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Environmental Factors Influencing the Growth Rate of *Naegleria fowleri* in Various Aquatic Ecosystems: Implications for Public Health

Astrid Berg, Bjorn Karlsson, Freja Olsson, Nils Andersson

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ABSTRACT
The free-living amoeba *Naegleria fowleri*, commonly known as the "brain-eating amoeba," is a pathogenic microorganism capable of causing primary amebic meningoencephalitis (PAM). This study investigates the growth dynamics of *N. fowleri* in different water bodies, including freshwater lakes, rivers, hot springs, and artificial water systems. Factors such as temperature, pH, nutrient availability, and chlorine levels are analyzed for their impact on amoebic proliferation. The findings contribute to a better understanding of environmental conditions conducive to *N. fowleri* growth and strategies for mitigating infection risks.

INTRODUCTION:

Naegleria fowleri, a thermophilic amoeba, poses a significant public health risk due to its ability to cause primary amebic meningoencephalitis (PAM), a rare but fatal brain infection. The organism thrives in warm freshwater environments such as lakes, rivers, and poorly maintained swimming pools, where it exists in three life stages: trophozoite, flagellate, and cyst. The trophozoite stage is the primary infectious form, capable of invading the human nervous system through the nasal passages. This study investigates how varying environmental conditions, including temperature, pH, and nutrient availability, affect the proliferation of N. fowleri across different water bodies. Understanding these factors is critical for improving early detection, implementing effective water treatment strategies, and mitigating public exposure risks. By identifying environmental conditions that promote amoebic growth, public health authorities can develop targeted interventions to reduce infection risks, particularly in recreational water sources. Future research should focus on advanced detection methods, predictive modeling, and potential mitigation strategies to enhance water safety and prevent outbreaks of N. fowleri infections.

Physicochemical Factors Affecting *Naegleria fowleri* Growth

The proliferation of *Naegleria fowleri*, a free-living, thermophilic amoeba, is influenced by various **physicochemical parameters**, including

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temperature, pH levels, and nutrient availability. Understanding these factors is essential in predicting its growth patterns in natural and artificial water systems, thereby aiding in risk assessment and mitigation strategies.

2.1 Temperature Dependency and Thermal Tolerance

Temperature plays a critical role in the survival and replication of *N. fowleri*. As a **thermophilic organism**, it thrives in **warm freshwater environments** such as hot springs, lakes, and poorly chlorinated swimming pools. Studies indicate that the amoeba exhibits **peak growth between 30°C and 45°C**, with growth inhibition observed at temperatures exceeding 50°C.

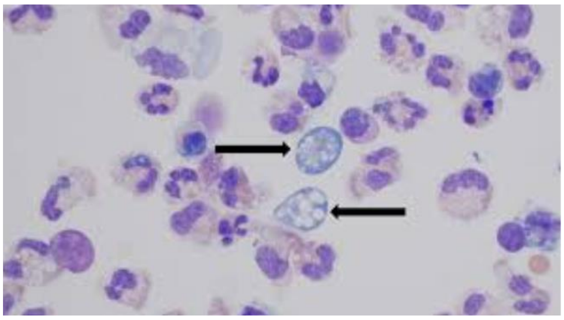

Fig. Naegleria fowleri growth rate

Table 1: Growth Rate of *N. fowleri* at Various Temperatures

Temperature (°C)	Growth Rate (cells/mL/day)
20°C	Minimal growth
30°C	Moderate growth
37°C	Optimal growth
45°C	Peak growth
>50°C	Growth inhibition

This data suggests that *N. fowleri* is well-adapted to **warm and thermally polluted water systems**, which may explain its increased prevalence in warmer climates and artificial water bodies such as **power plant effluents and heated industrial waters**.

2.2 pH Levels and Their Influence on Amoebic Proliferation

The pH of the surrounding environment significantly affects *N. fowleri* growth and survival. The amoeba **flourishes in a pH range of 6.5 to 8.5**, with **optimal proliferation occurring around neutral to slightly alkaline conditions**. Acidic environments (pH <6) inhibit its replication, reducing the likelihood of amoebic contamination in naturally acidic water bodies.

Water sources with fluctuating pH levels, such as those influenced by **industrial discharge or agricultural runoff**, may affect the amoeba's viability. Alkaline conditions (pH >8.5) have been reported to **reduce trophozoite activity**, but do not necessarily eliminate the organism, making pH regulation an important consideration in water treatment.

