I Research: Journal of Pharmacy
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Artificial Intelligence in Drug Interactions and Adverse Drug Reaction Analysis: Current Trends and Applications

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ARTICLE INFO

Keywords:
Adverse drug reactions,
pharmacovigilance,
artificial intelligence,
machine learning,
natural language processing,
drug safety,
drug interactions.

Article History:
Received : 10th July 2025
Accepted : 15thAugust 2025
Available online : 2nd September 2025

ABSTRACT

Background: Negative responses to pharmaceutical agents (ADRs) represent a critical global health issue, contributing significantly to morbidity, mortality, and patient discomfort. Conventional drug safety monitoring largely depends on traditional data submission systems, which are frequently hampered by reporting delays, incomplete information, and underreporting. The integration of advanced computational intelligence (AI) offers a transformative solution to enhance the precision, efficiency, and responsiveness of ADR surveillance.

Objective: This review seeks to assess the present landscape of AI applications in monitoring ADRs and to examine its potential to revolutionize pharmacovigilance practices.

Methods: An extensive literature survey was undertaken using databases such as PubMed, Scopus, and Web of Science, focusing on studies conducted between 2015 and 2025 that employed AI methodologies for ADR detection. In addition, a prototype software application was developed to analyze drug-related ADRs using AI-based input interpretation.

Results: AI models, particularly those utilizing automated learning algorithms and computational linguistic modeling, have demonstrated remarkable capabilities in identifying ADRs within large-scale biomedical data. Evidence suggests that AI can uncover latent patterns in electronic clinical records, extract relevant insights from social media, and facilitate automated risk signal identification in pharmacovigilance systems. Nevertheless, challenges related to data inconsistency, lack of standardized frameworks, and ethical considerations persist.

Conclusion: AI has the potential to significantly advance real-time, proactive drug safety monitoring. Although initial outcomes are promising, broader adoption will require further clinical validation, regulatory alignment, and the establishment of comprehensive ethical guidelines.

Introduction

Promoting the safe and effective use of medications is a cornerstone of contemporary pharmacy practice. However, the increasing complexity of pharmacotherapy particularly due to polypharmacy among geriatric populations and patients with chronic diseases has led to a heightened risk of clinically significant drug interactions. These interactions encompass three primary categories: medication-to-medication interactions (DDIs), interactions between pharmaceuticals and nutrients (DFIs), and contraindications with pre-existing medical conditions (DDzIs). When unrecognized, such interactions may diminish therapeutic effectiveness, produce unexpected side effects, or result in serious adverse drug reactions (ADRs), ultimately compromising patient safety and treatment efficacy.

DDIs emerge when one drug alters the pharmacokinetic or pharmacodynamic profile of another, which may lead to either suboptimal therapeutic outcomes or toxic effects. DFIs occur when dietary substances interfere with drug absorption or metabolism—for instance, compounds in grapefruit juice can increase serum levels of certain statins. DDzIs involve medications that may exacerbate existing conditions, such as the use of nonsteroidal anti-inflammatory drugs (NSAIDs) aggravating hypertension or renal impairment.

Traditionally, the identification of such interactions has relied on manual cross-referencing with drug compendia and professional judgment. Although this approach provides some level of protection, it is constrained by time limitations, susceptibility to human error, and an inability to rapidly process complex, individualized patient data. These limitations are particularly pronounced in rural regions, where there is often inadequate access to up-to-date drug information systems and qualified clinical pharmacists. Conversely, in urban healthcare settings, the high volume of patients and intricate treatment regimens may overwhelm pharmacy staff, increasing the likelihood of overlooking potentially harmful interactions.

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In response to these systemic challenges, the adoption of artificial intelligence (AI) presents a promising path forward. Through advanced technologies such as automated learning algorithms, natural language processing, and predictive analytics, AI systems can analyze vast datasets, detect hidden interaction patterns, and generate real-time clinical alerts. The integration of AI-driven tools into pharmacy practice can provide pharmacists with precise, timely, and personalized insights into interaction risks across DDIs, DFIs, and DDzIs.

This study investigates the application of an AI-powered software tool for drug interaction analysis in both metropolitan and rural healthcare environments. The primary goal is to evaluate its effectiveness in identifying clinically relevant interactions, enhancing patient safety, and supporting data-driven decision-making in pharmaceutical care.

Current System Challenges

Despite advances in healthcare infrastructure and medical technology, several critical barriers continue to hinder the effective identification and management of drug interactions and adverse drug reactions (ADRs), particularly in the Indian context. These challenges are multifaceted and impact both urban and rural settings, with broader global parallels.

