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The Environmental Cost of Artificial Intelligence

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Abstract

Artificial Intelligence (AI) has simultaneously amplified and simplified everything for people, from virtual assistants to climate probabilities. However, AI comes with a hidden ecological catch along its remarkable benefits—most notably, massive water consumption. This paper delves into the significant water footprint of AI and its primary data centres, examining the factors contributing to its unprecedented hydrological footprint and the subsequent environmental impacts. As AI continues to evolve into Generative AI like ChatGPT, its demand for fresh water is expected to rise, placing additional strain on already scarce finite drinkable water resources. The paper explores the broader natural and socio-economic impacts of AI's water usage, highlighting the potential for point of contentions for near-term water shortages. AI can be used to harness and visualise data sets for Disaster Risk Reduction (DDR), such as improving water management and forecasting weather which involves millions of data inputs. However, the overall toll it takes on natural resources are and will be unsustainable. Primary data collected for the paper highlights where

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water is being consumed and what are its implications in Pakistan. The paper concludes with recommendations for minimising AI’s water footprint, including the adoption of recycled water and innovative cooling technologies to ease the burden on the planet's precious water supply.

Keywords: Artificial Intelligence (AI), water footprint, Pakistan, weather forecasting, climate change, monsoon.

The Environmental Cost of Artificial Intelligence (AI)

We live in a technologically advanced world where AI has become deeply embedded in our lives. Data bits serve as the lifeblood of AI, enabling it to process massive datasets and generate innovations. Through Large Language Models (LLMs) and advanced machine learning, AI mimics human thought and decision-making, with the potential to surpass its creators. It is where algorithms meet intuition, blurring the boundaries between virtual and physical realities every day. AI is so integrated into daily life that it increasingly hinders people from thinking creatively, as they rely on advanced tools instead. While AI has made life more convenient, it also contributes to negative environmental impacts, including a significant water footprint alongside carbon emissions.

The term *water footprint* refers to the total amount of water, directly or indirectly, consumed by AI models. For instance, the water footprint of OpenAI’s GPT-3 is approximately 700,000 litres, with GPT-4 demanding even more due to its complexity. Understanding these numbers has become increasingly urgent. The current level of consumption is critical to address, as the world is facing increasing water scarcity, with dwindling reservoirs of fresh water available for drinking and daily use.

Pivotal Water

Advance supercomputing is used for LLMs such as OpenAI's ChatGPT, which generate considerable amount of heat for high-performance. They need a significant amount of water to cool down the data centres. The high specific heat capacity and thermal conductivity of water makes it specifically efficient for this purpose.

Servers are 'thirsty' for improvement of the hardware, and it has some environmental costs that may include air pollution or carbon emission.[1] There are the two ways for the consumption:[2]

On-site water consumption

Working AI models consume considerable amounts of energy and generates heat in the outside environment. So, they use a large amount of clean and fresh water to avoid overheating. In cooling towers evaporated water is used to generate chilled water. Heat from the surrounding environment helps in the evaporation process that effectively reduces the water's temperature. This method is useful for managing humidity and excessive heat, especially in dry external conditions.

Off-site water consumption

The AI mechanism installed at the site of the electricity production through thermal power and nuclear power plants also consume a large volume of water for cooling purposes, which is categorised as the off-site water consumption.

Hydro-footprint of LLMs

In 2022, water consumption for cooling of the data centres increased 20 per cent in comparison to 2021[3] and 34 per cent increase in water consumption by Microsoft in 2022.[4] According to the recent reports of 2024, Apple, Microsoft, Meta and Google emit 662 per cent of greenhouse gases such as carbon dioxide, etc. from 2020 to 2022, and this heat emission needed to be cooled down.[5] AI is becoming a large threat to the freshwater reservoirs on the world, and it will become difficult for the people living in the world to use water from the available resources.

According to the latest Sustainability Report released by Microsoft shown in table 1, a backer of OpenAI, there was a massive increase in the water consumption between 2021 and 2022 and is rising by the software companies.[6] It has increased by 35 per cent and 1.7 million gallons of water year by year. Where in 2021, 4,772,890 cubic meters of water will be used by Microsoft as compared to 6,399,415 presents.

