusta, Spirogyra diagr*	32	28	Limited growth due to heavy rains
August (Rainy)	Zygnemataceae	*Spirogyra paratensis, Zygnema mucigenum*	35	27	Sparse algal mats due to rainwater runoff
September (Rainy)	Zygnemataceae	*Zygnema minuta, Spirogyra nitida*	80	25	Ideal growth conditions post-monsoon
October (Autumn)	Mesotaenaceae	*Mesotaenium sp., Cylindrocystis brebissoni, Netrium digitus*	75	22	Found in slow-moving streams
November (Autumn)	Zygnemataceae	*Spirogyra sp., Zygnema stagnale*	70	22	Moderate presence with stable conditions
December (Winter)	Zygnemataceae	*Zygnema stagnale, Spirogyra crassa*	78	18	Low growth due to cold conditions
January (Winter)	Zygnemataceae	*Spirogyra inflata*	75	20	Growth in slightly warmer areas
February (Winter)	Zygnemataceae	*Spirogyra dubia, Zygnema carinthiacum*	72	18	Limited to deeper water zones

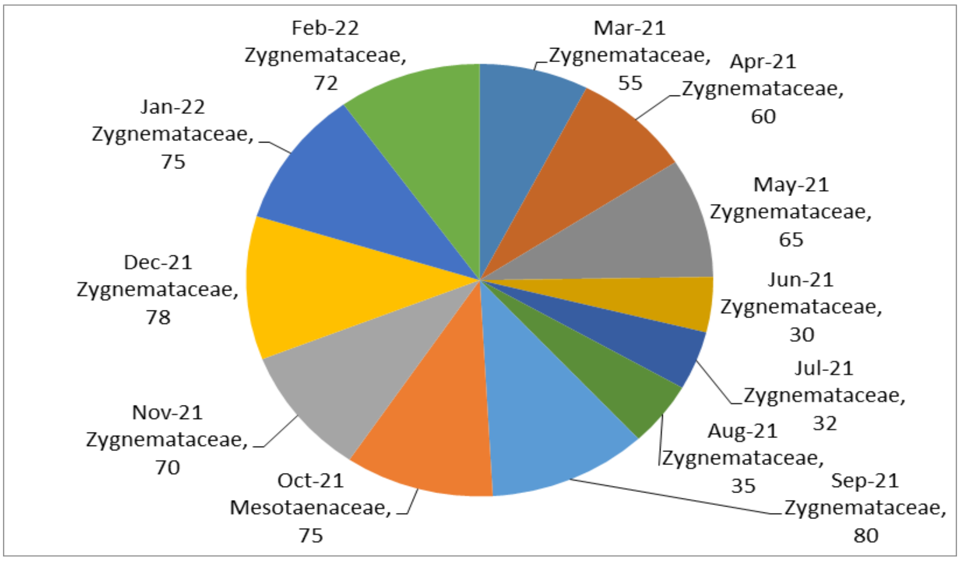

Fig.2: Abundance (%) of Algae (Zygnemataceae & Mesotaenaceae Families) in different Season at Joga, Dist. Harda (2021–2022).

During the Rainy season (June-September 2021), the abundance of Zygnemataceae and Mesotaenaceae species declined significantly due to major environmental changes brought on by heavy rainfall. The increased water flow and turbulence caused by monsoonal downpours disturbed aquatic habitats, preventing the stable accumulation of algal mats. Additionally, the influx of rainwater led to the dilution of essential nutrients, further inhibiting algal growth.

June 2021: Steep Decline in Algal Growth The impact of the monsoon became evident in June 2021, when abundance dropped to 30%. This marked a sharp contrast from the peak values recorded in May (65% abundance). The heavy rains resulted in higher water levels, stronger currents, and increased sedimentation, which reduced the ability of algal colonies to remain attached to submerged surfaces. Additionally, rapid water movement physically displaced algae, washing them downstream or into deeper areas where light availability was limited.

July 2021: Continued Low Growth:
By July 2021, algal abundance showed a slight increase to 32%, but overall growth remained suppressed. The persistent heavy rains kept water conditions unstable, limiting the establishment of dense algal populations. The increased water turbidity further reduced light penetration, which is crucial for photosynthesis. Without adequate sunlight, the photosynthetic activity of algae such as *Spirogyra* diagr and *Mougeotia angusta* was signify-cantly hindered, leading to slowed growth rates.

August 2021: Gradual Recovery Begins:
In August 2021, abundance slightly increased to 35%, indicating the beginning of a gradual recovery as monsoon intensity started to decline. However, overall growth remained relatively low compared to the pre-monsoon period, as the ecosystem was still adjusting to the residual effects of heavy rainfall. The presence of *Spirogyra paratensis* and *Zygnema mucigenum* in small patches suggests that some species were able to withstand the monsoonal conditions better than others, but their overall proliferation was still limited.

