Cooling the Cloud: Advancing Sustainable Solutions for Data Center Water Use

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***Abstract*—The rapid expansion of cloud computing and artificial intelligence has generated unprecedented global demand for data centers, which rely heavily on large-scale cooling systems to keep servers from overheating. This paper examines the environmental consequences of data center water consumption, with a focus on local ecosystems, and reviews existing responsible next-generation solutions rather than proposing new ones. Through an analysis of current literature, this study reveals that hyperscale data centers can consume millions of gallons of water daily, comparable to small municipalities with particularly severe impacts in water-stressed regions. The research identifies impacts of freshwater extraction, including reduced streamflows, altered thermal regimes, and declining viability of aquatic ecosystems. While industry responses show promise through zero-water cooling technologies and closed-loop systems, inconsistent reporting standards obscure the full scope of environmental impacts. This paper advocates for mandatory water-use disclosure policies and strategic geographic planning to balance technological advancement with long-term ecological sustainability.**

***Index Terms*—Data Center Water Consumption, Evaporative Cooling Systems, Freshwater Ecosystem Impact, Sustainable Cooling Technologies, Water-Stressed Regions, Hyperscale Data Centers.**

I. INTRODUCTION

Each time an AI chatbot is presented with a question, or a video is uploaded to social media, or a file is saved to the cloud, somewhere on the planet, within a large warehouse filled with computers, the temperature slightly rises. Many envision the “cloud” as something intangible. However, the cloud is physical, housed in enormous windowless buildings packed with thousands of computers running nonstop and generating so much heat that they need constant cooling to prevent overheating. These facilities are cooled using water, requiring millions of gallons to operate.

These data centers are draining rivers, emptying underground aquifers, and competing with local communities for water supplies. In drought-stricken areas of Nevada and Arizona, where water is scarce, technology companies are pumping out freshwater at unexpectedly high rates. Meanwhile, fish populations are declining, wetlands are drying up, and local communities are watching their water sources disappear, largely to support streaming services and AI training. As digital activities increase and artificial intelligence advances, this hidden environmental crisis will continue to escalate. Therefore, this paper explores the environmental impact of technology on water resources, the damage to ecosystems, and whether effective solutions can be implemented in time.

II. LITERATURE REVIEW

Research shows that modern data centers use large amounts of water because they rely on evaporative cooling and water-based chillers to keep servers from overheating (Nature, 2021). A single hyperscale facility can use hundreds of thousands to millions of gallons of water per day, which is similar to the needs of a small town (GRESB, 2025). This demand is rising quickly as AI systems and cloud computing expand, creating even higher energy and water use (Environmental Law Institute, 2025). These withdrawals can harm local ecosystems by lowering streamflows, warming water temperatures, and reducing the amount of freshwater available for wetlands and nearby communities (Ceres, 2025). The problem is especially serious when data centers are built in drought-prone places like Nevada or Arizona, where water supplies are already stressed, meaning water sources are limited, droughts are frequent, and existing demand from cities, agriculture, and ecosystems already exceeds sustainable supply (The Guardian, 2025).

Although many data center operators and technology companies still do not publicly report their water use, making it difficult to understand the full environmental impact, this gap has led experts to call for mandatory disclosure policies (The Guardian, 2025). Encouragingly, there are already new proven solutions in practice. Several data centers have significantly reduced water consumption through the use of recycled water, non-evaporative cooling systems, and local water-replenishment initiatives (Veolia, n.d.). In addition, leading technology companies are developing low-water or zero-water cooling systems, such as closed-loop cooling, chip-level liquid cooling, and seawater or geothermal cooling (Microsoft, 2024). Closed-loop systems reuse the same water in sealed pipes, greatly reducing evaporation losses, while chip-level liquid cooling improves heat efficiency by delivering coolant directly to server chips, lowering overall water demand. Seawater and geothermal cooling further reduce freshwater use by relying on ocean water or stable underground temperatures instead of limited local water supplies. Overall, while progress is being made, the literature shows that better planning, transparent reporting, improved technology, and government-enforced environmental regulations are essential to limit water overuse and prevent long-term ecological damage.

III. METHODOLOGY

This study employs a qualitative, secondary research methodology to examine the environmental consequences of data center water consumption and evaluate existing sustainable cooling solutions. Relevant sources were collected from peer-reviewed scientific journals, environmental research organizations, and industry publications, including Nature, the Environmental Law Institute, Ceres, and GRESB. Academic databases such as Google Scholar were used to identify literature published between 2021 and 2025, focusing on data center water use, freshwater ecosystem impacts, and next-generation cooling technologies. Corporate sustainability reports from major technology companies, including Microsoft, Google, and Amazon Web Services, were also reviewed to assess real-world implementation of water conservation measures. The selected literature was analyzed thematically to identify recurring patterns related to water consumption scale, ecological vulnerability, and technological innovation. This synthesis enabled a comprehensive evaluation of the environmental trade-offs associated with digital infrastructure expansion.