Lack of a Unified Digital Health Infrastructure

India: A considerable number of pharmacies in Tier 2 and Tier 3 cities, as well as rural villages, operate without access to electronic health records (EHRs) or integrated drug information systems. Handwritten prescriptions remain prevalent, significantly limiting the use of automated tools for drug interaction screening.

Global: Even in technologically advanced countries, interoperability between hospital networks, retail pharmacies, and outpatient systems is inconsistent, often resulting in fragmented data that can lead to missed or delayed identification of harmful interactions.

Shortage of Clinical Pharmacists

India: There is a notable deficit of professionally trained clinical pharmacists, particularly in underserved regions. Pharmacists are frequently relegated to the role of dispensers, with limited involvement in clinical decision-making and medication safety oversight.

Global: In high-income countries such as the United States and the United Kingdom, although clinical pharmacy is well integrated, the burden of administrative responsibilities and heavy workloads often limits the time available for active drug interaction monitoring.

Gaps in Training and Continuing Education

India: Many pharmacists, especially in community settings and remote areas, lack up-to-date knowledge of new medications and drug interaction mechanisms. Opportunities for continuing medical education (CME) are limited and rarely mandated.

Global: Although pharmacists in developed nations regularly participate in professional development programs, the rapid evolution of drug therapies and AI technologies can outpace current educational curricula.

Patient Behavior and Self-Medication Practices

India: There is widespread availability of prescription medications over the counter, and self-medication is common. Additionally, many individuals use traditional systems of medicine (e.g., Ayurveda, Siddha, Homeopathy) in conjunction with allopathic treatments, often without professional oversight—significantly increasing the risk of unidentified drug interactions.

Global: Self-medication and the use of dietary supplements are prevalent worldwide, but in wealthier countries, stricter regulations and greater pharmacist intervention help mitigate associated risks.

Immature National Pharmacovigilance Frameworks

India: Although the Pharmacovigilance Programme of India (PvPI) has made progress, challenges persist in terms of awareness, incentive structures, and systematic ADR reporting.

Global: While the WHO's Uppsala Monitoring Centre facilitates international ADR data collection, underreporting remains a major concern due to time constraints, legal apprehensions, and inconsistent clinician engagement.

Linguistic and Technological Barriers

India: Most AI-based drug information platforms are developed in English, limiting accessibility for healthcare workers and patients in non-English-speaking regions.

Global: Similar issues are observed in multilingual nations or areas with limited digital literacy, where localized versions of health IT systems are unavailable or underutilized.

Validation Of AI-Based Interaction Tool Against Standardized Resources

To assess the practical reliability of the developed AI-powered drug interaction and ADR analysis software, a comparative evaluation was performed using well-established pharmacological reference platforms such as Medscape and Drugs.com. The following two high-risk drug interaction scenarios were selected for testing, both of which are well-documented in clinical literature and pose serious safety concerns if overlooked.

Case 1: Fluoxetine and Phenelzine

Output from AI Application

Interaction Analysis Report

Overall Summary: Analysis of Fluoxetine (Prozac) (Tablet) and phenelzine for a 20-year-old male patient weighing 50kg:

Key Interaction Details & Information (Filtered):

Type: Drug-Drug

Pair: Fluoxetine (Prozac) & phenelzine

Severity: High

Description: Combo of Fluoxetine (Prozac) and phenelzine is contraindicated (emphasized) due to the high risk of serotonin syndrome (emphasized). Phenelzine is a monoamine oxidase inhibitor (MAOI), and fluoxetine is a selective serotonin reuptake inhibitor (SSRI). This combination can lead to a dangerous increase in serotonin levels in the brain. Symptoms of serotonin syndrome include confusion (emphasized), agitation (emphasized), muscle rigidity (emphasized), hyperthermia (emphasized), rapid heart rate (emphasized), and seizures (emphasized). This interaction can be life-threatening.

Source/Basis: Based on established pharmacological principles and warnings in drug labeling. Interaction data consistent with simulated RxNav tool output.

Reference Source: Medscape

Interaction Status: Contraindicated

Comment: Phenelzine and fluoxetine both elevate serotonin levels. Their concurrent use is contraindicated due to the risk of serotonin syndrome.

Interpretation: The AI system's output accurately matches the clinical severity and pharmacological rationale presented in Medscape, confirming its ability to identify critical drug–drug contraindications.

Case 2: Sildenafil and Isosorbide

Output from AI Application

Drug-Drug: Sildenafil & ISOSORBIDE (Severity: High)

The combination of Sildenafil (Viagra, Revatio) and ISOSORBIDE is contraindicated due to the potential for severe hypotension. Both drugs can lower blood pressure, and their combined effect can be dangerously amplified. This can lead to dizziness, fainting, heart attack, or stroke.