Table 1

Water Consumption by different Companies in 2021 and 2022

Company	Water Consumption 2021 (cubic meters)	Water Consumption 2022 (cubic meters)
Microsoft	4,772,890	6,399,415
Google	5,000,000 approx.	6,000,000 approx.
Amazon	3,500,000 approx.	4,200,000 approx.
Meta	2,800,000 approx.	3,360,000 approx.
Apple	2,000,000 approx.	2,400,000 approx.

AI consumes 9 litres of water per kWh of energy in cooling towers and air mechanisms to dispatch heat.[7] And according to the recent study in Nature, the consumption of water by AI will be increased from 4.2 billion and 6.6 billion cubic meters by 2027 that is equal to half of the consumption of water by the UK in half a year.[8] By the consumption of this amount the tech giants such as Google, Microsoft, and Meta are raising serious concerns about the environmental issues.[9] In this process the chilled water is used to absorb the heat produced by the working of the AI on the on-site or off-site and water is evaporated. This water is reused by some centres after recycling, but a large volume of fresh water is wasted for this purpose.[10]

By 2026 the energy consumption of the AI will be doubled and by 2027, 4.2 to 6.6 billion cubic meters of water will be dried for cooling down the technology firms and data centres.[11] According to researchers water will be scarcer than oil by 2030 and demand will be increased by 40 per cent of supply.[12] According to United Nations indexes, the world population is increasing and will reach 9 billion by 2037 and as a result the demand for water will also be increased with 2.2 billion people not having access to the drinking water services by UNICEF, 2019.[13]

Table 2 provides insights into the water consumption and energy intensity involved in running GPT-3 models across different countries. It highlights metrics such as Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE), and electricity water intensity, illustrating the environmental impact of AI operations.

Table 2

GPT-3: Average Operational Water Consumption Footprint Across Different Countries

Location	PUE	WUE (L/kWh)	Electricity Water Intensity (L/kWh)	Water for Training (million L)	Water for Each Inference (mL)	# of Inference for 500ml Water
US Average	1.170	0.550	3.142	5.439	16.904	29.6
India	1.430	0.000	3.445	6.340	19.704	25.4
Lowa	1.160	0.190	3.104	4.879	15.163	33.0
Arizona	1.223	2.240	4.959	10.688	33.219	15.1
Washington	1.156	1.090	9.501	15.539	48.294	10.4
Sweden	1.172	0.160	6.019	9.284	28.856	17.3

Impacts of AI Water Consumption

Environmental Impact

AI's extensive water use increases global water scarcity, affecting over 2 billion people without access to safe drinking water. This crisis contributes to droughts, floods, and biodiversity loss, jeopardising ecosystems and human well-being. For instance, each 10-50 prompts on GPT-3 equates to the water required to fill a 500ml bottle.[14]

a) Social and Economic Tensions

The increasing strain on water resources could trigger social unrest and economic instability. In Iowa, for example, AI data centres have depleted local aquifers, impacting residents' quality of life and property values. If unchecked, AI's water consumption could foster competition and conflict over scarce resources.

b) Water Pollution

The production of AI hardware involves extracting rare materials like boron and gallium, which contributes to water pollution and health risks.[15] Mining activities required for these components further harm the environment, exacerbating climate challenges.[16]

