

# RESILIENCE IN PHARMACEUTICAL SUPPLY CHAIN DURING PANDEMICS: A NARRATIVE REVIEW

## Original Article

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## ABSTRACT

**Background:** The pharmaceutical supply chain (PSC) plays a vital role in maintaining the continuity of healthcare systems. Disruptions in any segment of this chain, particularly during global crises such as pandemics, can lead to severe shortages of essential medical products, adversely affecting patient care. The COVID-19 pandemic revealed critical vulnerabilities within pharmaceutical logistics, highlighting the urgent need for resilience in supply chain operations to withstand and recover from such large-scale disruptions.

**Objective:** To review and synthesize existing literature on the obstacles faced by pharmaceutical supply chains during pandemics and evaluate strategies that enhance resilience and operational continuity in crisis settings.

**Methods:** A narrative review was conducted using studies published from 2019 onward, sourced from PubMed, Scopus, and ScienceDirect. Articles were included if they addressed pharmaceutical supply chain disruptions during pandemics and proposed or evaluated resilience strategies such as digitalization, diversification of suppliers, and agile procurement frameworks. Data from 11 selected studies were extracted and thematically analyzed for methodology, key findings, and practical implications.

**Results:** Out of 11 studies, 7 employed qualitative methods, while 4 used mixed or quantitative approaches. Across these, 82% reported a positive correlation between digital maturity and faster recovery from disruptions. Approximately 73% emphasized the need for supplier diversification, while 64% demonstrated that predictive analytics, including AI tools, significantly enhanced risk identification and inventory management. Public-private partnerships, flexible manufacturing systems, and proactive stockpiling were also identified as major contributors to improved resilience.

**Conclusion:** Pharmaceutical supply chain resilience is essential for safeguarding health systems during pandemics. Adoption of digital technologies, risk forecasting, supplier diversification, and strategic planning are key enablers of continuity. These findings support the formulation of adaptive, technology-driven policies to minimize disruption impacts in future crises.

**Keywords:** Artificial Intelligence, COVID-19, Disaster Planning, Drug Supply, Healthcare Resilience, Pharmaceutical Services, Supply Chain Management.

## INTRODUCTION

Since the outbreak of COVID-19 in late 2019 and its escalation into a global pandemic by early 2020, the world witnessed an unprecedented disruption in supply chains, not only on a local but also a global scale. This disturbance significantly hampered economic activity and challenged the stability of essential services, particularly healthcare. Lockdowns were imposed globally to curb the spread of infection, which, although necessary, brought the operations of markets and industries to a near standstill. Quarantine measures, including home isolation and designated COVID-19 treatment wards, further shifted the dynamics of daily life and business. Many enterprises were compelled to transition to online platforms and adopt remote working models (1). Alongside these efforts, standard operating procedures (SOPs) were formulated, such as maintaining physical distance and wearing masks, to protect public health. However, despite these measures, the continuity of supply chains—especially those involving healthcare and pharmaceuticals—faced severe setbacks (2,3). One of the most pressing concerns in this context was the behavior of markets in response to shortages. Hoarding practices emerged, intensifying stress on the distribution systems and amplifying the imbalance between supply and demand. In the pharmaceutical sector, this imbalance had critical implications for public health. The pharmaceutical supply chain (PSC), inherently complex due to its reliance on life-saving medications, became particularly vulnerable. Unlike traditional supply chains, PSC involves a diverse network of stakeholders, including manufacturers, wholesalers, retailers, pharmacy benefit managers, online pharmacies, and healthcare providers. This complexity, though necessary for its effectiveness, made the system susceptible to multifaceted disruptions from production to delivery (4,5).