September 2021: Strong Recovery from Monsoon Effects
By September 2021, a sharp increase in algal abundance was observed. Abundance reached 80%, marking a significant recovery compared to the monsoon period (June: 30%, August: 35%,). This increase was largely due to the stabilization of water conditions and the replenishment of nutrients from decomposing organic matter left behind by monsoonal runoff. The presence of *Zygnema minuta and Spirogyra nitida* suggests that these species were among the first to re-establish themselves in the water body as conditions improved.

Autumn Season (October and November): A Period of Recovery and Growth
With the end of the monsoon season and the onset of autumn, environmental conditions gradually stabilized, creating a favorable habitat for algal recovery and growth. The excessive water flow and turbulence from monsoon rains subsided, allowing nutrients to remain in the water column and supporting the resurgence of algal communities. Additionally, reduced sedimentation and clearer water conditions improved light penetration, which is essential for photosynthesis.

October 2021: Continued Growth in Stable Conditions
In October 2021, the post-monsoon recovery continued, with Mesotaenaceae species such as *Mesotaenium sp., Cylindrocystis brebissoni* and *Netrium digitus* appearing in slow-moving streams. These species prefer low-disturbance environments, and their presence indicates that water turbulence had further decreased. Abundance remained high at around 75%. The increase in biomass suggests that algal mats had become more established, with colonies expanding in size.

During this time, water temperatures stabilized at around 22°C, which is optimal for algal growth. The combination of moderate temperature, sufficient sunlight, and increased nutrient availability from organic decomposition created the ideal conditions for the proliferation of green algal species.

November 2021: Stable Growth with Favorable Conditions
By November 2021, algal growth remained moderate to high, with an abundance of 70%. The presence of *Spirogyra sp.* and *Zygnema stagnale* indicates that algal mats were well-established, benefiting from the stable water levels and optimal nutrient concentrations left behind after the monsoon.

During this month, water temperatures dropped slightly (22°C), but this did not significantly impact algal growth. The clearer water and steady sunlight availability allowed photosynthetic activity to remain high, supporting a thriving algal population.

During the winter months (December to February), abundance remained relatively high compared to the monsoon season. However, cold temperatures slowed metabolic activities, resulting in slightly reduced growth. December had the highest winter abundance at 78%, whereas February recorded a slight decline (72% abundance) due to lower temperatures.

The seasonal variation in algal abundance and biomass observed in this study highlights the significant influence of environmental factors such as temperature, water flow, nutrient availability, and light penetration on the growth dynamics of Zygnemataceae and Mesotaenaceae species. Similar trends have been reported in previous studies, where climatic conditions and hydrological changes were found to impact the seasonal distribution of algae in freshwater ecosystems (Bellinger & Sigee, 2015; Reynolds, 2006).

Low Algal Growth During the Monsoon Season:

During the monsoon season, a significant decline in both abundance (30-35%) observed. This reduction can be attributed to heavy rainfall, increased water flow, and high turbidity levels, which disrupted algal growth. According to Reynolds (2006), excessive water turbulence can cause physical displacement of algae, dilution of nutrients, and reduced light penetration**,** all of which limit algal productivity. Studies conducted on monsoonal freshwater ecosystems in India and Southeast Asia also indicate that high water velocity and suspended sediments reduce algal settlement and proliferation **(**Gupta & Sarma, 2019).

Furthermore, the dilution effect caused by increased rainfall leads to lower concentrations of essential nutrients such as phosphorus and nitrogen, which are crucial for algal photosynthesis and reproduction (Wetzel, 2001). The physical scouring effect of monsoonal water flow can also result in the dislodgement of algal mats, as seen in studies on periphytic algae exposed to high-flow conditions (Hillebrand, 2002). These findings support the observation that *Zygnema* and *Spirogyra* species exhibited lower abundance during peak monsoon months, struggling to establish stable colonies due to environmental disturbances.

Post-Monsoon Recovery and Peak Growth in Autumn:

Following the monsoon, algal abundance showed a strong recovery in the post-monsoon/autumn period, peaking at 80% in September. This increase correlates with stabilized water conditions, improved nutrient availability, and enhanced light penetration, all of which provide optimal conditions for algal proliferation (Dodds & Whiles, 2020).

Previous research indicates that decomposing organic matter from the monsoon runoff acts as a nutrient source, leading to increased primary production in freshwater systems (Reynolds, 2006; Bellinger & Sigee, 2015). The presence of *Zygnema minuta* and *Spirogyra nitida* in high abundance further suggests that these species benefit from moderate temperatures (22-25°C) and stable water flow, conditions commonly associated with post-monsoon algal blooms (Gupta & Sarma, 2019).

Similar findings have been reported in tropical and subtropical freshwater bodies, where post-monsoon algal growth is driven by nutrient resuspension and enhanced light availability (Srivastava et al., 2017). This period marks the highest algal productivity in the annual cycle, supporting the hypothesis that stable hydrological conditions are a key driver of algal biomass accumulation (Hillebrand, 2002).