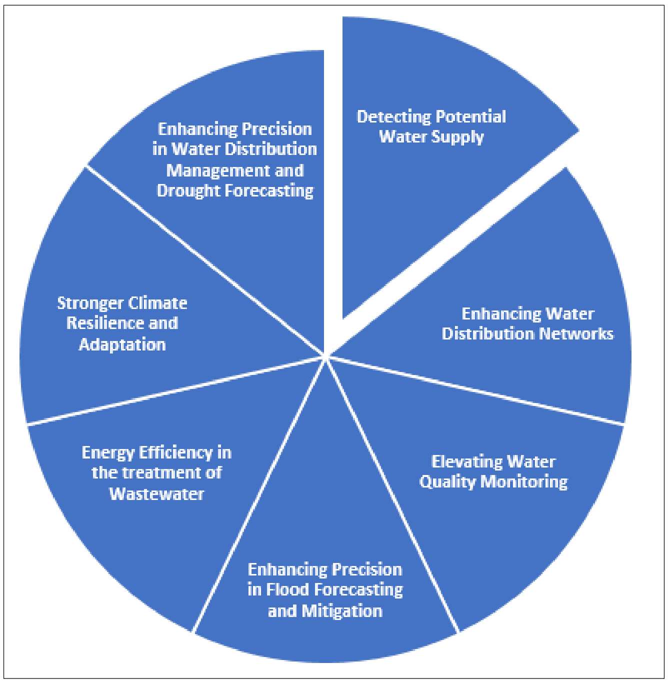
c) AI usage in Pakistan

In Pakistan, AI is integrated in the different sectors that highlights the country's commitment to the innovative technologies.[17] It is deployed in the agriculture field to improve agricultural practices, enabling precision farming for better crop yields, assists in tracking the deforestation rates and carbon storage in the forests as it is crucial for maintaining the ecological balance and helps in combating climate change with the weather prediction to restrain from extreme weather events, vital for disaster preparedness and response.[18]

Thus, the incorporation of advanced technologies, especially AI is revolutionizing our existence by offering solutions like digital twin, remote meter reading, and Internet of Things (IOT). These innovations foreshadow a new epoch in life management, enhancing areas such as water management, and predictive weather and flood forecasting,[19] leading to an unprecedented level of operational excellence. In addition to the weather and flood forecasting, Figure 1 illustrates some uses of AI in water management practices.

Figure 1

Uses of AI in Water Management Practices



AI Weather Forecasting and Applications

The recent significant advancement in AI enhanced its applications in earth systems, leading to the advancement of weather forecasting models by changing the traditional meteorological prediction limitations with precise atmospheric forecasting. Major tech companies such as Google, Microsoft, Huawei, Nvidia, etc. have developed their own AI models, that solely work on the data to forecast the weather [20] such as the Google DeepMind's Graph Cast[21] and MetNet-3.[22] As a result of the efficiency of these models, they have surpassed the traditional physics-based global numerical weather prediction (NWP) model in key forecast score which has made the task easier. These models are incorporated with historical weather data and provide comprehensive hour-to-hour accounts of the global ocean, land, and atmosphere waves. Mathematical models on the other hand are used to predict the weather based on current weather conditions. By integrating this analysis, the AI data-driven models refine their forecast and have the aspect of self-improvement and adaptation introduced in these models, which enhances a significant departure from the traditional models.[23]

Table 3 shows some weather prognosticating models of the different tech companies.

Table 3

The Representative LWMs developed Since 2020

Model	Institution	Spatial-Resolution	Methods	First Publication Time
CNN (Weather Bench)	Technical University of Munich	5.625°	CNN-based	2020.08
Resnet (Weather Bench)	Technical University of Munich	5.625°	CNN-based	2021.08
FourCastNet	NVIDIA	0.25°	Transformer-based	2022.02

SwinVRNN	Alibaba Damo Academy	5.625°	Transformer-based	2022.05
Pangu-weather	Huawei Cloud	0.25°	Transformer-based	2022.11
Graph Cast	Google DeepMind	0.25°	GNN-based	2022.12
ClimaX	Microsoft	1.4°	Transformer-based	2023.01
FengWu	Shanghai AI Lab	0.25°	Transformer-based	2023.04
Neural GCM	Google	0.7°	Hybrid model	2023.11
GenCast	Google	1°	Diffusion model	2023.12
FengWu-GHR	Shanghai AI Lab	0.09°	Transformer-based	2024.01

To conduct effective research on the use of water by AI data centres, an interview was held with Dr Kunwar Faraz, Head of the Department of Artificial Intelligence and Robotics at NUST University, Islamabad.

During the interview, Dr Faraz explained that AI and Machine Learning (ML) have not yet been extensively implemented in Pakistan for weather forecasting. Although some LLMs are being used in AI centres, their application remains limited, and there is ongoing research to determine which algorithms would be most effective for the country's needs. Dr Faraz acknowledged that the lack of implementation, meaning that, there is currently no data available on the water consumption of AI data centres in Pakistan. He referred to the National Centre of Artificial Intelligence (NCAI) for further information, but no relevant data was available.