Historically, pandemics have tested societal resilience and medical preparedness, as seen in prior outbreaks such as the Spanish flu, smallpox, and more recently, Ebola and SARS. COVID-19, caused by a novel Betacoronavirus, highlighted existing vulnerabilities within healthcare infrastructures. It paralleled past pandemics in its widespread impact but exceeded many in scale and economic consequences (6). The bullwhip effect—an amplification of demand fluctuation along the supply chain—became prominent during the pandemic, exposing how uncoordinated responses could further destabilize an already stressed system (7,8). Critical shortages in personal protective equipment (PPE), ventilators, and essential drugs underscored the fragility of pharmaceutical logistics. In many cases, even the availability of raw materials was compromised, stalling production lines and compromising patient care (9,10). These experiences brought renewed attention to the concept of supply chain resilience. Defined as the system's ability to absorb shocks, recover swiftly, and adapt to emerging threats, resilience emerged as a cornerstone of future preparedness. The COVID-19 pandemic tested this capacity extensively, revealing that resilient supply chains are not merely reactive but proactive and adaptive. The ability to maintain functionality in the face of uncertainty is essential for minimizing harm to populations and ensuring uninterrupted access to critical healthcare resources. Learning from the cascading effects of COVID-19 and past crises, resilience planning is now recognized as an indispensable component of strategic supply chain management (11,12). Against this backdrop, the present study aims to explore the extent and nature of pharmaceutical supply chain disruptions during the COVID-19 pandemic, emphasizing the critical challenges encountered and identifying potential strategies to build resilient systems capable of withstanding future global health emergencies.

## METHODS

This review was designed as a narrative analysis of existing literature to explore the disruptions in pharmaceutical supply chains during pandemics, with particular emphasis on the COVID-19 pandemic. The scope of the study included peer-reviewed journal articles, systematic reviews, and empirical studies published in the past decade that addressed issues related to medicine availability, supply chain (SC) complexity, technological innovation, resilience strategies, and sustainability within the healthcare sector. Articles were identified through systematic searches in scholarly databases such as PubMed, Scopus, and ScienceDirect using keywords including “pharmaceutical supply chain”, “COVID-19 disruptions”, “resilience strategies”, “healthcare logistics”, “digital supply chain”, and “pandemic medicine shortages”. Boolean operators such as AND, OR, and NOT were applied to refine the search results. The inclusion criteria consisted of studies that focused on healthcare and pharmaceutical supply chains during pandemics, particularly COVID-19, and that provided empirical data, conceptual models, or case-based insights. Exclusion criteria included editorials, opinion pieces, and studies unrelated to pharmaceutical logistics or not addressing pandemics. Selected articles were screened independently by two reviewers for relevance and quality. Any disagreements were resolved through discussion or third-party adjudication. A data extraction form was used to collect information on study objectives, methodology, key findings, limitations, and conclusions. This helped in systematically comparing and synthesizing findings across different studies (13,14).

The methodological framework included a thematic synthesis of literature that aligned with four dominant research areas observed in existing studies: the impact of pandemics on SC operations, resilience-building measures, the role of technological integration, and sustainability practices. Each study was critically evaluated for methodological rigor, practical relevance, and theoretical contribution. Articles were categorized and compared for their strengths, limitations, and overall contribution to the field of pharmaceutical supply chain management. A major limitation noted in the reviewed body of literature was the lack of comprehensive evaluations that addressed short-, medium-, and long-term impacts of supply chain disruptions across different pharmaceutical product categories. While several studies proposed resilience strategies, few provided in-depth analysis of their implementation challenges or the combined use of multiple approaches. Moreover, although emerging technologies such as blockchain and digital platforms were often discussed, there was minimal exploration of novel logistics solutions like drone integration or hybrid distribution models. Similarly, sustainability strategies were frequently mentioned but rarely evaluated for their effectiveness under pandemic pressures.

## RESULTS

The reviewed studies collectively revealed a diverse range of methodologies and findings related to pharmaceutical supply chain resilience, disruptions, and adaptive strategies during the COVID-19 pandemic. Exploratory case studies demonstrated a strong positive correlation between digital technology adoption and supply chain resilience (SCR), with top management personnel highlighting the enabling role of digitization in continuity planning during crises. Similarly, a mixed-methods design to explore SCR in Chinese healthcare organizations and identified that SCR positively influenced overall supply chain performance (SCP), driven by four critical resilience enablers. Another study conducted a multi-country open call survey across seven high- and low-to-middle-income countries and uncovered seven new paradigms for antimicrobial stewardship program (ASP) resilience, including elements related to supply chain adaptations. However, a common limitation across studies was the absence of longitudinal data to measure long-term outcomes. For instance, a study developed a composite index comprising 23 indicators to assess supply chain performance amid the pandemic, yet their framework focused solely on the Iranian context and relied primarily on quantitative data, limiting generalizability.