Justification: A qualitative secondary methodology is appropriate for this study because substantial empirical data on data center water consumption and its ecological consequences already exist across environmental, governmental, and industry sources. Directly measuring water extraction or ecosystem damage in hyperscale facilities would require access to proprietary infrastructure that is neither publicly available nor ethically viable to intrude upon. Moreover, since the paper's goal is to review and synthesize existing responsible solutions rather than propose untested ones, a secondary approach ensures the findings remain grounded in verified, real-world evidence. This methodology also enables a broad, interdisciplinary analysis, spanning hydrology, environmental policy, and technology, that a single primary study could not achieve.

IV. RESULTS AND DISCUSSION

The Mechanics and Scale of Data Center Water Consumption

Understanding why data centers use so much water starts with understanding how computers work. Modern servers generate massive amounts of heat when processing data, because billions of tiny electrical signals move through transistors on computer chips as calculations are performed. As electricity flows through these components, some energy is lost as heat due to electrical resistance, and this heat builds up rapidly as servers run continuously at high speeds. Without cooling, servers would quickly overheat and break down. To solve this problem, many data centers use evaporative cooling systems or water-based chillers that transfer heat away from the servers using water as a cooling medium (Nature, 2021). In evaporative systems, water absorbs heat and evaporates into the air, taking the thermal energy with it, but this means the water is constantly used up and requires replacement.

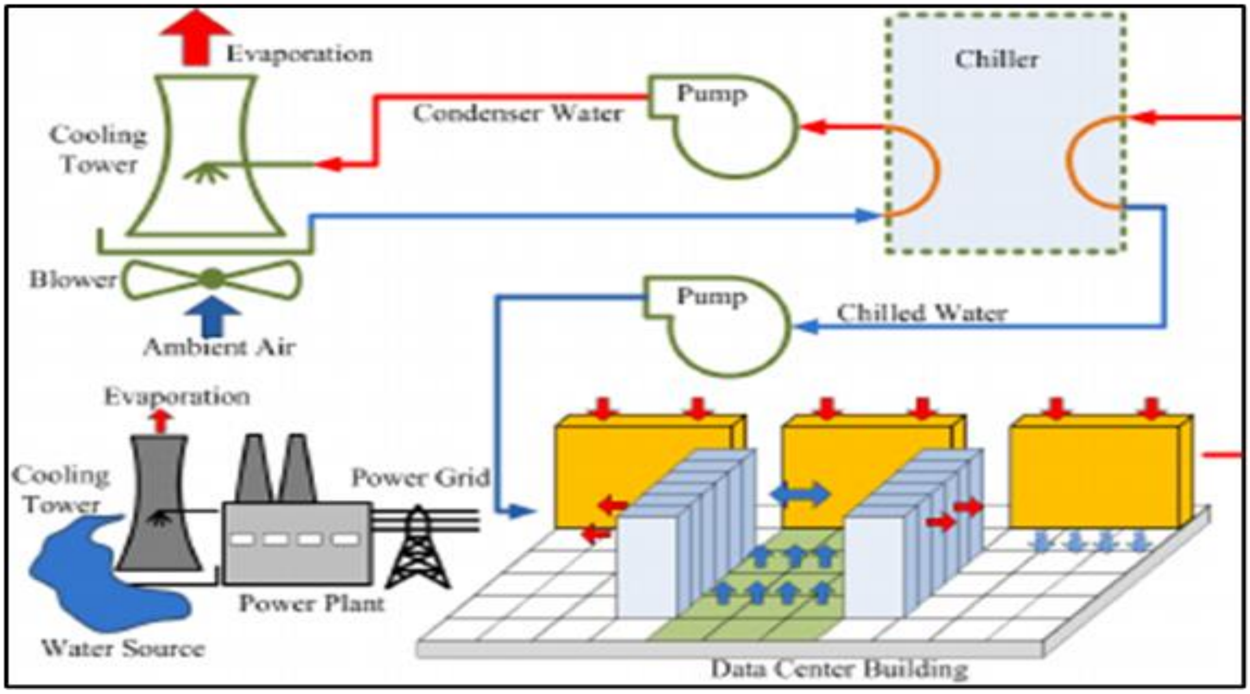

Figure 1: Water Consumption in a Data Center

The scale of water use in these facilities is enormous. A single large data center can consume hundreds of thousands to millions of gallons of water every day, which is about the same amount a small town would use (GRESB, 2025). To put this in perspective, a facility using one million gallons daily consumes enough water to serve approximately 10,000 people based on typical household usage. As observed in Figure 2, the total amount of water used in 2025 reached 279 gigalitres (GL). The rise of artificial intelligence has amplified this problem. As companies invest in constructing larger facilities to keep up with demand for services, these sites account for a large share of local water consumption.

