

Global Health Commodities Supply Chain in the Era of COVID-19 Pandemic: Challenges, Impacts, and Prospects: A Systematic Review

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Background: The COVID-19 pandemic led to the most substantial health crisis in the 21st Century. This pandemic interrupted the supply of essential commodities for human beings. Among the essential commodities for human survival, disruption of the supply of essential health commodities has become a global concern.

Objective: The study aimed to systematically analyze published articles on the challenges, impacts, and prospects of the global health commodities' supply chain in the era of the COVID-19 pandemic.

Methods: A standard searching strategy was conducted in seven research databases to retrieve pertinent articles. Finally, 459 articles were retrieved for further screening, and only 13 articles were selected for final synthesis.

Results: Almost 38.5% of the studies targeted the supply chain of health commodities used to treat HIV, TB, and malaria. Lockdown policies, travel restrictions, lack of transportation, low manufacturing capacity, and rising costs were the significant challenges indicated for the supply interruption of essential health commodities and COVID-19 vaccines. Findings indicated that the supply interruption of essential health commodities leads to a devastating impact on global health.

Conclusion: Global medicine shortages due to the pandemic crisis can have a devastatingly harmful impact on patient outcomes and might result in a devastatingly long-lasting effect on the health of the world community. Supply-related challenges of the COVID-19 vaccine affect countries' ambitions for achieving herd immunity quickly. Monitoring the pandemic's effect on the health commodities' supply system and designing a short-term and long-term resilient health supply chain system that can cope with current and future health catastrophes is pivotal.

Keywords: global supply chain, health commodities, health product, pharmaceuticals, challenges, opportunities, prospects, COVID-19, COVID-19 vaccine

Background

Novel coronavirus scientifically called as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It was first spotted in December 2019 in Hubei Province of China's Wuhan City. The viral strain then walked over drastically, leading to a nationwide epidemic outbreak.¹ The World Health Organization (WHO) declared "COVID-19" as a "public health emergency of international concern" on January 31, 2020.² The COVID-19 outbreak is considered the most significant crisis of health in the 21st century. Since then, the World has been in unprecedented conditions in which the Pandemic has resulted severe economic recession in a century.³ The global pandemic has caused a pause in activity worldwide for over a year, impacting nearly every country on the planet.⁴ The Pandemic is unlikely to end until the world population takes enough vaccines that protect against severe strains of the virus and preferably drive herd immunity.⁵ It has also revealed the lack of early preparedness and the fragility of the global health systems. It has also badly tested the world economy, political system, legal system, and social structures and institutions.⁶

According to historical records, major natural crises, including; wars, famines, and pandemics, constantly interrupt the supply chains of essential commodities for human beings. The world supply system is distinctively sensitive to crises

and uncertainties related to many logistics components.^{7,8} The global erratic lockdown policies aggravated this condition, leading to community quarantines, travel restrictions, and state of emergencies declared.^{4,9} Unless proactive measures are taken in response to the pandemic, there will be severe consequences on poverty, disease control, food security, and economic growth.¹⁰ Consequently, the ongoing pandemic crisis, combined with the world healthcare system crisis and lockdown, disrupted the upstream global supply chains. Equally, disruptions to the downstream of the supply chain have occurred due to commodity hoarding and panic buying.⁴

Among the essential commodities for human survival, disruption of the essential health commodities' supply chain has become a global issue.⁹ The Pandemic triggered a shortage of essential health commodities needed to treat and protect the pandemic due to a huge rush in need all over the world. Export controls over personal protective equipment (PPE) were imposed by many affected countries and sought to boost domestic manufacturing.^{11,12} The pandemic also severely hampered worldwide endeavors to prevent and address various acute and chronic illnesses.¹³ In addition to diverting the attention of health professionals towards the pandemic, there was a disruption of vital medicine supply for other diseases because of repurposing it to the COVID-19 pandemic fight,¹⁴ including antiviral medicines used for ART, antimalarial drugs,¹⁵ and medical supplies.¹⁶ This repurposing approach of essential health commodities for COVID-19 management resulted in supply gaps for managing routine cases.^{14,15}

