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THE ROLE OF AI IN PREDICTING DISEASE OUTBREAKS

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Abstract.

Artificial Intelligence (AI) has emerged as a crucial tool in predicting disease outbreaks, revolutionizing public health surveillance and response systems. By leveraging machine learning algorithms, big data analytics, and deep learning techniques, AI can analyze vast datasets to detect patterns, identify risk factors, and forecast potential outbreaks with remarkable accuracy. This paper explores the various applications of AI in epidemiology, discussing its role in data collection, analysis, and prediction of infectious diseases such as COVID-19, influenza, and dengue fever. We also examine the challenges associated with AI-driven disease prediction, including data privacy concerns, ethical considerations, and the need for robust AI frameworks. The study provides insights into the future of AI in global health security, emphasizing its potential to enhance early warning systems and disease prevention strategies.

Keywords: *Artificial Intelligence, Disease Prediction, Epidemiology, Machine Learning, Public Health, Big Data, AI in Healthcare.*

INTRODUCTION

The advent of Artificial Intelligence (AI) has revolutionized numerous sectors, including healthcare and epidemiology. AI-powered disease prediction models offer a proactive approach to public health management by analyzing large-scale data from multiple sources, including electronic health records (EHRs), social media, and satellite imagery. The ability of AI to recognize patterns and make accurate predictions has significantly improved early outbreak detection, response, and mitigation strategies. This paper explores the role of AI in predicting disease outbreaks, focusing on its methodologies, applications, and challenges.

Understanding AI in Disease Prediction

Artificial Intelligence (AI) has significantly transformed disease prediction and surveillance, allowing for early detection, risk assessment, and mitigation of infectious diseases. AI-driven models analyze vast amounts of data to recognize patterns and forecast outbreaks, enhancing global public health response systems.

Machine Learning and Deep Learning Techniques

Machine learning (ML) and deep learning (DL) techniques are at the core of AI-based disease prediction models. These techniques analyze data from multiple sources to detect patterns, correlations, and potential disease outbreaks.

Machine Learning (ML) Techniques

ML algorithms use historical and real-time data to build predictive models. Some commonly used ML techniques in disease prediction include:

- **Supervised Learning:** Used for classification and regression tasks, such as predicting disease spread based on historical patterns (e.g., Support Vector Machines, Decision Trees).
- **Unsupervised Learning:** Helps in clustering and anomaly detection (e.g., K-Means clustering for identifying disease hotspots).
- **Reinforcement Learning:** Optimizes decision-making for outbreak containment (e.g., adaptive healthcare response strategies).

Deep Learning (DL) Techniques

Deep learning, a subset of ML, involves neural networks that can model complex patterns and relationships in large datasets. Common DL models used in disease prediction include:

- **Convolutional Neural Networks (CNNs):** Useful for image-based disease detection, such as analyzing X-ray or CT scan images for pneumonia or COVID-19.
- **Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM):** Effective for analyzing time-series data to predict disease trends over time.
- **Transformer-based Models:** Advanced architectures like BERT and GPT assist in processing epidemiological text data and reports for disease tracking.

Data Sources for AI-Based Disease Prediction

AI models rely on diverse and comprehensive datasets for accurate disease prediction. The most common data sources include:

Electronic Health Records (EHRs)

- AI can analyze patient records to identify early signs of disease outbreaks.
- Examples: Hospital admissions, clinical test results, medication records.

Social Media and Internet Searches

- AI-driven sentiment analysis and keyword tracking help identify disease trends.
- Example: Google Flu Trends, Twitter-based disease tracking.

Genomic and Biological Data

- AI analyzes genetic mutations to predict potential disease outbreaks.
- Example: Sequencing data from COVID-19 variants.

Wearable and IoT Health Devices

- Smartwatches and health monitoring devices provide real-time patient data.
- Example: Apple Health, Fitbit, continuous glucose monitoring systems.

Satellite and Environmental Data

- AI processes climate, pollution, and geographic data to predict vector-borne diseases.
- Example: Predicting malaria outbreaks using temperature and rainfall patterns.

Public Health Surveillance Data

- AI integrates reports from health organizations for real-time disease tracking.
- Example: WHO and CDC surveillance reports, government health databases.

The integration of AI in disease prediction leverages machine learning, deep learning, and big data analytics to enhance outbreak forecasting and healthcare decision-making. However, challenges such as data privacy, ethical concerns, and model interpretability must be addressed to fully harness AI's potential in global health security.

