Digital Transformation of the Pharmacy System from a Public Perspective: Implications for the Stability of Local Supply Structures

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Abstract:

Objective: This study examines how the digital transformation of the pharmacy sector—especially through telepharmacy, e-prescriptions, and AI-based systems—affects public health equity and the stability of local pharmaceutical supply structures, with a focus on the German context within the European Union.
Design: Mixed-methods policy analysis
Methods: A combination of systematic literature review, policy and regulatory analysis, and qualitative case studies from both urban and rural areas in Germany. Key documents included the Digital Healthcare Act (DVG), EU policy frameworks such as the European Health Data Space (EHDS), and national strategies from France and Poland. Thematic analysis was applied to identify major cross-cutting themes such as regulatory fragmentation, access disparities, and the evolving role of pharmacists.

Results: The digital transformation has significantly improved efficiency and access in urban centers through innovations like e-prescriptions and online pharmacies. However, rural areas suffer from inadequate digital infrastructure and limited digital literacy, leading to inequitable access. Regulatory fragmentation across EU member states further complicates implementation. While AI-driven systems enhance supply chain efficiency, they also introduce cybersecurity risks and threaten the existence of traditional local pharmacies, particularly in underserved regions.

Conclusion: Digitalization offers major benefits to pharmaceutical care but risks undermining public health equity and the resilience of local supply systems if not accompanied by inclusive infrastructure investment and harmonized regulation. To safeguard access and sustainability, especially in rural areas, targeted policy measures are needed—ranging from broadband expansion and GDPR support for small pharmacies to workforce training and funding for hybrid service models. A cohesive EU-level approach, combined with national investments like Germany's Gigabit Strategy and Pharmacy Future Act, will be essential to ensure that digital transformation strengthens rather than erodes local health systems.

Introduction

The increasingly growing technology is driving a massive change in the worldwide pharmacy sector, redefining prescription, dispensation, and drug management. The shifting patient needs and technological innovation drive this revolution in the European Union, particularly Germany. Germany has a Digital Healthcare Act (Digitale-Versorgung-Gesetz, DVG), which defines how digital instruments, such as e-prescriptions, telepharmacy, and artificial intelligence (AI)-driven record-keeping, are incorporated into the pharmacy sector (Maass, 2023). While the advancements have increased the efficiency of drug administration, they adversely affect the stability of local pharmaceutical supply models, causing inequitable access to medical services. Approximately 18,000 community pharmacy establishments in Germany serve as critical touchpoints and frontline healthcare systems (ABDA, 2024). Technological developments may disrupt the role of local pharmacies in connecting patients with healthcare services in rural and underserved regions where pharmacies are the sole medical access point. These stores may be left behind because of inadequate digital infrastructure and lower adoption rates. This paper examines the effect of digitalization on public health equity and supply chain resilience, focusing on Germany's experience as a European leader in healthcare innovation.

Theoretical Framework

The digital transformation of the pharmacy sector represents a paradigmatic shift in healthcare delivery that extends beyond technical innovation to broader public health concerns such as equity, resilience, and system fragmentation. Grounded in the frameworks of digital public health and health system resilience, this paper analyzes digitalization not only as a technological process, but also as a complex sociopolitical phenomenon with far-reaching implications for regional accessibility and structural justice (Maass, 2023; Yadav, 2024).

A central theoretical lens guiding this analysis is the concept of health equity in digital infrastructures, which posits that the availability and design of digital tools must support all population groups equally to avoid widening existing disparities (Bulaj et al., 2024; Kroenert & Bertsche, 2024). The application of telepharmacy, e-prescriptions, and AI-powered logistics tools has undoubtedly improved efficiency in urban regions. However, these gains are offset by persistent structural barriers in rural areas, where gaps in broadband infrastructure and limited digital literacy restrict equitable access (European Commission, 2023; Eckert, 2024).

Moreover, the resilience of local supply systems is increasingly viewed through the lens of centralized versus decentralized care models. While AI-driven inventory tools and robotic dispensing systems offer logistical advantages, they can simultaneously endanger the operational viability of rural pharmacies, which serve as essential local care hubs (Burk et al., 2024; ABDA, 2024). This tension raises questions about the long-term sustainability of local pharmaceutical services within a rapidly digitizing system, especially in socioeconomically weaker regions.