Mainly, the disruption of essential health commodities' supply chains in low- and middle-income countries is expected to result in further loss of life over the next five years, particularly due to the heavy burdens of HIV, tuberculosis, and malaria.¹³ It is difficult to predict the eventual consequences of the patient outcome. This might create another health catastrophe in the coming few years.⁹

Furthermore, the outbreak caught the attention of pharmaceutical scientists and pharmaceutical industries focused on searching for vaccines for COVID-19.¹⁷ Although mass vaccination became a new world direction for controlling the pandemic, quickly achieving herd immunity against the infection is not easy for many developing countries.^{18,19} Access to COVID-19 vaccine and lack of adequate vaccine supply chain infrastructure will negatively affect low- and middle-income countries' ambition to achieve herd immunity by vaccinating their 60–70% population. More than 70% of doses are pre-ordered by developed countries despite the limited vaccine production capacity. Consequently, the multifaceted impact of the virus will continue to unforeseen future.²⁰

Therefore, examining the impacts and challenges posed by the COVID-19 outbreak on the global health commodities' supply chain and identifying potential prospects for improvement is a pertinent and timely issue. The objective of this study was to analyze articles addressing the challenges, impacts, and potential prospects associated with the global health commodities' supply chain during the COVID-19 pandemic era. This study will serve as valuable insight for industrial managers, researchers, supply chain stakeholders, logistics firms, and government policymakers. It aims to guide initiatives to redesign a resilient health commodities' supply chain system, both during the current pandemic and beyond.²¹

Methods

To get the best relevant literature, a standard search strategy was used in Science Direct, and later, it was adapted according to each specific database. The basic search approach was built based on the study questions formulated. First, a trial search was done to identify another relevant term within each concept from accessed papers. Then, an improvement on the search term was made. The following keywords were used for searching articles on health commodities' supply chains (Supply Chain, Health commodities, and COVID-19) combined with Boolean Operators (AND, OR).

After repeated trials and improvement of search terms, the final keywords for online databases were formulated as follows: “Supply Chain” AND “Health commodities” OR “Health Products” OR “Pharmaceuticals” OR “Medications” AND “COVID-19” “COVID-19 Vaccine” AND “Challenges” OR “Opportunities” OR “Future Prospects”.

Before proceeding to the final search procedures, both inclusion and exclusion criteria were framed;

Inclusion Criteria

- Any original article/supply chain modeling studies published on global health commodities' supply chain indicating challenges, opportunities, and prospects at COVID-19 Pandemic era.
- Written in English language.
- No restriction regarding country.
- Published in the COVID-19 Era (from December 2019 up to June 2021).

Exclusion Criteria

- Articles published on other commodities supply chains other than health products.
- Overlapping, unreliability extracted, and duplicated data.
- Papers with only abstracts, proceedings, editorials, conferences, commentary, policy briefs, perspectives, author responses, thesis, and books.
- Case series studies, case reports, meta-analysis and systematic review.

Articles Screening and Selection

To access relevant articles, search words were checked in different online databases. The search strategy was modified according to the database's unique search strategy. Finally, only seven online research databases that are rich with the topic of interest were selected to search for pertinent articles per the research question. As a result, published articles were searched from seven online catalogs, including Mendeley, Scopus, Google Scholar, Springer, Emerald Insight, Science Direct, and PubMed (Medline). In order to reduce bias, repeated manual searching was conducted to access studies that might have been dropped from the first-hand search in the respective seven databases. Additionally, manual searching was performed from studies/reviews and looking at related articles/cited articles.

Accordingly, 22,234 articles were retrieved from the seven databases using a combination of search engines. Then, only 412 of them were downloaded or synced into the Mendeley library based on a preliminary online assessment of the title and previewed abstracts. In addition, a total of 47 articles were identified through manual searching. For screening, the number of articles retrieved from Scopus, Mendeley, Google Scholar, Springer, Emerald Insight, Science Direct, and PubMed was 67, 26, 24, 28, 37, 244, and 33, respectively. Finally, all retrieved documents were synced and uploaded into the Mendeley library to delete duplicates and for better reference management. Subsequently, all 459 articles underwent screening based on the inclusion and exclusion criteria delineated in the PRISMA flow diagram. Finally, 13 articles were selected for final synthesis (Figure 1). The selection process was independently conducted by two experts, in order to minimize bias and to increase validity. After the final decision was reached with consensus, the methodological approach was reviewed and approved by one senior expert.