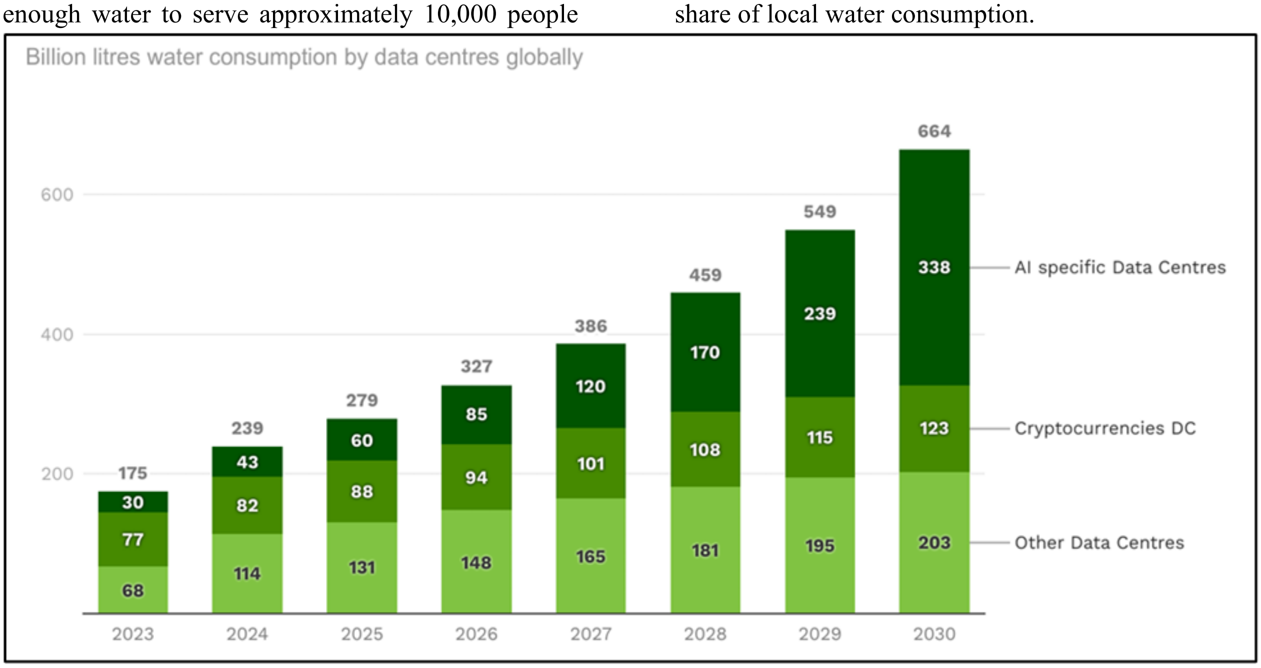

Figure 2: Projected growth in global data center energy use, water consumption, and resource demand driven by artificial intelligence, showing steep increases in electricity and water needs through 2030.

Data centers consume vast amounts of energy: AI hyperscale facilities often consume tens to over a hundred megawatts (MW) of power continuously, comparable to the electricity needs of 15,000–75,000 homes. At a global scale, data centers used approximately 410 terawatt-hours (TWh) of electricity in 2025, according to the International Energy Agency (IEA). The IEA also projects that global data center electricity demand will continue rising rapidly through 2030, largely driven by the growth of artificial intelligence and cloud computing. To better interpret this annual energy use, electricity consumption can be converted into average power demand using the formula:

$$Power\ (GW)\ = \frac{Energy\ (TWh)}{Time\ (hours)}$$

Using this formula to convert 410 TWh for 1 year (365 days = 8760 hours) of use, the power consumption is 46.8 gigawatts (GW). As higher electricity use generates more heat, cooling systems must work harder, increasing water consumption. Therefore, as AI becomes more common in everyday applications, data center water use will likely continue to rise unless more efficient technologies are widely adopted.

At the national scale, overall data center demand is rapidly growing. Industry forecasts estimate that the total U.S. data center electricity demand could exceed 100 gigawatts (GW) by 2035, a dramatic increase driven largely by AI workloads. To put this into perspective, one gigawatt can power roughly 750,000 homes, meaning future data center demand could rival that of major metropolitan areas. Some projections suggest that grid demand from data centers may nearly triple by 2030 if current trends continue (451 Research via S&P Global).