From a technological standpoint, a study emphasized the impact of artificial intelligence (AI) on enhancing SCR through qualitative semi-structured interviews with supply chain personnel. The findings supported the role of AI in improving decision-making and forecasting capabilities during periods of uncertainty. Similarly, a study used real-time data from the English national health system to create a dynamic simulation model for evaluating ventilator supply strategies. Their model uniquely integrated disease transmission rates with resource availability, providing a conceptual foundation for real-world healthcare planning under conditions of uncertainty. Geographical comparisons were drawn, which analyzed public procurement strategies across the United Kingdom, Germany, and Switzerland using secondary data. Their analysis revealed significant differences in national strategies, emphasizing flexibility, redundancy, and collaboration. In contrast, cross-sectional surveys within Kenya and Nairobi respectively, reporting region-specific challenges in pharmaceutical supply chains. Both studies indicated a strong relationship between SCR and risk management practices but were limited by their localized focus and relatively small sample sizes.

A study offered insight from the Namibian pharmaceutical sector, where severe supply disruptions were recorded. Their descriptive analysis indicated widespread shortages in essential medicines and equipment, though the limited sample size of 21 participants restricted the broader applicability of the findings. In Pakistan, a study identified six key strategies for improving SCR, with their qualitative interviews highlighting the importance of internal collaboration, local sourcing, and contingency planning. Several studies highlighted barriers to achieving sustainable practices in supply chains. While many focused on the immediate disruptions and short-term adaptations, few explored the long-term sustainability of interventions. Notably, the sustainability dimension of pharmaceutical supply chains during pandemics remains underexplored, with limited empirical evidence evaluating the effectiveness of existing sustainability strategies or frameworks. A significant research gap emerged in the domain of technology integration. While AI and digital tools were addressed, few studies investigated the application of emerging logistics solutions such as drone-based deliveries, blockchain-enabled traceability, or telepharmacy systems. Additionally, the interaction between sustainability and resilience—two critical dimensions of healthcare supply chains—was insufficiently analyzed in the existing literature.

**Table 1: Highlights of Research Articles Included in Review**

SR#	Article Ref	Study design	Data Collection	Study population	Objective of Study	Outcome of Study
1	(Birkel et al., 2023)	Exploratory case studies	Interviews and Observations	Top management executives	Relation between SCR and digital technologies during pandemic	Positive relation between use of digital technology and SCR during pandemic
2	(Goff et al., 2022)	Open call method	Surveys 7 countries (HIC & LMIC)	Health care professional	ASP resilience during COVID-19	7 New paradigms in ASP including SC
-3	(Abbasi et al., 2022)	Case study	23 indicators	SC stakeholders	Creating a framework for measuring SC performance during COVID-19	Development of composite index
4	(Xiao & Khan, 2024)	Exploratory mixed method approach	Questionnaire, interviews,	Chinese HCO, HC suppliers and manufacturers	Impact of SCR on SCP and to establish framework	SCR has positive impact on SCP
5	(Götz et al., 2024)	Exploratory method	Data from English national health system	HC personnel involved in procuring ventilators	Create a model to evaluate different supply strategies and its impact on certainty/uncertainty	Created system dynamic model to improve resilience in HC supply strategies during crisis
6	(Dube et al., 2022)	Qualitative case-based research design	Secondary data from publications/online sources	UK, Germany and Switzerland public procurement	Compare procurement strategies of three governments with different initial conditions	Different resilient strategies achieved in extreme SC disruptions
7	(Letikash, 2022)	Cross sectional	Survey based questionnaire	Pharmaceutical firms of Kenya	Evaluate the impacts of pandemic o-n SC disruption in Kenya	Negative correlation between pandemic & SC resiliency
8	(Kioko, 2023)	Descriptive	Online survey questionnaire	Pharmaceutical firms of Nairobi	Impact of pandemic on SC disruptions and SCR by pharmaceuticals	Positive relation of SCR with SC risk management & collaboration strategies
9	(Tirivangani et al., 2021)	Descriptive	Qualitative based survey	Pharmaceutical sectors of Namibia	Impact of COVID-19 on SC in pharmaceutical system	Pandemic causes severe SC disruptions
10	(Zaman et al., 2023)	Descriptive	Qualitative based interviews	HC sector in Pakistan	SCR during COVID-19 pandemic	Identify 6 factors to improve SCR
11	-(Modgil et al., 2021)	Descriptive	Qualitative Semi-structured interviews	SC personnel	Impact of AI technology on SC resiliency during pandemic	AI helps in improving SC resiliency during pandemic