Dr Faraz emphasised the importance of using unbiased data and deploying appropriate algorithms to ensure effective research and performance. He also noted that Pakistan is actively working on policies for AI development. The establishment of dedicated committees to formulate AI strategies, while also considering the environmental impacts of extensive AI usage, is essential. As discussed later, Pakistan is already employing AI in river monitoring for flood prediction and weather forecasting.

Precipitation Trend in Monsoon 2024

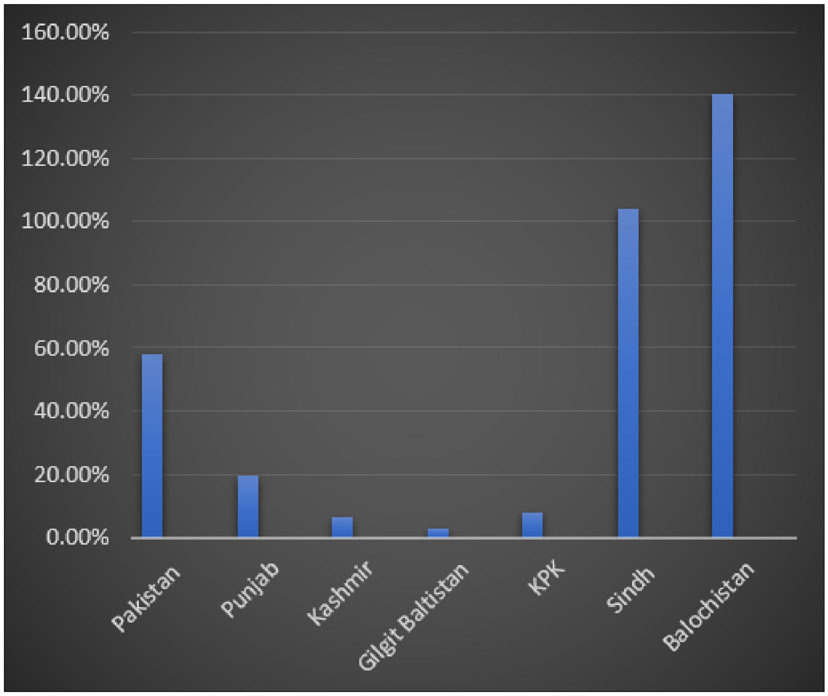
The distinctive location of Pakistan, straddling the Indian subcontinent and the edges of the Middle East, gives rise to a diverse climate that ranges from the coastal breezes of Karachi to the frigid peaks of the Karakoram. Hence, Pakistan is on the landscape where the heavy rains of monsoon cause rivers to swell, overflow and leading to floods.[24]

The monsoon season in Pakistan usually spans from June to September and is crucial for the cultivation of crops such as rice and cotton. Through intense rains to catastrophic floods, water is causing a lot of widespread destruction and hardship for farmers, risking crop damage with the far-reaching effects on food security and the economy. As Pakistan is among the countries that have frequent exposure to natural hazards like floods, unpredictable monsoon has recently become a crop killer.

According to the Monsoon Forecast 2024 shown in Figure 2, the expected percentage of departure of the monsoon 2024 in Pakistan is +57.8 per cent and a standard deviation of ±38.7 per cent of LPA.[25] And according to the Pakistan Monsson 2024 Rainfall Update, the average rainfall across Pakistan will be slightly below -15 per cent. Whereas, in Gilgit-Baltistan it is recorded at -67 per cent, in Punjab +11 per cent, in Sindh -48 per cent, in Balochistan it is -7 per cent, in KPK -33 per cent and in AJ&K it is -52 per cent.

Figure 2

Rainfall departure for Pakistan - Monsoon 2024



Hamza Hashmi, a meteorologist contends: "Monsoon 2024 is expected to enter the country around June 25-28.[26] During the months of July, August, and September, 105% to 115% more rain than usual is expected in Sindh province and Baluchistan… Similarly, 100% to 105% more rain than normal is expected in Punjab and K.P.K…"

The use of smart AI in weather and flood predicting models can aid the district disaster management authorities in efficient detecting of the floods and uncertain weather patterns. Although there is need of much enhancement of this section of Pakistan to move with the advancement of technology with the up developing era.