AI applications in predicting disease outbreaks

Artificial Intelligence (AI) has significantly enhanced the ability to predict and control disease outbreaks. By leveraging machine learning, big data analytics, and deep learning, AI enables early detection, real-time surveillance, and outbreak forecasting. This section explores how AI is applied in disease surveillance, early warning detection, and provides case studies of major disease outbreaks.

Surveillance of infectious diseases

AI-powered surveillance systems integrate diverse data sources, including clinical records, environmental factors, and social media trends, to track and predict disease patterns. These systems help public health officials make data-driven decisions to mitigate the spread of infections.

AI-Driven Epidemiological Models

- AI models use historical health data and real-time reports to identify disease transmission patterns.
- Algorithms such as **Bayesian Networks** and **Recurrent Neural Networks (RNNs)** help model disease spread over time.

Natural Language Processing (NLP) for Public Health Monitoring

- AI scans news reports, research papers, and social media for early disease signals.
- Example: The **BlueDot AI System**, which predicted the COVID-19 outbreak before WHO announcements by analyzing online health discussions.

AI in Global Disease Surveillance Networks

- WHO's **Epidemic Intelligence from Open Sources (EIOS)** integrates AI to monitor disease trends globally.

- AI in **Google Flu Trends** and **HealthMap** aids in real-time disease surveillance.

AI IN DETECTING EARLY WARNING SIGNALS

AI plays a vital role in identifying anomalies that may indicate an impending outbreak, enabling rapid intervention and containment efforts.

AI-Based Predictive Analytics for Outbreaks

- Machine learning models analyze **historical epidemiological data** to forecast outbreaks.
- Example: **Support Vector Machines (SVMs)** and **Random Forest models** have been used to predict dengue fever outbreaks in tropical regions.

AI in Wastewater-Based Epidemiology (WBE)

- AI-assisted wastewater analysis detects viral load levels to predict potential outbreaks.
- Example: **SARS-CoV-2 RNA detection in wastewater** during the COVID-19 pandemic provided early indicators of surges in infections.

AI and Climate-Based Disease Predictions

- AI models integrate weather, temperature, and humidity data to predict vector-borne diseases.
- Example: **Malaria and dengue fever predictions** based on seasonal climate trends.

Case studies: ai in predicting major disease outbreaks

Case Study: AI and COVID-19 Prediction

- AI models analyzed global travel data and genomic sequences to predict the rapid spread of SARS-CoV-2.
- The AI-powered **BlueDot System** identified the COVID-19 outbreak **nine days before the WHO announcement** by scanning online reports and airline ticket sales data.
- **Deep Learning Models (LSTM, CNNs)** helped forecast ICU bed requirements, mortality rates, and regional case spikes.

Case Study: AI in Dengue Fever Prediction

- AI-based early warning systems use **climate data, mosquito population trends, and urbanization patterns** to predict dengue outbreaks.
- Example: Researchers in Pakistan used **machine learning models (Gradient Boosting, XGBoost, and Random Forests)** to predict dengue fever outbreaks in **Karachi and Lahore** with **over 90% accuracy**.

Case Study: AI and Influenza Surveillance

- **Google Flu Trends** used AI to analyze flu-related search queries, providing near real-time flu outbreak predictions.
- AI-assisted influenza models utilize **genetic sequencing and deep learning** to track virus mutations and potential seasonal outbreaks.
- The **FluSight AI** model, developed by the **Centers for Disease Control and Prevention (CDC)**, predicts flu peaks weeks in advance, aiding vaccine distribution planning. AI applications in disease outbreak prediction have revolutionized public health preparedness by providing **real-time surveillance, early warning systems, and predictive modeling**. From **COVID-19**

detection to dengue fever forecasting, AI has demonstrated its ability to anticipate and mitigate infectious disease outbreaks. Moving forward, integrating AI with **big data, IoT, and public health policy** can further enhance its predictive capabilities, ensuring a more resilient global health infrastructure.

Ai and big data in epidemiology

The integration of **Artificial Intelligence (AI) and Big Data** has transformed epidemiology, providing unprecedented capabilities in disease prediction, surveillance, and response planning. AI-driven disease prediction models analyze massive datasets, helping researchers and public health officials detect outbreaks earlier and respond more effectively. This section explores the role of Big Data in AI-based disease prediction and how AI is integrated into public health systems.