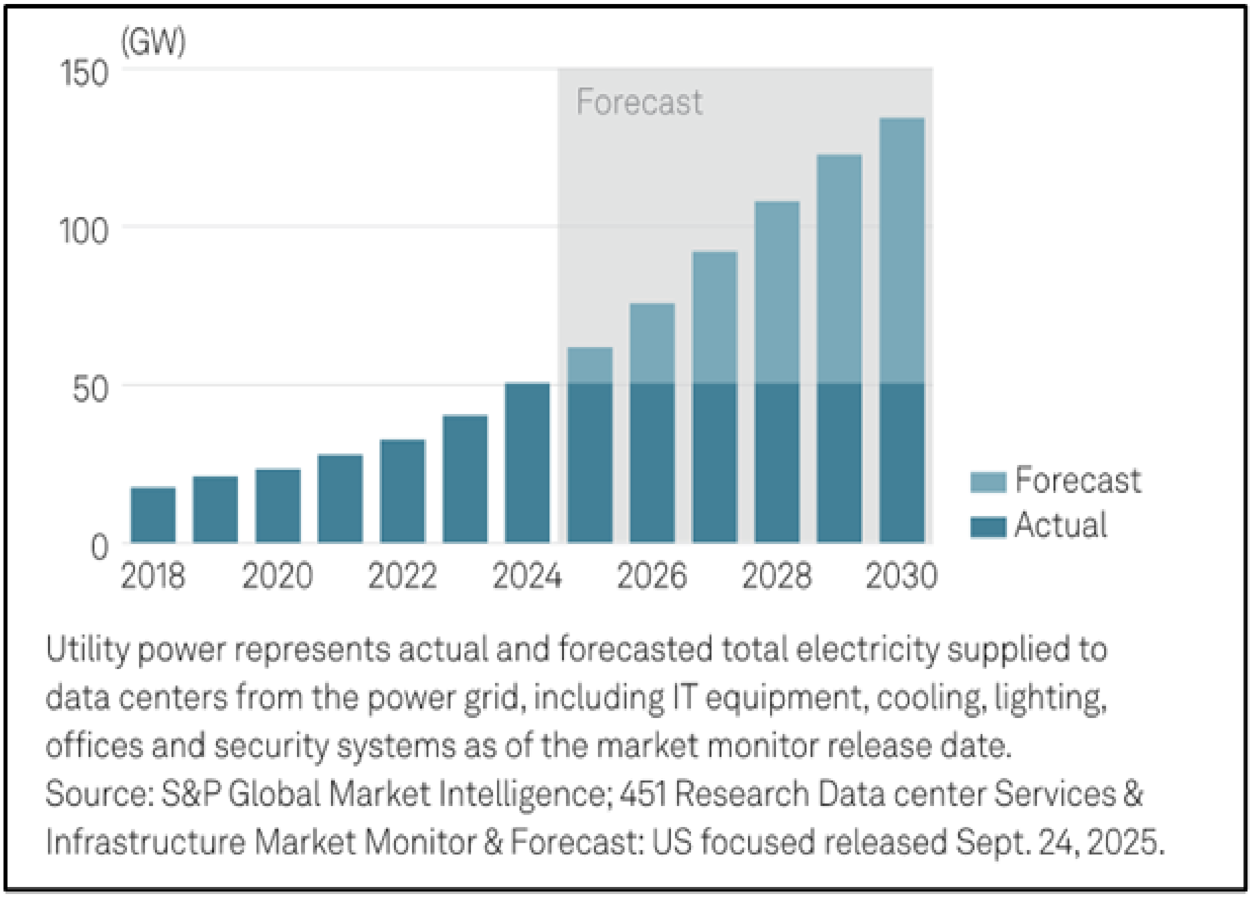

Figure 3: US data-center power demand and projection to 2035

In addition to their substantial energy consumption, these facilities cover a vast amount of physical space. A single hyperscale data center can occupy hundreds of thousands to millions of square feet. To put this in perspective, some of the largest data center complexes are nearly as large as a small city, and in extreme cases, approach half the size of Manhattan (The Guardian, 2025).

Figure 4: Comparison of the physical size of large hyperscale data center campuses with Manhattan, illustrating the massive land footprint of modern digital infrastructure.