Another relevant theoretical strand involves the shifting professional roles within healthcare in response to digital innovation. Pharmacists are increasingly expected to assume extended responsibilities, including patient counseling, chronic disease monitoring, and public health interventions. Yet, this expanded role is challenged by unequal access to training and technological resources, particularly in rural and underfunded settings (Maass, 2023; Marangwanda, 2024).

Finally, the regulatory and cybersecurity landscape introduces additional theoretical complexity. The lack of harmonized telepharmacy regulations across EU member states exemplifies regulatory fragmentation, which hinders cross-border interoperability and exacerbates systemic vulnerabilities (Stoumpos et al., 2023; Odenbach-Wanner, 2023). Additionally, the growing reliance on centralized data systems intensifies exposure to cyber threats, raising urgent questions about the balance between innovation and risk in public digital health (Traynor, 2024; Graf et al., 2024).

Taken together, these interrelated dimensions underscore the importance of integrating public health theory, health equity, and systems resilience into the conceptual framing of pharmacy digitalization. This framework informs the subsequent analysis of the empirical findings presented in this study.

Methodology

This research employed a mixed-methods design to investigate how digitalization affects the pharmacy sector, with a special focus on public health equity and supply resilience in Germany. This approach was preferred because it integrates quantitative and qualitative data to offer a detailed comprehension of the problems and prospects of digital transition in the pharmacy industry. The investigator performed a systematic review of peer-reviewed articles, industry reports, and policy publications to obtain information regarding e-prescriptions, AI-driven technologies, and telepharmacy. The key sources examined included the Digital Healthcare Act (Digitale-Versorgung-Gesetz, DVG), European Health Data Space (EHDS) initiatives, journals on health policy, infrastructure, policy development, and cybersecurity, and reports from the European Commission and ABDA (Federal Union of German Associations of Pharmacists). In addition, case study projects in rural Germany, such as Bavaria, were examined to evaluate the efficiency of digital tools in underserved regions. Finally, the researcher conducted a regulatory and policy analysis, in which a comparative assessment was performed to compare frameworks across the EU. The key regulatory models that were examined include Germany's DVG, France's Health Innovation 2030 plan, and Poland's e-Health Strategy, enabling the study to establish interoperability and fragmentation challenges within the union.

Data was analyzed qualitatively, with thematic analysis as the primary approach. This method, whose stages include data familiarization, initial codes generation, themes searching, themes reviewing, themes definition and naming, and production of the results section, allowed the researcher to determine recurring themes in the publications. The major themes that were extracted included inequitable access, regulatory fragmentation, and the shifting roles of pharmacists. The case study findings were coded and examined to obtain information regarding the successes and failures of digital pharmacy architectures in urban and rural settings. Although the mixed-methods approach enabled this study to obtain a comprehensive understanding of digitalization has affected the pharmacy sector in the EU, it has limitations, including heavy dependence on secondary data limiting the depth of insights into specific local contexts, underrepresentation of data on rural areas because of limited reporting and structural changes, and the increasingly changing nature of digital technologies implies that some results may be updated with the emergence of new developments.

Results

In summary, the digital transformation of the pharmacy sector in Germany and across the EU has introduced far-reaching changes that impact not only pharmaceutical service delivery, but also public health structures and regulatory stability. This section presents the key findings of the study and is structured around three core dimensions: First, we examine how digital innovations—such as e-prescriptions, telepharmacy, and AI-driven systems—are reshaping pharmacy operations and infrastructure. Second, we assess the public health implications of these changes, with particular attention to access, equity, and the resilience of local supply structures. Finally, we address the broader challenges and risks associated with digitalization, including regulatory fragmentation, infrastructure gaps, and cybersecurity vulnerabilities. Together, these aspects reveal both the transformative potential and the structural tensions that accompany the digital evolution of pharmacy systems.