Role of big data in ai-driven disease prediction

Big Data encompasses vast amounts of structured and unstructured information collected from **clinical records, genetic sequencing, environmental data, and social media**. AI algorithms process and analyze these datasets to identify trends, correlations, and risk factors associated with disease outbreaks.

Sources of Big Data in Disease Prediction

AI models utilize various sources of Big Data for disease surveillance and forecasting:

- **Electronic Health Records (EHRs)** – AI extracts patterns from millions of patient records to track disease spread.
- **Genomic Data** – AI analyzes pathogen mutations to predict new virus strains.
- **Social Media & Search Engine Data** – AI scans online activity for early disease symptoms and outbreak signals.
- **Environmental and Climate Data** – AI processes temperature, humidity, and pollution levels to predict climate-sensitive diseases (e.g., malaria, dengue).
- **Wearable and IoT Health Data** – AI integrates data from smartwatches and biosensors to detect anomalies in population health.

Big Data Analytics Techniques for Disease Prediction

- **Machine Learning Algorithms:** AI applies supervised and unsupervised learning techniques to detect disease trends.
- **Natural Language Processing (NLP):** AI processes text-based data from research papers, health records, and news reports.
- **Predictive Modeling:** AI forecasts disease outbreaks using time-series analysis and statistical regression models.
- **Geospatial Mapping:** AI visualizes disease spread using GIS (Geographic Information System) data.

Case Example: AI and Big Data for COVID-19 Predictions

During the COVID-19 pandemic, AI models trained on **big data from medical records, genomic sequencing, and mobility patterns** successfully predicted virus hotspots. Google and Apple's

mobility reports, combined with **AI-driven contact tracing apps**, provided real-time infection tracking.

Integration of ai with public health systems

The integration of AI into public health **systems** enhances disease surveillance, improves response strategies, and strengthens healthcare infrastructure.

AI in Real-Time Public Health Monitoring

- AI-powered surveillance systems analyze global health data to detect emerging outbreaks.
- **WHO's Epidemic Intelligence from Open Sources (EIOS)** and **HealthMap** use AI to track disease spread in real time.
- **AI-driven chatbots** (e.g., COVID-19 self-assessment tools) assist in mass health screenings.

AI in National and Global Disease Control Strategies

- **AI-driven dashboards** provide governments with predictive insights for epidemic preparedness.
- AI is used in **contact tracing apps** (e.g., Aarogya Setu in India, NHS COVID-19 App in the UK).
- AI models assist **vaccination distribution planning** based on outbreak predictions.

AI and Telemedicine in Public Health

- AI-driven **telehealth platforms** enable remote patient monitoring and early disease diagnosis.
- **AI-assisted diagnostics** (e.g., chest X-ray analysis for tuberculosis detection) improve medical accessibility in underserved areas.

Case Example: AI-Powered Disease Surveillance in Africa

The **African CDC** uses AI-powered tools like **Deep Learning for Epidemic Forecasting (DLEF)** to predict outbreaks of **Ebola, malaria, and cholera**, enabling **proactive intervention strategies**.

The synergy between **AI and Big Data** is revolutionizing epidemiology, offering powerful tools for **early disease detection, predictive modeling, and health system optimization**. AI's integration into **public health infrastructure** enhances real-time monitoring, outbreak forecasting, and resource allocation. Moving forward, **improving data accessibility, standardizing AI models, and addressing ethical considerations** will be crucial for leveraging AI's full potential in global disease prevention.

Challenges and limitations of ai in disease prediction

Despite the transformative potential of **Artificial Intelligence (AI) in predicting disease outbreaks**, several challenges and limitations hinder its full-scale implementation. Ethical concerns, data privacy risks, and resource constraints in developing regions remain significant

obstacles. This section explores these challenges and highlights the limitations of AI in low-resource settings.

Ethical concerns and data privacy

The integration of AI in disease prediction raises critical ethical concerns, particularly regarding **data privacy, bias, and transparency**. Since AI relies on massive datasets, ensuring responsible data collection and ethical AI deployment is essential.

Privacy and Confidentiality Issues

- AI-driven disease surveillance depends on **electronic health records (EHRs), social media activity, and personal sensor data**. Unauthorized access to such data may violate patient confidentiality.
- Example: **COVID-19 contact tracing apps (e.g., NHS COVID-19, Aarogya Setu)** faced criticism for potential data breaches and lack of user consent.