These sprawling campuses can house tens of thousands of servers, operating 24 hours a day, and require complex infrastructure, including backup generators, water treatment systems, and security perimeters. According to the Environmental Law Institute (2025), the growth of AI and cloud computing caused substantial increases in both energy and water consumption. As these facilities scale up in both size and power demand, the strain on local electricity grids and water supplies becomes even more severe. The combination of enormous heat generation, continuous operation, and massive size means that cooling these facilities consumes millions of gallons of water daily, comparable to the water usage of a small town or city. High energy use produces significant heat, and cooling systems must work harder, which increases water use. As AI becomes increasingly integrated into our daily lives, from chatbots to autonomous vehicles, data centre water consumption will likely continue to rise unless changes are made.

Ecological Consequences and Geographic Vulnerabilities

The environmental harm caused by data centers' excessive water consumption can occur through interconnected hydrological and ecological impacts. Large withdrawals of freshwater from rivers, lakes, and groundwater sources reduce water availability for natural ecosystems and downstream communities.

Research by Ceres (2025) indicates that these withdrawals can lower streamflows, alter water temperatures in rivers and streams, and reduce water availability for wetlands. These changes place significant stress on aquatic ecosystems and threaten species that depend on stable flow conditions and temperature ranges for survival and reproduction. For example, fish species such as trout and salmon require cool, oxygen-rich water to survive, while amphibians such as frogs depend on wetlands for breeding.

Therefore, these lower streamflows harm the aquatic life that depends on them. Pollutants become more concentrated, lowering dissolved oxygen levels and eliminating shallow-water areas critical for feeding and reproduction. Decreased water volume also accelerates warming, as reduced water flows absorb sunlight more rapidly, often exceeding the temperature limits of many sensitive species. Elevated water temperature can be lethal for cold-water fish, such as rainbow trout, while the loss of wetlands threatens turtles, migratory birds, and aquatic insects that support aquatic food webs. Collectively, these stressors can reshape entire ecosystems and their functions, favoring the more resilient species while reducing biodiversity to those adapted to cooler, stable environments.

Broader sustainability frameworks emphasize that environmental harm produces long-term consequences that extend beyond short-term economic gains. For example, the Aga Khan Development Network's framework emphasizes responsible stewardship of natural resources and long-term water security. It demonstrates this through infrastructure planning and community engagement, offering a conceptual model for addressing environmental challenges such as water consumption (Aga Khan Development Network, n.d.). AKDN's approach to water infrastructure shows how development strategies can combine technical solutions with governance, transparency, and long-term resilience, which aligns with the guiding principles needed for sustainable data center water management.

The severity of these environmental impacts is strongly influenced by the geographical location of data centers. In regions with abundant rainfall and water resources, data center water use may represent a small fraction of the total available supply. However, in drought-prone or water-stressed areas, these facilities can significantly worsen existing water shortages. According to The Guardian (2025), data centers in regions such as Las Vegas and Reno, Nevada, and Phoenix and Mesa, Arizona, draw from already limited water supplies, creating direct competition between technological infrastructure, agriculture, urban populations, and ecosystem conservation. These regions rely on fragile river systems, including the Colorado River, which also supports endangered species such as the razorback sucker fish and southwestern willow flycatcher. In these areas, each gallon of water used for cooling data centers reduces water availability for other essential needs. The concentration of data centers in major cities worldwide, including Ashburn (Virginia), Singapore, and London, shows that water and ecosystem pressures are a global concern.