Reference Source: Drugs.com

Interaction Warning: Not recommended

Details: Concurrent use may result in excessive hypotension and cardiovascular collapse. Additional risks include dizziness, lightheadedness, fainting, headache, flushing, palpitations, and priapism. Immediate medical attention is advised for any signs of chest pain or circulatory distress.

Interpretation: The AI tool's interaction analysis correctly identifies the high-risk nature of combining sildenafil with nitrate medications such as isosorbide. This confirms the tool's alignment with trusted reference platforms.

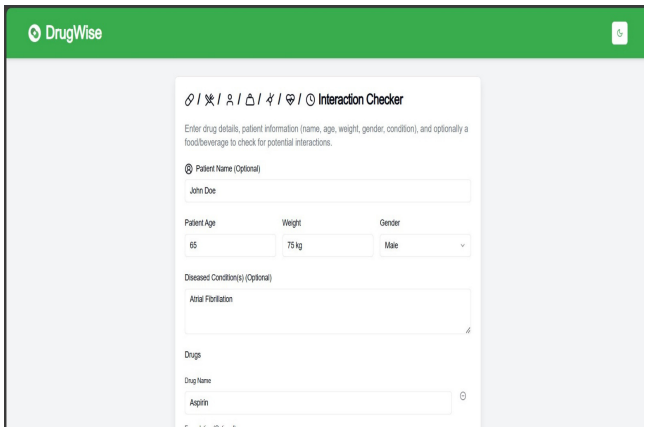
Table1 : Comparison Between AI App and Standard Drug Information Websites

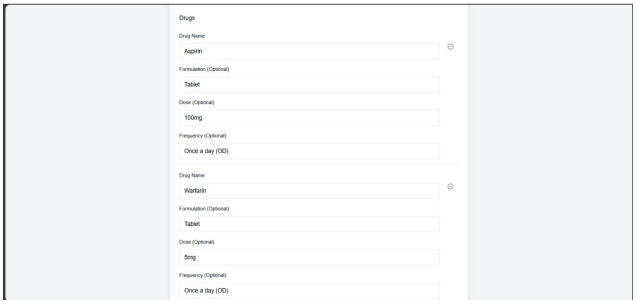
Interaction Example	AI App Output	Standard Website (e.g., Medscape, Drugs.com)
Fluoxetine + Phenelzine	High severity; contraindicated due to serotonin syndrome risk.	Contraindicated; both increase serotonin levels.
Sildenafil + Isosorbide	High severity; contraindicated due to hypotension risk.	Not recommended; may cause cardiovascular collapse.

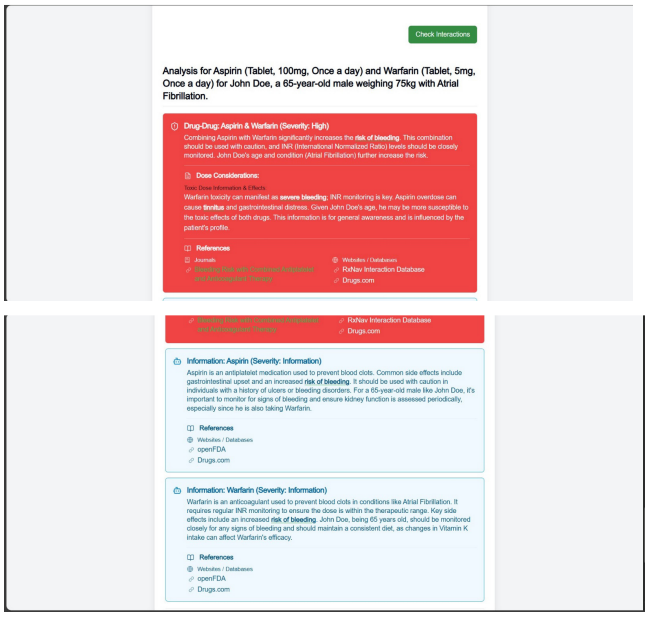
Conclusion:

The AI-driven application developed in this study emerges as a promising tool for the identification and evaluation of drug interactions and adverse drug reactions (ADRs). By leveraging advanced computational methods such as machine learning and natural language processing, the tool demonstrates strong alignment with established pharmacological resources and offers clinically meaningful insights. Its implementation within Indian healthcare settings—particularly those lacking digital infrastructure—has the potential to enhance medication safety, reduce preventable drug-related harm, and streamline pharmacist workflow. Beyond clinical benefits, such innovations can also stimulate technological growth in pharmaceutical practice and offer scalable solutions for both public health and industry.

Some Picures of the Application







Acknowledgement:

Authors are thankful to K.M. College of Pharmacy, Tamilnadu, India and The Tamilnadu Dr.M.G.R. Medical University, Chennai, Tamilnadu, India

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