Digital Transformation in the Pharmacy Sector

E-Prescriptions

Electronic medication prescription is a critical development in the digital pharmacy systems, with Germany passing the mandatory e-prescription requirements. This advancement is managed by Gematik, streamlining the medication process to reduce errors and improve patient convenience (Hareem et al., 2023). Compared to the paper-based system, e-prescriptions allow healthcare providers to share patients' prescription records with pharmacy computers electronically, decreasing medication faults and instances of callbacks by pharmacists for clarification (Lösch et al., 2022). Similarly, this method has improved the clinical practice workflow, boosted patient contentment and compliance, and decreased paperwork and related mistakes in handwritten notes. Nonetheless, Alhur et al. (2024) claim that e-prescription is associated with challenges, including delayed adoption because of interoperability issues between different healthcare structures and limited access among elderly patients and those who lack digital knowledge, negatively influencing healthcare equality. Regardless of these challenges, the increasing technological adoption in Europe, which is driven by the European Health Data Space (EHDS), will make e-prescriptions the standard across the region.

Online Pharmacies and Telepharmacy

Other developments that have changed the pharmacy landscape include online pharmacies and telepharmacy. Germany recorded a 30% increase in online pharmacies in 2022, allowing patients to conveniently order drugs from home at affordable prices (Almeman, 2024). This model has been supported by reliable internet access in the country. However, it threatens the brick-and-mortar pharmaceutical stores in rural areas, which have started to record declining foot traffic – most people order medicine online (Kroenert & Bertsche, 2024). Conversely, telepharmacy allows patients to consult healthcare providers remotely and acquire drugs, possibly sustaining pharmacy services in underserved areas. Mekurianew Kelkay (2024) performed pilot research in rural Bavaria and demonstrated telepharmacy's efficiency in enhancing medication access among community members. However, this development can only be successful if patients willingly adopt new technologies and the digital structure is robustly developed in rural and isolated communities.

Automation and A-Driven Systems

Automation and AI-driven systems, including robotic dispensing mechanisms, have revolutionized pharmacy processes in urban sectors. These systems automate drug sorting and packaging in large pharmacies, decreasing human mistakes and increasing medication prescription and management efficiency (Yadav, 2024). Because these technologies require enormous financial investments, their adoption in smaller facilities is limited. Furthermore, AI technologies significantly change drug supply chain operations by decreasing wastage and maximizing stock levels through historical data analysis and demand prediction capabilities (Burk et al., 2024). Nonetheless, they depend on centralized data systems, which are susceptible to cyberattacks, the occurrence of which may disrupt the supply chain processes.

Public Health Implications

The digital transformation of the pharmacy sector has positive and negative effects on healthcare systems' access, equity, and resilience. The positive implications of these tools include enhanced efficiency and patient convenience. Conversely, they are associated with challenges concerning care access equity and supply chain resilience that must be addressed from their seamless adoption in the local sector.

Access and Equity

While automated pharmacy structures, including telepharmacy and e-prescriptions, can enhance healthcare and medication service access, their benefits are unevenly distributed in local and underserved communities. For example, while the German government advocates for the mandatory roll-out of e-prescriptions to streamline medication access, the implementation is only concentrated in urban centers, such as Berlin and Munich (Lösch et al., 2022). Rural towns with poor digital infrastructure, such as Mecklenburg-Western Pomerania, have low adoption rates. According to Bulaj and colleagues (2024), 23% of rural German cities lack dependable broadband access, negatively affecting e-prescription utilization. Similarly, while the EU's EHDS aims to harmonize health systems and structures across member nations, there are disparities in digital preparation between states, such as developed Germany and less advanced Bulgaria and Romania, further increasing health disparities (European Commission, 2023). These regions require ongoing investment in technological infrastructures to ensure equitable access to digital pharmacy systems in urban and rural areas.