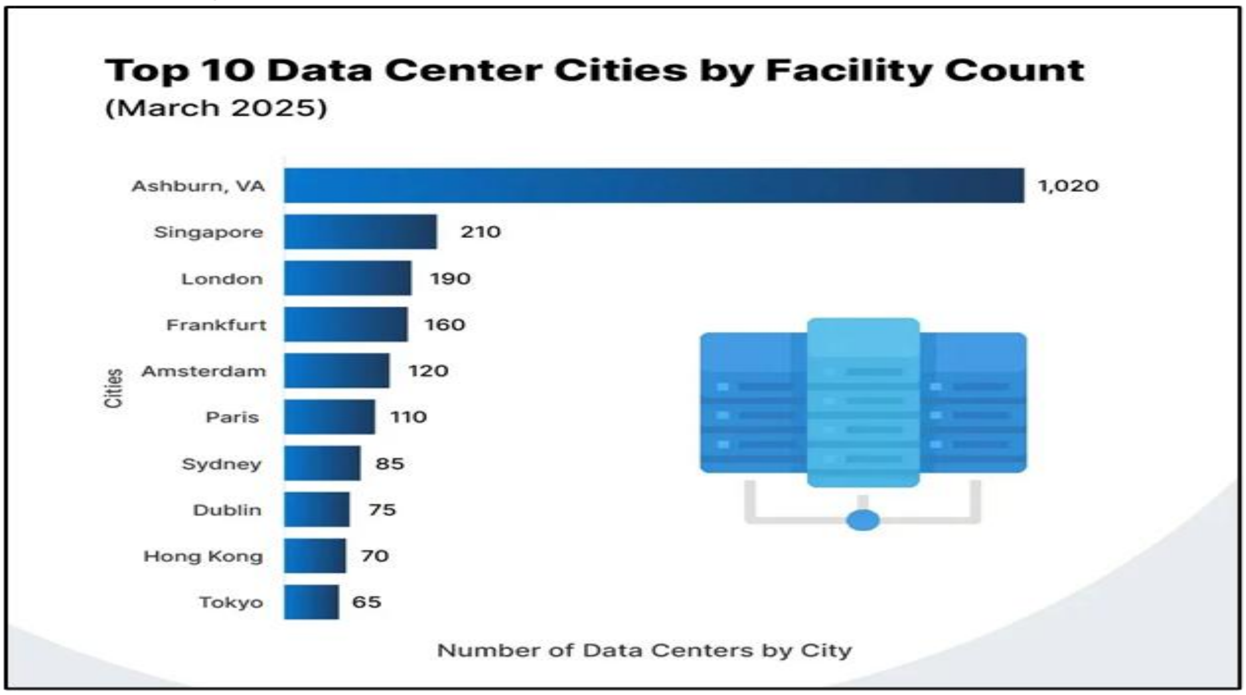

Figure 5: Top cities hosting the world's most data centers in 2025, illustrating global data center concentration in key metropolitan hubs such as Ashburn (Virginia), Singapore, and London.

Industry Innovation and the Path Toward Sustainability

Awareness of these environmental challenges has led the data center industry to develop more sustainable solutions. Major technology companies have started investing in cooling systems that dramatically reduce or completely eliminate water consumption. For example, Microsoft (2024) has announced plans to reduce or eliminate water use in new data center facilities. These reductions are achieved through the use of liquid cooling directly on the computer chips and closed systems that continuously recycle the same water rather than wasting it. In certain locations, alternative approaches such as seawater or geothermal energy are used to cool their facilities. Starting in August 2024, Microsoft introduced data centers featuring zero water evaporation cooling designs that recycle water in a closed loop, conserving up to 125 million liters of water annually per data center (Data Center Frontier, 2024). In aggregate, these technologies demonstrate that high-performance computing can be supported without reliance on freshwater resources.

Several technology companies have made public commitments to water conservation. Google has committed to replenishing 20% more water than it consumes by 2030 and currently uses reclaimed or non-potable water in over 25% of its data center locations (Data Centre Magazine, 2023). Similarly, Amazon Web Services (AWS) announced plans to become water positive by 2030 and has already implemented purified wastewater to cool 20 of its data centers, effectively converting waste streams into a productive resource (Data Centre Magazine, 2023). The company is also using reclaimed and recycled water in water-scarce regions like Texas, California, and Singapore. Additionally, Google is developing new cooling solutions capable of reducing data center water consumption by as much as 50% without compromising energy efficiency (Data Center Frontier, 2023).

Closed-loop cooling systems represent one of the most promising approaches to reducing data center water consumption. Unlike traditional evaporative systems, which constantly consume and discharge water, closed-loop designs recirculate the same water through the cooling infrastructure, with minimal losses to evaporation or minor leaks. NVIDIA has implemented closed-loop liquid cooling systems that use an engineered coolant composed of a blend of propylene glycol, water, and corrosion inhibitors, which eliminates evaporative water loss and significantly improves water efficiency (NVIDIA, 2024). The company reports that this innovation allows high computing performance with reduced environmental impact. Some advanced facilities have achieved water reductions exceeding 90% by combining these systems with air-cooling during cooler seasons (Veolia, n.d.). In addition, NVIDIA has introduced new high-temperature water cooling systems capable of operating without traditional chillers, using water at approximately 45 °C to remove heat directly from servers. This design reduces both energy and water consumption by eliminating chiller requirements and allowing dry ambient air to reject heat. Together, these features illustrate an additional pathway toward more sustainable data center operations (Fierce Network, 2025).

In addition to cooling systems, major technology companies are rolling out comprehensive water conservation initiatives. NVIDIA's LEED Gold-certified facilities incorporate low-flow plumbing fixtures, use recycled water for toilet flushing and cooling towers, and feature drought-tolerant landscaping irrigated with reclaimed water (NVIDIA, 2024). The company also conducts annual water risk assessments across facilities and supply chain partners to identify where conservation initiatives are most needed, demonstrating strategic planning for addressing water impacts. Similarly, Microsoft has also invested in nearly 50 water replenishment projects worldwide, including land conservation, aquatic habitat restoration, and water quality improvement efforts (Data Center Frontier, 2024).