Results and Discussion

Focus Area of Reviewed Articles

Most studies (54%) used a modeling study design, and the rest (46%) used a cross-sectional study design. Modeling studies used publicly available epidemiological data and routine data from databases, whereas cross-sectional studies used electronic questionnaires to collect quantitative and qualitative information (Table 1).

Five studies were conducted in Africa, and two of the studies were based in the USA, one study in low- and middle-income countries (LMICs) and the rest conducted in Canada, Saudi Arabia, Iran, India, and two continents (Africa & South America) (Figure 2).

Almost 38.5% of the studies focused on the supply chain of drugs used for the treatment of HIV, TB, and malaria.^{8,13,22,27,28} The supply chain of essential health commodities was specifically examined by three of the studies (23%).^{23,31,32} Two (15.4%) studies targeted infection prevention supplies and personal protective equipment.^{29,32} The rest of the studies was focused on medicines for self-medication,²⁵ opioids and benzodiazepines,²⁶ medical waste,²⁴ and COVID-19 vaccines³⁰ (Figure 3).

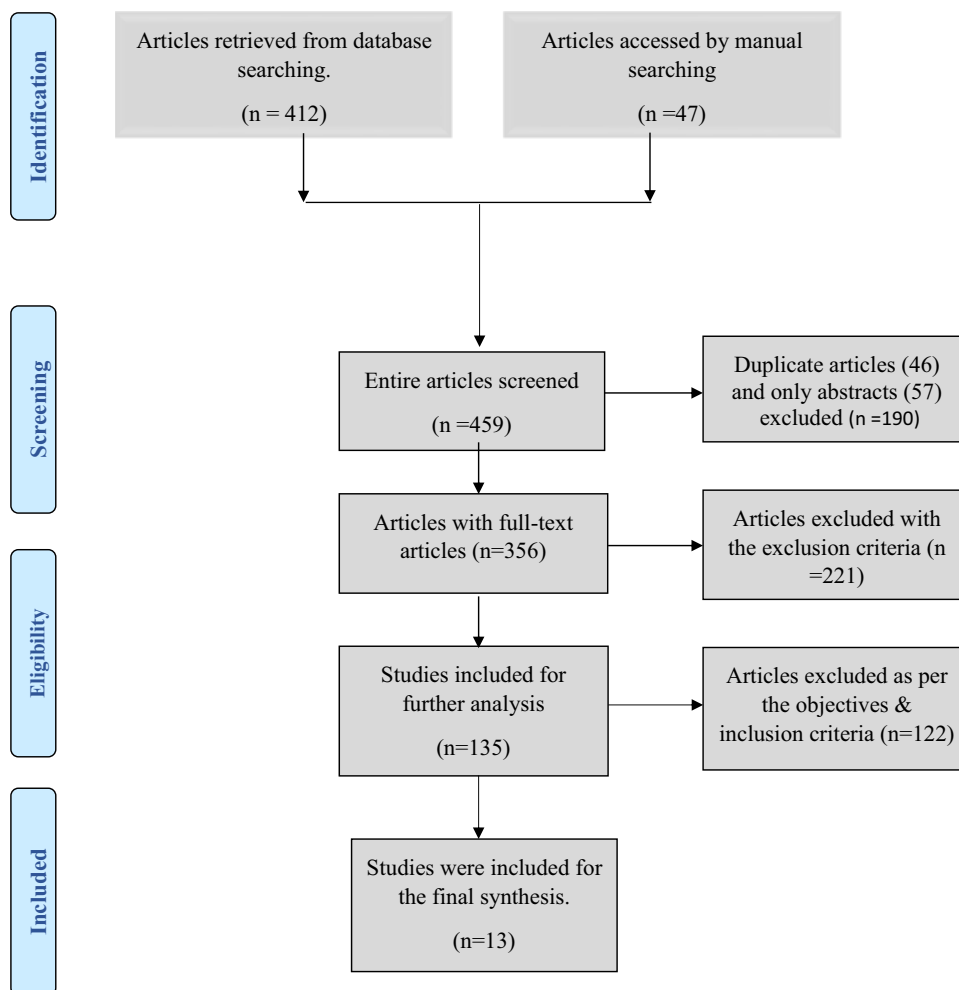


Figure 1 PRISMA flow diagram showing screening and selection of published articles.