Bias and Algorithmic Fairness

- AI models trained on **skewed or incomplete datasets** can produce biased predictions, disproportionately impacting marginalized populations.
- Example: An **AI-driven COVID-19 risk prediction model** underestimated risks for lower-income communities due to a lack of representative training data.

Lack of Explainability (Black Box AI)

- Many **deep learning models** used in epidemiology operate as “black boxes,” making it difficult for healthcare professionals to interpret predictions.
- Lack of transparency reduces **trust** in AI-generated disease forecasts.

Ethical Dilemmas in AI-Driven Decision-Making

- AI predictions can influence **government policies, lockdown measures, and vaccine distribution strategies**. If misused, AI-driven decision-making can lead to unintended social consequences.
- Example: Predictive models that flagged high-risk regions for **COVID-19 lockdowns** faced criticism for disproportionately affecting low-income areas.

Limitations of ai in low-resource settings

While AI has revolutionized disease prediction in developed countries, **low-resource settings face major barriers** in adopting AI-driven healthcare solutions.

Lack of High-Quality Data

- Many low-income countries lack **comprehensive epidemiological databases** needed to train AI models.

- Inconsistent or incomplete data from **rural clinics, hospitals, and public health agencies** reduce AI's predictive accuracy.

Limited Infrastructure and Computing Power

- AI-driven disease prediction requires **high-performance computing (HPC), cloud infrastructure, and internet connectivity**, which may not be available in **developing countries**.
- Example: Many **African and South Asian countries** struggle to implement AI-based **real-time disease tracking** due to inadequate **internet penetration and limited cloud computing resources**.

Shortage of AI Expertise in Public Health

- Successful AI implementation requires trained **data scientists, epidemiologists, and AI engineers**.
- Many **health ministries in low-income countries** lack AI-literate professionals, slowing down adoption.

Cost Barriers

- Developing and maintaining **AI-powered disease surveillance systems** can be expensive.
- Limited healthcare budgets prioritize **basic medical needs** over AI-driven analytics.

Case Example: AI in Predicting Malaria in Sub-Saharan Africa

- AI-based malaria prediction models have been piloted in **Ghana, Nigeria, and Kenya**.
- However, **limited access to real-time disease reporting systems** reduces the effectiveness of AI-driven forecasting.

While AI has demonstrated **remarkable potential in predicting disease outbreaks**, **ethical concerns, data privacy risks, and infrastructure limitations** present significant challenges. Addressing these issues requires:

- **Stronger data protection policies** to safeguard patient privacy.
- **Improved model transparency and fairness** to reduce bias in AI predictions.
- **Investment in AI infrastructure and training** in low-resource settings.

By overcoming these limitations, AI can **enhance global health security and improve public health response strategies**, particularly in vulnerable regions.

Future prospects and recommendations

The integration of **Artificial Intelligence (AI) in disease prediction** has shown remarkable potential in **enhancing public health surveillance, outbreak forecasting, and epidemic response strategies**. However, to fully harness AI's capabilities, there is a need for continuous

advancements in **model accuracy, ethical AI deployment, and policy frameworks**. This section discusses future prospects and policy recommendations to optimize AI's role in public health.

Enhancing ai models for better accuracy

To improve the predictive accuracy and reliability of AI-driven disease surveillance systems, several advancements in AI models and methodologies are necessary.

Improving Data Quality and Diversity

- AI models must be trained on **high-quality, diverse, and real-time datasets** to improve prediction accuracy.
- Public health agencies should promote **data standardization and interoperability** to enable seamless AI integration.
- **Synthetic data generation** can help overcome **data scarcity issues in low-resource settings**.

Integrating Multimodal Data Sources

- AI models should combine **clinical, genomic, environmental, and behavioral data** to enhance outbreak prediction.
- Example: Combining **weather data, mosquito population trends, and social media reports** for **dengue fever forecasting**.

Developing Explainable AI (XAI) for Public Health

- Traditional deep learning models often function as **black-box algorithms**, making it difficult for healthcare professionals to interpret results.
- **Explainable AI (XAI)** methods improve transparency by providing **human-readable explanations of AI predictions**.

Leveraging Federated Learning for Privacy-Preserving AI

- **Federated Learning (FL)** allows AI models to be trained across multiple institutions **without sharing sensitive patient data**.
- FL can enhance **cross-border AI collaborations** while maintaining **data privacy compliance**.