Despite these technological advances, several barriers still prevent widespread adoption. Many operators continue to rely on using legacy, water-intensive cooling systems, and transparency about water consumption varies dramatically across the industry. The Guardian (2025) reports that voluntary disclosure of water use has been inconsistent, making it difficult to assess the industry’s full environmental impact. This lack of transparency has prompted environmental organizations and policy analysts to advocate for mandatory reporting requirements to establish industry standards and enable more effective oversight of water use.

Counterarguments and Limitations

Although environmental concerns with data center water use are significant, it is important to recognize some opposing perspectives and current research limitations. Some critics argue that mandating the adoption of expensive advanced cooling technologies could impose a financial burden on smaller companies that lack the capital for major upgrades. Certain advanced cooling systems, such as seawater cooling approaches, only work in certain geographical locations and can not be implemented universally. Additionally, current research faces limited data availability as many data centers do not disclose detailed water use metrics, complicating efforts to assess the full picture of the industry’s real impact. At the same time, data centers provide essential critical services, including remote work, online education, and telemedicine. Accordingly, the goal is not to eliminate data centers, but to find optimal ways to operate them more sustainably that balance the economic challenges and genuine environmental protection that is technically feasible.

V. DISCUSSION

The research evidence shows that data center water consumption represents a real environmental challenge that is likely to get worse as AI and cloud computing continue to grow. At the same time, facilities that have successfully implemented low-water and zero-cooling systems show that these solutions are a viable way forward. The primary obstacles to broader adoption are not about technology but about economic, regulatory, and transparency issues. Policy measures can play a central role in closing these gaps. Governments could require standardized public reporting of their water use, similar to existing emissions disclosure, to improve accountability and enable more accurate impact assessment. Policies for new data center site selections should also incorporate water availability as a major criterion, where abundant regions are suitable for conventional cooling, or water-stressed areas that require low water technologies. In parallel, market pressure from consumers and businesses can play a key role by favoring cloud providers that prioritize sustainability. As climate change intensifies water scarcity in many regions, the long-term viability of digital infrastructure will rely on reducing its environmental footprint. The challenge is not a choice between technological progress and environmental protection, but whether policy, investment, and facility decisions will align to support both advancements.

VI. CONCLUSION

Data center water consumption presents a serious challenge where technological advancement meets ecological responsibility. This paper demonstrates that data centers consume water at scales similar to entire towns, with measurable consequences for local ecosystems, including reduced streamflows, altered water temperatures, and increased stress on aquatic life. These effects are especially severe in water-stressed regions where data center demands directly compete with agricultural use, urban cities, and environmental needs.

Advances in sustainable technologies offer hope. Technological innovations have produced viable alternatives to water-intensive cooling, with several facilities achieving near zero water consumption through advanced systems. These successful outcomes indicate that tension between digital infrastructure and ecological sustainability is not inevitable, but largely driven by older practices that can be replaced through investment and continued innovation.

Meaningful progress will require coordinated action across multiple fronts. Policymakers can establish mandatory water usage reporting requirements and incorporate water resource availability into data center facility approval decisions. Industry operators must accelerate the adoption of water-efficient technologies while improving transparency in their water disclosures. Researchers can continue to play a key role in evaluating cumulative environmental impacts and assessing the effectiveness of emerging solutions. Finally, consumers and businesses should recognize their role in demanding sustainable practices and supporting providers that demonstrate them.

The digital revolution has transformed society in profound ways, enabling connection, access to knowledge, and technical capabilities that previous generations could not have imagined. Ensuring transformation proceeds sustainably, meeting today's needs without compromising future generations' access to essential resources, is one of the defining challenges of our time. Data center water consumption exemplifies this broader sustainability challenge while also representing a problem that can be effectively addressed. The extent to which society implements these solutions will determine not only the fate of local aquatic ecosystems but also whether technological advancement and environmental stewardship can successfully coexist.