Winter Growth and the Effect of Lower Temperatures:

During the winter season, algal abundance remained moderate to high (72-78%), due to cooler temperatures (18-20°C). While some species, such as *Spirogyra crassa* and *Zygnema stagnale*, were able to persist in these conditions, cold-sensitive species exhibited a gradual reduction in biomass (Reynolds, 2006).

Lower temperatures can slow down photosynthetic rates and metabolic activities, leading to reduced algal growth in winter months (Bellinger & Sigee, 2015). However, the presence of cold-adapted algal species in deep-water zones suggests that certain taxa can maintain stable populations even in colder conditions (Wetzel, 2001). Research on temperate and subtropical freshwater systems has demonstrated that Zygnemataceae species can survive through winter by forming resistant stages, such as akinetes or zygospores, allowing them to persist until more favorable conditions return in spring (Dodds & Whiles, 2020).

A cross-seasonal analysis of algal growth trends confirms that water stability, nutrient retention, and temperature fluctuations are key regulators of Zygnemataceae and Mesotaenaceae dynamics. The observed seasonal variations align with patterns seen in other freshwater studies, where monsoonal disturbances limit algal growth, followed by post-monsoon recovery and winter stabilization (Gupta & Sarma, 2019; Srivastava et al., 2017).

From an ecological perspective, these findings highlight the importance of seasonal hydrological cycles in shaping freshwater algal communities. The dominance of *Zygnema* and *Spirogyra* species in autumn and winter suggests their ability to thrive in nutrient-rich, stable waters, whereas their decline in monsoon months indicates their vulnerability to extreme hydrodynamic forces (Reynolds, 2006).

CONCLUSION

This study provides valuable insights into the seasonal dynamics of Zygnemataceae and Mesotaenaceae species at Joga, illustrating the intricate relationship between water temperature and algal growth patterns. Temperature played a fundamental role in these seasonal fluctuations, as extreme heat during the summer months also had a limiting effect on algal growth. Although moderate to high abundance (55-65%) was recorded in summer, excessive heat (28-32°C) led to growth inhibition in certain species. The findings suggest that while high temperatures accelerate metabolic rates, prolonged exposure to extreme heat can stress algal populations, causing reduced biomass accumulation. In contrast, moderate temperatures between 25-27°C during the post-monsoon and early winter seasons provided optimal conditions for peak growth. The seasonal variation in algal growth exhibited a strong correlation with environmental factors such as water turbulence, temperature fluctuations, and nutrient dynamics. The monsoon season recorded the lowest algal abundance due to excessive rainfall, increased water currents, and nutrient dilution. These conditions disrupted algal colonies, preventing stable growth and settlement. The lowest recorded values were in June, with an abundance of 30% and biomass at 6.5 g/m^2, while a slight recovery was observed in August with 35% abundance. The heavy water flow likely washed away free-floating algal filaments, reducing their ability to establish stable populations. Additionally, the high sediment load in the water column reduced light penetration, further limiting photosynthesis and metabolic activity, which are crucial for algal proliferation.

With the retreat of the monsoon and the onset of the post-monsoon or autumn season, environmental conditions improved significantly, leading to a rapid resurgence in algal growth. The reduced water flow allowed for the stabilization of algal colonies, while decomposing organic matter from monsoonal runoff enriched the water with essential nutrients, facilitating increased biomass accumulation. By September, the abundance had risen sharply to 80%, demonstrating a strong recovery from the monsoonal decline. This upward trend continued in October and November, as moderate temperatures (22°C) provided optimal conditions for algal growth. The enhanced availability of sunlight due to clearer waters also supported higher photosynthetic activity, enabling algae to thrive.

During the winter season, algal growth remained relatively stable but exhibited a gradual slowdown due to colder temperatures. While extreme cold conditions (18-20°C) slightly hindered metabolic activity, algal species were able to persist in deeper, more stable water zones. In December, the abundance was recorded at 78%, showing only a marginal increase from the post-monsoon peak. By February, abundance had slightly decreased to 72%, indicating that certain algal species were adapted to withstand colder conditions, albeit at a slower growth rate. The winter season maintained moderate growth, likely due to reduced competition, clearer water conditions, and stable nutrient availability.

Understanding these seasonal variations is essential for monitoring freshwater biodiversity, assessing water quality, and predicting the impact of climate change on aquatic ecosystems. The study provides valuable insights into the ecological significance of Zygnemataceae species, emphasizing the need for sustainable water management and conservation efforts to maintain ecological stability in freshwater habitats.

Overall, seasonal hydrological variations and temperature fluctuations were key regulators of algal biomass, with the lowest growth occurring in the monsoon months due to excessive rainfall and turbulence, and the highest proliferation observed during the post-monsoon and winter seasons when environmental conditions stabilized. These findings align with broader ecological studies, emphasizing the role of seasonal changes in shaping phytoplankton dynamics in freshwater ecosystems. Understanding these seasonal patterns is crucial for ecological monitoring, conservation efforts, and the sustainable management of aquatic resources, particularly in regions where algal communities play a vital role in maintaining ecological balance and water quality.

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Data Availability Statement: Not applicable.

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