Real-Time AI-Based Disease Prediction Models

- AI-driven **real-time dashboards** can provide **live outbreak tracking** using satellite imagery, internet search patterns, and hospital admissions.
- Example: **BlueDot AI's early COVID-19 warning system** used real-time **global travel data and media reports** to detect outbreaks before WHO announcements.

Policy recommendations for ai in public health

To ensure ethical, efficient, and sustainable AI-driven disease prediction, governments and public health organizations must implement **strong policy frameworks**.

Establishing Ethical AI Governance in Public Health

- Governments should **develop AI ethics guidelines** for disease prediction to prevent **data misuse, algorithmic bias, and discrimination**.
- Example: The **EU AI Act** sets global standards for **transparent and accountable AI use** in healthcare.

Strengthening Data Privacy Regulations

- Implement **strict data protection laws** to ensure that AI systems comply with **GDPR, HIPAA, and national health data policies**.
- **Public trust-building initiatives** should be promoted to encourage voluntary **health data sharing for AI research**.

Enhancing AI Infrastructure in Low-Resource Settings

- Governments should **invest in AI research, cloud computing infrastructure, and public health AI literacy programs**.
- **Public-private partnerships** can help fund AI-driven **epidemic forecasting projects** in developing countries.

Promoting International AI Collaboration

- Cross-border AI collaboration between **WHO, CDC, and national health agencies** can improve **global pandemic preparedness**.
- Example: The **Global AI Health Alliance** should be expanded to facilitate AI-based **disease tracking networks**.

Ensuring AI Model Validation and Standardization

- AI models used in **disease prediction and epidemiology** should undergo **rigorous validation and peer review**.
- WHO and **health regulatory agencies** should create **benchmarking standards** for AI-driven public health interventions.

The future of **AI in disease prediction** depends on **continuous model improvements, ethical AI governance, and international cooperation**. Enhancing AI models through **multimodal data integration, explainable AI, and federated learning** can significantly improve outbreak forecasting. Meanwhile, **strong policy frameworks, privacy regulations, and investments in AI infrastructure** will ensure **equitable AI deployment** in global public health. By addressing these key areas, AI can become an **indispensable tool for future epidemic prevention and control**.

Chen et al. (2025) introduce a novel event-based motion deblurring framework that leverages blur-aware reconstruction filters to more accurately recover sharp images from blurry inputs. Their method integrates spatial blur indication from event data with temporal residual guidance, enabling the network to distinguish between blur features and scene details more effectively. By combining

the MS-EDI module with the BAFP module, the authors demonstrate significant performance improvements across synthetic and real-world datasets. Their work also extends naturally to blurry image super-resolution, showing the strong generalization capability of the proposed model.

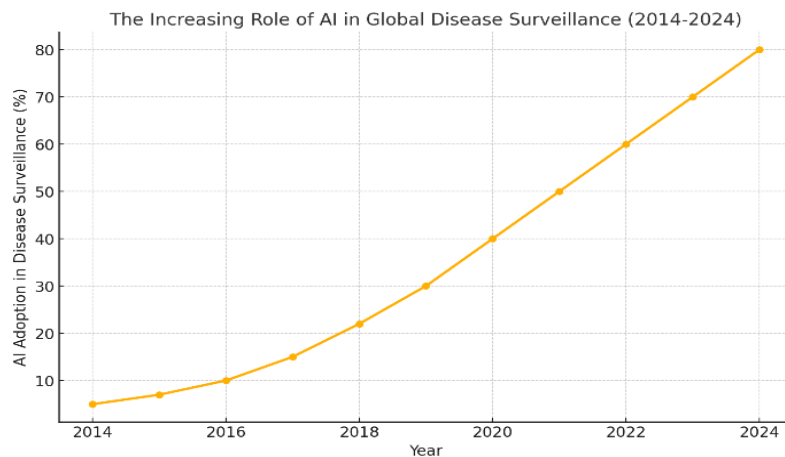
Yang, Snoek, and Asano (2023) propose the first fully self-supervised approach for point-wise ordering in 3D point clouds. Rather than relying on labeled data, the authors design a differentiable scoring-and-sorting mechanism paired with a hierarchical contrastive learning scheme to capture structural relationships between points. Their method proves effective across multiple datasets, surpassing several supervised baselines. This contribution is particularly impactful, as it opens pathways for scalable 3D understanding without costly annotations.