REFERENCE

[1] Aga Khan Agency for Habitat. (n.d.). Water and sanitation. Retrieved January 30, 2026, https://the.akdn/en/how-we-work/our-agencies/aga-khan-agency-habitat/water-and-sanitation
[2] Aga Khan Development Network. (n.d.). Environment and climate. Retrieved November 20, 2025, https://the.akdn/en/how-we-work/our-agencies/aga-khan-health-services/environment-and-climate
[3] Aga Khan Development Network. (n.d.-b). Environment and climate change. Retrieved January 30, 2026, https://the.akdn/en/what-we-do/building-resilient-communities/environment-climate-change
[4] Aga Khan Development Network. (n.d.-c). Our approach to development. Retrieved January 30, 2026, https://the.akdn/en/how-we-work/our-approach/our-approach-to-development
[5] Aga Khan Foundation Canada. (2017). Policy for environmental sustainability 2015–2024. https://cooperation.ca/wp-content/uploads/2020/09/AKFC-Policy-for-Environmental-Sustainability-2015-2024_UPDATED-JULY-2017-1.pdf
[6] Amplyfi. (n.d.). AI’s growing ecological footprint: Energy, water, and resource challenges. Retrieved January 30, 2026, https://amplyfi.com/blog/ais-growing-ecological-footprint-energy-water-and-resource-challenges/
[7] Ceres. (2025). Drained by data: The cumulative impact of data centers on regional water stress. Retrieved November 30, 2025, https://www.ceres.org/resources/reports/drained-by-data-the-cumulative-impact-of-data-centers-on-regional-water-stress
[8] Data Center Frontier. (2023, March 1). Google developing new climate-conscious cooling tech to save water. https://www.datacenterfrontier.com/cooling/article/33001080/google-developing-new-climate-conscious-cooling-tech-to-save-water
[9] Data Center Frontier. (2024, December 26). Microsoft's 'sustainable by design' initiative seeks to transform data center water efficiency. https://www.datacenterfrontier.com/sustainability/article/55249649/microsofts-sustainable-by-design-initiative-seeks-to-transform-data-center-water-efficiency
[10] Data Centre Magazine. (2023, November 28). Reclaimed wastewater to be used at 20 AWS locations. https://datacentremagazine.com/articles/reclaimed-wastewater-to-be-used-at-20-aws-locations
[11] Environmental Law Institute. (2025). AI's cooling problem: How data centers are transforming water use. Retrieved December 10, 2025, https://www.eli.org/vibrant-environment-blog/ais-cooling-problem-how-data-centers-are-transforming-water-use
[12] Fierce Network. (n.d.). NVIDIA has no chill: AI drives explosive data center cooling demand. Retrieved January 30, 2026, https://www.fierce-network.com/cloud/nvidia-has-no-chill
[13] GRESB. (2025). Cooling data centers: Managing water use in the age of AI and ESG. Retrieved December 10, 2025, https://www.gresb.com/nl-en/cooling-data-centers-managing-water-use-in-the-age-of-ai-and-esg/
[14] International Energy Agency. (2025). Global data centre electricity consumption, by equipment, Base Case, 2020–2030 — chart. https://www.iea.org/data-and-statistics/charts/global-data-centre-electricity-consumption-by-equipment-base-case-2020-2030
[15] Microsoft. (2024, December 9). Sustainable by design: Next-generation datacenters consume zero water for cooling. Microsoft Cloud Blog. https://www.microsoft.com/en-us/microsoft-cloud/blog/2024/12/09/sustainable-by-design-next-generation-datacenters-consume-zero-water-for-cooling/
[16] Nature Water. (2021). Data centers and water use (Article 101). https://www.nature.com/articles/s41545-021-00101-w
[17] NVIDIA Corporation. (2024). FY2024 corporate sustainability report. https://images.nvidia.com/aem-dam/Solutions/documents/FY2024-NVIDIA-Corporate-Sustainability-Report.pdf
[18] OilPrice.com. (2025). U.S. data center demand could hit 106 GW by 2035. Retrieved January 15, 2026, https://oilprice.com/Energy/Energy-

General/US-Data-Center-Demand-Could-Hit-106-GW-by-2035.html

[19] Pew Research Center. (2025, October 24). What we know about energy use at U.S. data centers amid the AI boom. https://www.pewresearch.org/short-reads/2025/10/24/what-we-know-about-energy-use-at-us-data-centers-amid-the-ai-boom/

[20] S&P Global. (2025, October 14). Data center grid-power demand to rise 22% in 2025, nearly triple by 2030. https://www.spglobal.com/energy/en/news-research/latest-news/electric-power/101425-data-center-grid-power-demand-to-rise-22-in-2025-nearly-triple-by-2030

[21] The Guardian. (2025, July 16). Zuckerberg says Meta will build a data center the size of Manhattan in latest AI push. https://www.theguardian.com/technology/2025/jul/16/zuckerberg-meta-data-center-ai-manhattan

[22] The Guardian. (2025, December 4). Nevada AI data centers. https://www.theguardian.com/technology/2025/dec/04/nevada-ai-data-centers

[23] Veolia. (n.d.). Data center cuts annual water consumption by more than 12 million gallons [Case study]. Retrieved January 5, 2026, https://www.watertechnologies.com/case-study/data-center-cuts-annual-water-consumption-more-12-million-gallons