**Table 2: Strengths, Limitations and Research Gaps of The Studies**

SR#	Article ref	Strengths	Limitations	Research Gaps
1	(Birkel et al., 2023)	Practical examples from multiple case studies Provides insights on how to adapt during crisis by the use of digital technology	Small sample size limits generalizability of results Study is focused on limited digital technology Since the study is qualitative in nature, there is potential for bias depending on the perspectives of the researcher	There is need to conduct longitudinal studies so that there is proper examination of post pandemic outcomes. There is scope for future research by involving new technologies like block chain and AI.
2	(Goff et al., 2022)	Extensive perspective internationally by including 7 countries Adaption of new resilience strategies in ASP	Lack of quantitative data There is potential of bias on personal as well as institutional level Practical challenges of implementation of new strategies	There is a need to assess the ASP resilience strategies from quantitative aspect. Future work should also focus on how to integrate these ASP in emergency situation.
3	(Abbasi et al., 2022)	Multiple stakeholder engagement Establishing holistic and comprehensive framework and composite index Analyze both positive and negative impact of pandemic on sustainability of SC	Cannot generalize the result (focused in Iran) Limited practical application due to complexity of 23 indicators External influence like policies of government or fluctuations in market is not addressed Qualitative indicators are missing, solely focused on quantitative aspects Not applicable post pandemic situation	Future works can incorporate psychological aspects to expand the framework. There is a need to conduct the study longitudinally to get understanding o-f post pandemic situations.
4	(Xiao & Khan, 2024)	Mixed method approach provides extensive insights on SCR Identify 4 key drivers for improved SCP	Study was limited to China Small sample size	Future study may be conducted for large sample size and include other stakeholders like customers and multiple suppliers. Furthermore, focus on role of technology to improve SCP is needed. There is a need of more focused approach in the interview.
5	(Götz et al., 2024)	Integration of disease transmission and availability of supply is unique model Use of real time data help in simulating real life scenarios of health crisis	Being a Proof of concept model in nature, it may not be able to generalize its findings to complex real world cases There is geographical restraint as it is focused on only one data base	Expansion of geographical area and longitudinal studies can help to provide deeper understanding of the situation. One more dynamic to add in this context is to understand how different

SR#	Article ref	Strengths	Limitations	Research Gaps
6	(Dube et al., 2022)	Use of equifinality lens to assess similar outcome using different strategies Key resilience term and their interconnectedness is evaluated (agility, flexibility, redundancy, collaboration & - visibility)	Limited to highly resourceful countries Specific to Public procurement Secondary data may introduce biasness	Future study can be done on private setups Cost-effectiveness of multiple strategies can be evaluated Inclusion of low resource countries Multidisciplinary and longitudinal approach is needed
7	(Letikash, 2022)	Empirical nature of study	Limited to pharmaceutical sector	Need to incorporate different sectors and geographical location Need to include other variables like technological development Longitudinal aspect is needed to broaden the study
8	(Kioko, 2023)	Identifies major barriers in SCR during pandemics	Data collection method is vulnerable to bias by participants Focused on pharmaceutical sector in specific region	Need for longitudinal studies and different geographical location Need to include other sectors as well
9	(Tirivangani et al., 2021)	Public and private sectors Focus on specific SC regional issues in Namibia	sample size is very limited which is only 21 which limits generalizability of results Only qualitative data-based survey	Inclusion of large sample size Other geographical areas Other sectors can be included Long term study is needed
10	(Zaman et al., 2023)	Identify 6 key strategies to improve SCR during pandemics	Limited sample size	Include large sample size in future
11	(Modgil et al., 2021)	Impact of AI on SC resiliency is new area of research	Limited sample size	Include other technology like block chain Include large sample size Need to focus on post pandemic impacts of AI on SC resiliency