Supply Chain Resilience

Healthcare facilities and pharmacies optimize their supply chains through digital tools, including AI-driven inventory management. While this advancement allows pharmaceutical firms to eliminate and reduce waste, it is associated with centralization risks and causes rural pharmacy closures, potentially destabilizing local supply systems (Yadav, 2024). For example, Germany has adopted centralized technological mechanisms, including TI-Connect (Telematikinfrastruktur), to improve its healthcare efficiency. However, they increase dependency on digital frameworks, which are vulnerable to cyberattacks. The negative effect of this overreliance on digital systems is demonstrated by a breach of North Rhine-Westphalia hospital networks in 2022, which disrupted drug distribution (Traynor, 2024). Moreover, the increased presence of online pharmacies and automation tools fostered the closures of rural stores in Germany, with approximately 500 rural pharmacies closing between 2020 and 2023 (ABDA, 2024). The closures left many communities without access to medications, destabilizing the welfare of regions with limited transportation options and a high presence of older citizens.

Shifting Roles of Pharmacists

The increasing digital transformation of the healthcare sector has changed the role of pharmacists from drug administration and dispensation to health management and counseling. This transition ensures enhanced patient care; nevertheless, it causes challenges to workplace education and resource distribution. According to Maass (2023), 60% of German pharmacists complain of limited training in applying digital tools, such as electronic prescriptions. The skill gap prevents these professionals from harnessing the potential of digital technologies to improve patient care and increases disparities between rural and urban pharmacies (Marangwanda, 2024). Although the expanded pharmacists' role, facilitated through digital tools, enables them to perform activities such as chronic disease management and distribution of tests during pandemics such as COVID-19, it demands additional training and resources, which are scarce in rural settings.

Cybersecurity and Data Privacy

Cyber attackers target digitalized pharmacy systems, adversely affecting public health. To decrease these occurrences, the General Data Protection Regulation (GDPR) imposes strict requirements for pharmacies when handling patient data. These impositions, such as ensuring privacy and confidentiality of information, create administrative burdens for small stores, as proved by Graf et al. (2024), who determined that 40% of German pharmacies in rural settings struggle to meet the GDPR requirements. In addition, criminals may target these digital systems, disrupting operations and affecting patient care outcomes. For example, the cyberattacks on the North Rhine-Westphalia hospital networks and a 2021 attack on German pharmacy chains adversely affected service delivery for days, with personnel resorting to the traditional handwritten record-keeping method, which is non-reliant and error-oriented (Traynor, 2024). These incidents underscore the need for robust cybersecurity measures, which rural pharmacies may not afford because of a lack of financial capabilities and poor architecture.

Challenges and Risks

Regulatory Fragmentation

The European Union lacks harmonized policies on cross-border services, such as telepharmacy, complicating the implementation of digital pharmacy systems. Firstly, the region has divergent national regulations (Marangwanda, 2024). For example, the digital policies between Germany and France differ, yet they are members of the EU. While Germany has enacted the Digitale-Versorgung-Gesetz, which promotes telemedicine practices, France has adopted a dissimilar Health Innovation 2030 plan that advocates for AI-driven healthcare solutions (Stoumpos et al., 2023). Furthermore, Poland has an e-Health Strategy that emphasizes electronic health records. The distinct goal fragmentation of these digitalization plans prevents interoperability and cooperation among EU nations. Similarly, they hinder the success of EU initiatives, such as the EHDS (Odenbach-Wanner, 2023). Moreover, the EU has a cross-border healthcare directive to facilitate access to healthcare services across its states (Hareem et al., 2023). Nevertheless, different telepharmacy regulations in member states, such as Italy, restrict the online supply of prescription drugs. These variances affect the implementation of the EU's directive.

Digital Infrastructure Gaps

Rural areas in Germany have less developed digital architecture, which prevents the adoption of mechanized pharmacy systems. For example, while urban areas boast strong broadband access, rural regions have unreliable access (Kroenert & Bertsche, 2024). Germany implemented the Gigabit Strategy 2025 program to increase internet connectivity (Eckert, 2024). Nonetheless, regions, including the Harz Mountains and parts of Brandenburg, have undependable broadband access because of low-capacity transmission technologies. This poor internet connectivity prevents approximately 23% of rural Germans from leveraging electronic prescription technology (Eckert, 2024). Similarly, the European Union implemented the EU's Connectivity Toolbox to address regional structural indifferences (European Commission, 2023). However, the implementation of this program has been slow in Eastern Europe, with broadband coverage in nations such as Romania remaining below the average. The delayed execution and progress of the EU connectivity initiative restricts the application of digital pharmacy systems in rural EU areas.