2.3 Role of Nutrient Availability

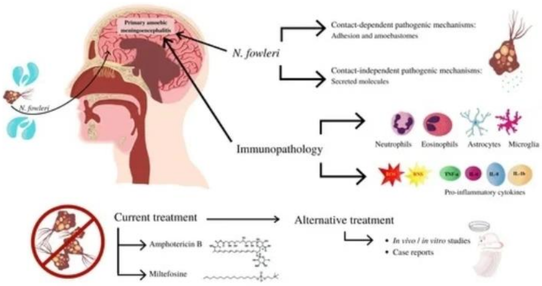

Fig. Nutrient Availability in Naegleria fowleri

The availability of **organic matter and bacterial populations** plays a crucial role in the survival and multiplication of *N. fowleri*. This amoeba primarily feeds on **bacteria, algae, and detritus**, making **eutrophic water bodies with high bacterial loads** an ideal habitat.

Key factors influencing nutrient availability include:

- **Bacterial Density**: The presence of *Escherichia coli*, *Pseudomonas*, and *Legionella* species has been linked to enhanced amoebic proliferation.
- **Organic Load**: Increased levels of decaying plant matter, sewage runoff, or **biofilm formation** provide essential nutrients for amoebic survival.
- **Dissolved Oxygen**: Although *N. fowleri* is an aerobic organism, it can survive in **low-oxygen environments** if nutrient availability compensates for reduced respiration efficiency.

Comparative Study of *Naegleria fowleri* Growth in Different Water Bodies

The presence and proliferation of *Naegleria fowleri*, a thermophilic amoeba, vary across different aquatic environments. Factors such as **temperature, water flow, nutrient composition, and disinfection efficiency** influence its survival. This section examines its growth dynamics in **freshwater lakes and rivers, hot springs, and artificial water systems**.

3.1 Growth in Freshwater Lakes and Rivers

Lakes and rivers act as **natural reservoirs** for *N. fowleri*, where its proliferation is influenced by **temperature fluctuations, nutrient availability, and seasonal variations**.

- **Temperature Influence**: Growth is significantly higher during **summer months**, with peak populations detected in waters exceeding **30°C**. During colder seasons, trophozoite activity declines, and cyst formation increases, allowing the amoeba to persist until conditions become favorable.
- **Flow Rate and Stagnation**: **Slow-moving or**

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stagnant waters provide an ideal environment for *N. fowleri* to thrive. Rivers with strong currents are less conducive to its growth due to continuous water turnover and dilution.

- **Nutrient Enrichment**: Agricultural runoff, organic debris, and microbial biofilms contribute to higher bacterial loads, indirectly promoting amoebic proliferation.

Several **case studies of primary amebic meningoencephalitis (PAM) outbreaks** have been linked to swimming in warm freshwater lakes, particularly in **the United States, Australia, and Southeast Asia**, highlighting the risks associated with natural water bodies.

3.2 Growth in Hot Springs and Geothermal Waters

Hot springs and geothermal waters provide a **near-ideal habitat** for *N. fowleri*, supporting its continuous proliferation due to their **sustained high temperatures**.

- **Thermal Adaptation**: Unlike other environments, geothermal waters **maintain temperatures between 35°C and 45°C**, aligning with *N. fowleri's* optimal growth range. Studies confirm that such conditions consistently harbor **viable trophozoites**, posing a greater risk of exposure.
- **Minimal Seasonal Variation**: Unlike lakes and rivers, **hot springs exhibit minimal temperature fluctuations**, ensuring a stable population year-round.
- **Chemical Composition Influence**: The **mineral content and pH** of geothermal waters may affect amoebic growth, but many hot springs fall within *N. fowleri's* preferred pH range of **6.5 to 8.5**.

Notable **PAM cases** have been associated with bathing in **hot springs**, emphasizing the necessity of **public health advisories and water monitoring** in these areas.

3.3 Growth in Artificial Water Systems

Artificial water systems, including **cooling towers, swimming pools, and industrial water reservoirs**, can inadvertently support *N. fowleri* growth if **disinfection protocols are inadequate**.

- **Cooling Towers and Industrial Water Systems**: Warm water discharge from industrial facilities provides **persistent thermal conditions**, allowing the amoeba to thrive in biofilms and poorly maintained reservoirs.
- **Swimming Pools and Water Parks**: Properly chlorinated pools do not support *N. fowleri* growth; however, **improper chlorination or stagnant water sections** can lead to contamination.
- **Tap Water and Plumbing Systems**: In rare instances, *N. fowleri* has been detected in **municipal water supplies**, particularly in cases where **chlorine levels were insufficient** to inactivate amoebic populations.