AI Forecasters in Pakistan

The heavy rainfalls of the monsoon in Pakistan are significantly contributing their role by causing severe floods. The floods of 2022 in Pakistan led to severe challenges for the country, affecting 33 million people, resulting in more than 170+ deaths, according to the reports.[27] Artificial Neural Network (ANN) and Support Vector Machine (SVM) are playing their significant role by collecting historical data regarding floods[28] and rainfalls in Pakistan for the flood forecasting by the machine learning technology. [29]

The significant AI integrated weather forecasters of the Pakistan include:

1. Nation Weather Forecasting centre (NWFC), Islamabad
2. AccuWeather (that provides the weather forecast and radar information of the major cities of Pakistan)
3. Pakistan Meteorological Department
4. Weather-Forecast.com (that provides the static weather maps for Pakistan)

Where in the flood forecasting, the machine learning techniques such as MLP, RF, and SVR are installed at Hunza River for monthly predictions, the AI models of the Jhelum River are trained and evaluated by the hit-and-trial method. According to the data of 1256 vectors, 70 per cent (885) vectors were considered for training, and the remaining 30 per cent were considered for testing by observing and building on the analyses from the previous studies.[30] Following are some of the notable flood forecaster initiatives in Pakistan working with AI.[31]

1. Ghulam Ishaq Khan of Engineering Sciences and Technology AI Research Group
2. Hunza River Dataset Study
3. Jhelum River Flood Forecasting Models
4. Disaster Mapping and Assessment

Recommendations

According to the water technology trends 2023, the demand for the water will rise to 30 per cent by 2050[32] and for the better management of water resources following measures should be adopted for their better usage:

Increasing the Recycled Water for Cooling

Sustainable water sources can be used for cooling down the data centres and can be used as water footprints. These water sources may include recycled water and rainwater, harvesting it where it can be. For instance, Amazon Web Series (AWS) are shifting to these water sources for cooling down their data centres. Currently, 20 data centres around the world of AWS are using recycled water. The first data centre of the AWS operating on the recycled water in direct cooling system was established in the Northern Virgina, London,[33] as an alternative to freshwater usage.

Using the Sea Water Instead of the Fresh Water

As the data centres use large amount of the fresh water for the cooling mechanism of their system that is already less than 1 per cent on the Earth so it should be replaced with the sea water for the cooling down purpose of the data centres. Such as in Finland, Hamina data centre uses the sea water in its cooling system.

Use of Renewable Resources

Companies including Meta, Microsoft, and Google have committed to top up more water by 2030 than they are using at present. For this purpose, they need to develop efficient projects for water conservation resources by using renewable resources such as wind and solar to reduce the water and carbon footprint and associated usage of the water.[34]

Technological Innovations

Technological innovation can help to reduce the extensive consumption of the water and non-renewable energy resources. This may include several strategies such as optimising the algorithm of the AI for the less consumption of the water, introduction of the advanced cooling techniques like the closed-loop system can be developed that will recycle the water and it can be reused. By optimisation, shifting the high electricity demands of the AI by changing in the system and algorithms of the artificial intelligence can help reduce the need of the water for cooling down the AI model(s) and data centres, where AI can itself be leveraged to manage the water resources efficiently. Adoption of such innovations in modern technology can help mitigate the water crisis that is going to be a significant risk to the world.

Conclusion

Artificial Intelligence offers remarkable benefits across various sectors, from enhancing everyday conveniences to supporting areas like weather forecasting and disaster management. However, its environmental costs, particularly water consumption, poses serious challenges. The growing reliance on AI models, such as GPT-3 and GPT-4, has resulted in the depletion of freshwater resources, with large data centres consuming vast amounts of water for cooling systems. As AI usage expands, so does environmental risk(s), including water pollution, biodiversity loss, and societal tensions over resource scarcity. In Pakistan, the implementation of AI remains limited, particularly in areas like weather forecasting, but efforts are underway to align AI policies with national priorities. The country must address the ecological impacts of AI adoption by ensuring that water management strategies are in place.

To mitigate the negative impact of AI, sustainable practices should be adopted such as using recycled water, switching to seawater for cooling, and investing in renewable energy resources. Technological innovations like advanced cooling systems and algorithmic optimisation will also play a role in reducing AI's environmental footprint. Without responsible water management and environmental conservation strategies, the benefits of AI may come at an unaffordable ecological cost.

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