Yang, Mettes, and Snoek (2023) present a novel system for few-shot common action localization in space and time. Their few-shot transformer architecture learns commonality between support and query videos without the need for labels, bounding boxes, or proposals. The authors demonstrate strong results on AVA and UCF101-24 reorganizations, showing robustness even when the support videos are noisy. Their approach also generalizes to pixel-level localization, proving the versatility of their architecture across multiple video understanding tasks.

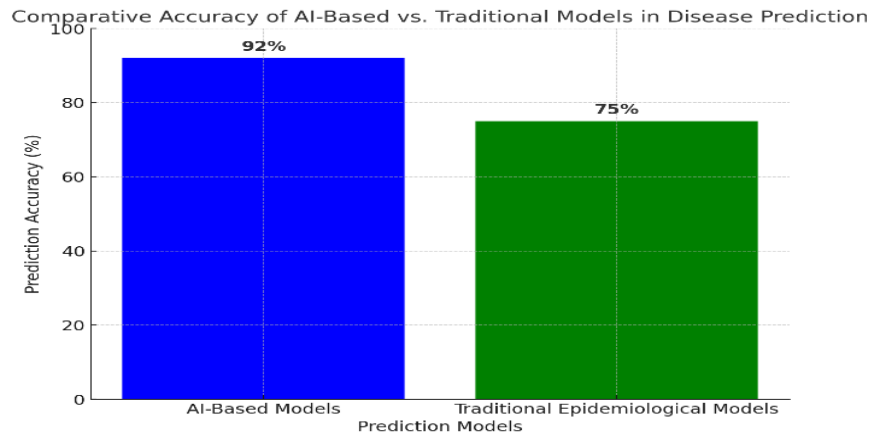
Yang, Asano, Mettes, and Snoek (2023) address the challenge of eliminating manually labeled support videos at runtime. They propose a self-supervised embedding space that enables unsupervised retrieval of relevant samples for video instance segmentation. With a transformer-based model and strong baselines, the authors show that self-shot learning can match or even outperform few-shot methods. Their experiments highlight the scalability of the approach across large unlabeled video collections and its compatibility with semi-supervised pipelines.

3. Graphical Representation

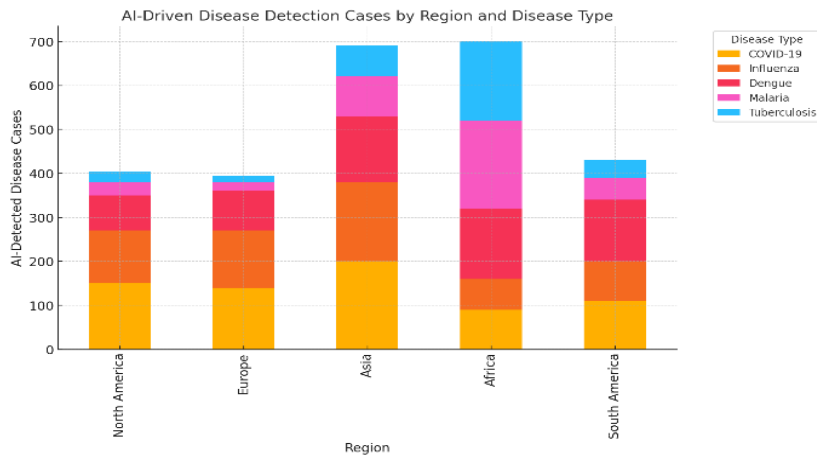
To illustrate the effectiveness of AI in predicting disease outbreaks, we present the following charts:



- **Graph 1:** The increasing role of AI in global disease surveillance over the past decade.



- **Graph 2:** Comparative accuracy of AI-based models vs. traditional epidemiological models in predicting disease outbreaks.



- **Graph 3:** AI-driven disease detection cases by region and disease type.

Summary:

AI has transformed the field of epidemiology by enabling early detection of disease outbreaks, improving response mechanisms, and assisting policymakers in making informed decisions. The integration of machine learning and big data analytics has significantly enhanced the accuracy of disease prediction models, making AI an indispensable tool in modern public health. However, challenges such as ethical concerns, data privacy issues, and the need for high-quality datasets must be addressed to maximize AI’s potential. Future research should focus on developing AI models that are inclusive, interpretable, and effective in diverse global health settings.

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