Table 2 compares *N. fowleri* growth across different water bodies:

Water Body Type	Temperature Range	pH Range	Growth Rate
Freshwater Lakes	20–35°C	6.5–8.5	Moderate
Rivers	15–30°C	6.0–8.0	Low
Hot Springs	35–50°C	7.0–8.5	High
Artificial Pools	25–37°C	6.8–8.2	Moderate (if untreated)

4. Public Health Implications and Risk Mitigation Strategies

The presence of *Naegleria fowleri* in natural and artificial water systems poses a **significant public health concern**. While infections are rare, they are nearly always **fatal**, making prevention and risk mitigation strategies critical. This section discusses **human exposure risks, infection pathways, and effective disinfection and control measures** to reduce outbreaks.

4.1 Human Exposure and Infection Risks

Recreational water users face the highest risk of *N. fowleri* infection, particularly in **warm, stagnant freshwater environments**. **Primary amebic meningoencephalitis (PAM)**, the disease caused by *N. fowleri*, occurs when contaminated water enters the **nasal passages**, allowing the amoeba to migrate to the brain.

Key Risk Factors for Infection:

- **Water Temperature**: Warm temperatures (**above 30°C**) enhance amoebic growth, making summer months particularly risky.
- **Stagnation and Water Quality**: Lakes, ponds, and poorly maintained artificial water systems with **low circulation and high bacterial content** favor proliferation.
- **Nasal Exposure**: Activities such as **diving, water sports, and using untreated tap water for nasal rinsing** (e.g., neti pots) increase exposure risks.
- **Geographical Distribution**: PAM cases have been reported in **the United States, India, Australia, and tropical regions**, particularly in **hot, arid climates**.

Despite its **low infection rate**, the **high fatality rate (>95%)** of PAM necessitates **strict public health interventions** to minimize exposure.

4.2 Disinfection and Control Measures

Effective **water treatment and regulatory strategies** play a vital role in reducing *N. fowleri* contamination in artificial and natural water sources.

Water Disinfection Methods

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- **Chlorination**: Maintaining **free chlorine levels above 1.0 ppm** effectively inactivates *N. fowleri*. Higher concentrations (**3-5 ppm**) may be required for heavily contaminated water systems.
- **Ultraviolet (UV) Radiation:** UV exposure disrupts amoebic DNA, preventing replication and reducing *N. fowleri* viability.
- **Ozone Treatment:** Used in municipal water supplies, ozone-based disinfection is highly effective against amoebas and other microbial pathogens.

Preventive Measures for Public Water Systems:

- **Monitoring and Testing**: Routine water quality assessments help detect contamination before outbreaks occur.
- **Temperature and pH Control**: Reducing **thermal pollution** and maintaining pH **outside the optimal growth range (6.5–8.5)** can limit proliferation.
- **Improved Filtration**: Advanced **sand filtration** and **reverse osmosis** systems remove amoebas and their cysts from drinking water sources.

Personal Protection Recommendations:

- **Avoid nasal exposure to untreated water**, especially in **warm lakes and rivers**.
- **Use properly treated water for nasal irrigation** (e.g., boiled or sterile water in neti pots).
- **Encourage awareness campaigns** in high-risk areas to educate the public about preventive measures.

5.CONCLUSION:

Understanding the environmental conditions that favor Naegleria fowleri growth is crucial for developing effective preventive strategies against primary amebic meningoencephalitis (PAM). This opportunistic pathogen thrives in warm freshwater environments, where factors such as temperature, pH, and nutrient availability influence its proliferation. Identifying high-risk water sources, such as poorly maintained swimming pools, hot springs, and stagnant lakes, can help mitigate public health risks. Rigorous monitoring, coupled with advanced detection methods, is necessary to track N. fowleri presence and assess infection risks. Effective disinfection protocols, including chlorination, ultraviolet (UV) treatment, and improved water management practices, can reduce amoebic contamination in recreational and domestic water supplies. Additionally, public awareness campaigns should emphasize the dangers of nasal exposure to untreated or warm freshwater, particularly in endemic regions. Future research should focus on refining rapid detection techniques, exploring novel disinfection methods, and developing predictive models to assess environmental conditions that increase the likelihood of N. fowleri outbreaks. By implementing these measures, public health authorities can enhance water safety, minimize infection risks, and prevent future cases of PAM.

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