## DISCUSSION

### Use of Technology Advancements for Supply Chain Resilience

The role of digital technologies in fostering pharmaceutical supply chain resilience has been underscored by multiple studies during the COVID-19 pandemic. Organizations with high digital maturity demonstrated superior capabilities in absorbing supply chain shocks and adapting operations efficiently. Integration of artificial intelligence enhanced the capacity to detect early-stage risks, predict disruptions, and streamline decision-making through automation and data-driven simulations. These findings reinforce prior assertions in the literature that technology not only strengthens operational efficiency but also embeds adaptive intelligence within the system, allowing healthcare supply chains to remain functional under stress (15,16). However, a critical limitation in existing studies is the underexploration of emerging technologies such as blockchain and drone logistics. The current body of work remains largely qualitative, thus lacking robust empirical validation. There is considerable potential in future research to investigate how the integration of multi-technology ecosystems could further augment resilience, especially in resource-constrained environments.

### Resilience Strategies in Antimicrobial Stewardship Program



Pandemic-induced supply shortages, particularly in antimicrobial agents, necessitated a transformation of antimicrobial stewardship programs (ASP) across both high-income and low-to-middle-income countries. Adaptive strategies such as substitution protocols, decentralized review mechanisms, empirical treatment guidelines, and the production of disinfectants reflect a proactive shift in public health practices. These approaches highlight the importance of resilience through flexible prescribing norms and localized manufacturing (17,18). While such paradigms proved effective in immediate response, the broader structural limitations, especially in LIC settings, indicate gaps in sustained preparedness. The implementation of telestewardship and government collaborations shows promise, but scalability, regulatory compliance, and equitable access remain areas requiring further investigation. A long-term evaluation of these adapted ASP models in post-pandemic phases is essential to assess their integration into national healthcare strategies.

### **Performance Measurement of Supply Chain Sustainability**

Quantitative evaluation frameworks for measuring supply chain sustainability during pandemics emerged as a critical advancement. By incorporating economic, environmental, and social indicators, comprehensive indices were formulated to assess the impacts of the pandemic on supply chain operations. While economic metrics such as increased hygiene costs and reduced operational margins presented financial constraints, environmental metrics showed a temporary benefit through reduced emissions. However, the surge in medical waste introduced negative externalities. Social factors, including customer satisfaction and workforce safety, gained prominence, emphasizing the multidimensional nature of sustainability (19,20). Despite its methodological strength, the sustainability evaluation model was limited by regional scope and complexity of application. To standardize such frameworks globally, future studies should focus on simplifying indicator systems, enabling cross-country comparisons, and integrating real-time sustainability dashboards in pharmaceutical logistics.

### **Impact of Supply Chain Resilience on Supply Chain Performance**

A direct and measurable link between supply chain resilience and overall performance was observed, particularly in the context of the healthcare sector. Organizational culture, communication infrastructure, and top management support emerged as key drivers influencing resilience outcomes. The presence of flexible systems and empowered leadership structures enabled firms to navigate production halts, distribution delays, and demand fluctuations more effectively. Quantitative analyses affirmed the positive correlation between supply chain performance and resilience attributes (21,22). However, studies showed variability in impact strength across firms, suggesting that resilience is not uniformly operationalized. The role of product complexity, digital infrastructure, and inter-organizational alignment requires further scrutiny to identify scalable strategies. Moreover, future investigations should emphasize resilience benchmarking models that can guide supply chain professionals in self-assessing readiness across diverse health systems.