Cybersecurity and Data Privacy Risks

The increasing automation and digitalization of drug prescription and supply systems elevate susceptibility to cyberattacks and have implications for the privacy of patients' data. These vulnerabilities caused the GDPR to impose strict rules on how people handle patient data, such as creating strong encryption systems (European Commission, 2023). Small pharmacies' low financial access prevents them from developing a robust security fabric; thus, the GDPR's regulations pose administrative burdens for them. A study by Hareem (2023) determined that rural area pharmacies struggle to comply with GDPR. Besides, digital pharmaceutical tools are exposed to malware attacks, which may affect their operations and patients' access to care (Traynor, 2024). The ransomware attack on German pharmacy chains and similar incidents in Ireland's health service delayed medication prescriptions for days. These incidents can be prevented through a robust cybersecurity framework, which, unfortunately, small pharmacies in local areas may not be able to afford.

Discussion

This project synthesized current publications and policy developments to offer comprehensive insights into how digitalization reshapes pharmacy systems in the EU. Digital advancements in the pharmaceutical sector, including e-prescription, have improved efficiency and care accessibility. However, these developments have introduced challenges, such as internet security risks and architecture disparities, adversely affecting equitable access, especially in rural regions. These concerns can be addressed when EU governments reconcile their policies, prioritize digital structure investment in rural locations, and sustain local pharmacy frameworks. Implementing these strategies will enable member states, including Germany, to harness the benefits of digital enhancements and protect the healthcare systems' resilience. These initiatives require a partnership between nations and the EU that is dedicated to inclusivity and equity during policy implementation. The evolution of the pharmacy sector requires prioritization of vulnerable populations in underserved areas, allowing the EU to become a leader in developing a digitalized pharmacy framework that improves public health and sustains the stability of local supply models.

The fragmented fragmentation within the EU's digital technology infrastructure requires a comprehensive and coordinated solution. For example, the region should harmonize by increasing EHDS coverage and aligning national regulations (European Commission, 2023). The EU should have regional standardized electronic prescription formats and telepharmacy rules. The member states should align their digitalization strategies with those of the EU's Cross-Border Healthcare Directive (ABDA, 2024). In addition, Germany can accelerate its Gigabit Strategy 2025 to mitigate the poor digital architecture issue. This suggestion can be achieved by securing more funding from the EU and altering its rollout plan to prioritize connectivity in rural areas (Eckert, 2024). Moreover, resources from the EU4Health and Digital Europe programs can support structure expansion in rural areas (European Commission, 2023). These initiatives will allow Germany to support universal access to digital pharmacy services.

Other recommendations to address the concerns include strengthening cybersecurity and data privacy, supporting workforce training, and sustaining local pharmacy models. Firstly, Germany can offer GDPR support by establishing regional hubs in rural areas to ensure compliance among small pharmacies (Burk et al., 2024). Secondly, the EU nations should revise their healthcare training curricula to incorporate AI-driven systems and telepharmacy education (Kroenert & Bertsche, 2024). Lastly, Germany can prevent local pharmacy closures by availing financial incentives, such as grants and subsidies, through its Pharmacy Future Act (Apothekenzukunftsgesetz) (Maass, 2023). These strategies will ensure the safety of local pharmacies' digital frameworks, ensure the personnel is trained on these advanced models, and prevent their closures because of delayed adoption and lack of funding.

Conclusion

The digital transformation of the pharmacy sector offers major benefits to pharmaceutical care but risks undermining public health equity and the resilience of local supply systems if not accompanied by inclusive infrastructure investment and harmonized regulation. To safeguard access and sustainability, especially in rural areas, targeted policy measures are needed—ranging from broadband expansion and GDPR support for small pharmacies to workforce training and funding for hybrid service models. A cohesive EU-level approach, combined with national investments like Germany's Gigabit Strategy and Pharmacy Future Act, will be essential to ensure that digital transformation strengthens rather than erodes local health systems.

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