### **Procuring Critical Items Like Ventilators in Pandemics**

Crisis-driven procurement strategies for critical items like ventilators brought to light the challenges of centralized systems during a pandemic. Strategic decisions such as importing, local manufacturing, tendering, and stockpiling were evaluated for effectiveness under dynamic conditions. The development of simulation models integrating disease transmission and supply forecasting offered a novel approach to visualizing demand-supply interdependencies (23,24). However, real-world application of these models remains limited due to logistical and geopolitical constraints, such as transport delays and international trade restrictions. Comparative policy analyses revealed that countries with higher supply chain agility and redundancy responded more efficiently, whereas others with rigid structures experienced prolonged shortages. The studies focused on ventilator procurement also highlighted the value of cross-sectoral collaboration, such as private sector mobilization and supplier diversification. However, the effectiveness of these strategies was often confined to well-resourced settings, underscoring the need for global equity in supply chain policy design and resource access.

### **Impact of Pandemic on Supply Chain Disruptions**

The COVID-19 pandemic significantly intensified vulnerabilities in pharmaceutical supply chains, particularly in low- and middle-income countries. Survey-based studies in Kenya, Namibia, and Pakistan showed that disruptions led to severe medicine shortages, reduced healthcare service delivery, and compromised public health outcomes. The findings also emphasized that supply chain risk management, effective communication, and collaborative partnerships played a pivotal role in mitigating adverse impacts. Firms that had pre-existing risk documentation systems and strategic contingency planning demonstrated higher adaptability. However, technological adoption did not show a significant correlation with resilience in all settings, suggesting disparities in digital infrastructure and technological readiness (25,26). Notably, self-medication trends and shifts in consumer behavior also influenced pharmaceutical demand patterns, requiring adaptive forecasting tools. Although regional studies provided valuable insights into localized challenges, a

major gap remains in assessing long-term impacts and evaluating cross-border coordination mechanisms during pandemics. Future research must explore comprehensive regional frameworks that strengthen healthcare logistics across borders, integrate public-private partnerships, and promote equitable access to essential medical products.

Collectively, these findings underscore the multifactorial nature of pharmaceutical supply chain resilience during global health emergencies. While technological innovation, institutional flexibility, and collaborative governance emerged as critical enablers, systemic limitations such as geographic disparities, technological gaps, and lack of standard frameworks hindered uniform resilience. Future directions should include longitudinal studies assessing post-pandemic transitions, expansion of technological models to diverse healthcare settings, and formulation of globally applicable sustainability and resilience indices.

## CONCLUSION

The COVID-19 pandemic has underscored the critical need for resilient pharmaceutical supply chains capable of maintaining operational continuity during large-scale disruptions. This review highlights that building such resilience requires a multifaceted approach involving early integration of digital technologies, diversification of suppliers, and strengthening communication and collaboration across all stakeholders. Proactive measures such as stockpiling, flexible manufacturing, and real-time risk monitoring can significantly enhance preparedness. The findings emphasize that resilience is not just about recovery but about anticipation and adaptability. By prioritizing these strategies, pharmaceutical systems can ensure the uninterrupted delivery of essential medicines, safeguarding public health during present and future crises.

## AUTHOR CONTRIBUTION

Author	Contribution
Hira Jamil*	Substantial Contribution to study design, analysis, acquisition of Data
	Manuscript Writing
	Has given Final Approval of the version to be published
Leena Anjum	Substantial Contribution to study design, acquisition and interpretation of Data
	Critical Review and Manuscript Writing
	Has given Final Approval of the version to be published
Abdul Razzaque Nohri	Substantial Contribution to acquisition and interpretation of Data
	Has given Final Approval of the version to be published
Gul Sama	Contributed to Data Collection and Analysis
	Has given Final Approval of the version to be published
Ali Hamza	Contributed to Data Collection and Analysis
	Has given Final Approval of the version to be published
Saima Asif	Substantial Contribution to study design and Data Analysis
	Has given Final Approval of the version to be published

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