Almost all of the studies addressed pandemic-induced challenges, impacts, and prospects of the global health commodities' supply chains. However, the reviewed literature did not address the disruption of the supply chain of vaccines for routine immunization and drugs used to treat non-communicable diseases. This might be due to the fact that supply interruptions of vaccines and health commodities for chronic diseases have no immediate impact on the health of society (Table 2).

Challenges of the Global Health Commodities Supply Chain in COVID-19 Era

The literature identified different challenges that health commodities' supply system disruption faces because of the COVID-19 virus. The majority of literature mentioned supply interruption of the respective essential health commodities due to lockdown policies, travel restrictions, lack of transportation, lack of APIs, international shipping interruption, workforce shortage, income decrement, and the rising cost of health commodities^{8,13,22,23,27,28} (Figure 4).

Lack of enough vaccine manufacturing companies, high vaccine costs; absence of financial support for the vaccine; absence of cold-chain infrastructure, consumers' unwillingness to vaccinate were the main challenges mentioned in the COVID-19 vaccines' supply chain system.³⁰ These findings are supported by other scholars indicating similar challenges for health commodities' supply interruption as a result of pandemics.^{8,12,33–35}

As a consequence of the pandemic, all health systems around the globe were overstretched;²⁷ and many countries released policies on elective medical procedure restrictions, including medication refills.²⁶ Most health professionals are working in stressful conditions,²⁵ and due to fear of contracting the virus, they refuse to attend to patients.²³ They also

Table 1 Summary of Reviewed Articles on Global Health Commodities' Supply Chain in the Era of COVID-19 Pandemic: Challenges, Impacts, and Prospects: A Systematic Review, June 2021

Authors	Study Design	Methods of Data Collection/ Source	Study Location	Targeted Category of Health Commodities	Identified Challenges	Identified Impacts on the Supply Chain	Prospects Indicated
[13]	Modeling	Epidemiological prevalence data	South, East, and West Africa; South America	HIV, TB, and Malaria treatments	Yes	Yes	Yes
[22]	Geospatial modeling analysis	Baseline epidemiologic data from the database	Malaria endemic African countries	Malaria Treatments	Yes	Yes	Yes
[8]	Cross-sectional	Qualitative information collected via email	India	HIV Treatments	Yes	Yes	Yes
[23]	Cross-sectional	Data collected via Electronic Questionnaire	Nigeria	Essential Medicines for Chronic & Acute Diseases Treatment	Yes	Yes	Yes
[24]	Modeling	Real data collected from centers in northern Iran	Iran	Medical Wastes	Yes	Yes	Yes
[25]	Cross-sectional	Data collected via Electronic Questionnaire	Kenya	Drugs for self-medication	Yes	Yes	Yes
[26]	Modeling (Interrupted time series analysis)	Texas Prescription Monitoring Program	Texas, USA	Opioids and Benzodiazepines	Yes	Yes	Yes
[27]	Modeling	Data was from 12 countries of sub-Saharan Africa	Sub-Saharan Africa	HIV drugs	Yes	Yes	Yes
[28]	Mathematical Modelling	Publically available Prevalence data	Sub-Saharan Countries (South Africa, Malawi, Zimbabwe, and Uganda)	HIV drugs	Yes	Yes	Yes
[29]	Cross-Sectional Survey	Data collected via Electronic Questionnaire	USA	Personal protective equipment and infection prevention supplies	Yes	Yes	Yes
[30]	Modeling (IF-DEMATEL)	Expert Interview, Self-administered Questionnaire	LMICs	COVID-19 vaccine	Yes	Yes	Yes
[31]	Retrospective Cross-Sectional	Data from Electronic Database (Drug shortage Canada)	Canada	All medicines	Yes	Yes	Yes
[32]	Cross-sectional study	Online Self-administered questionnaire	Saudi Arabia	Essential medicine and personal protective equipment (PPE)	Yes		Yes

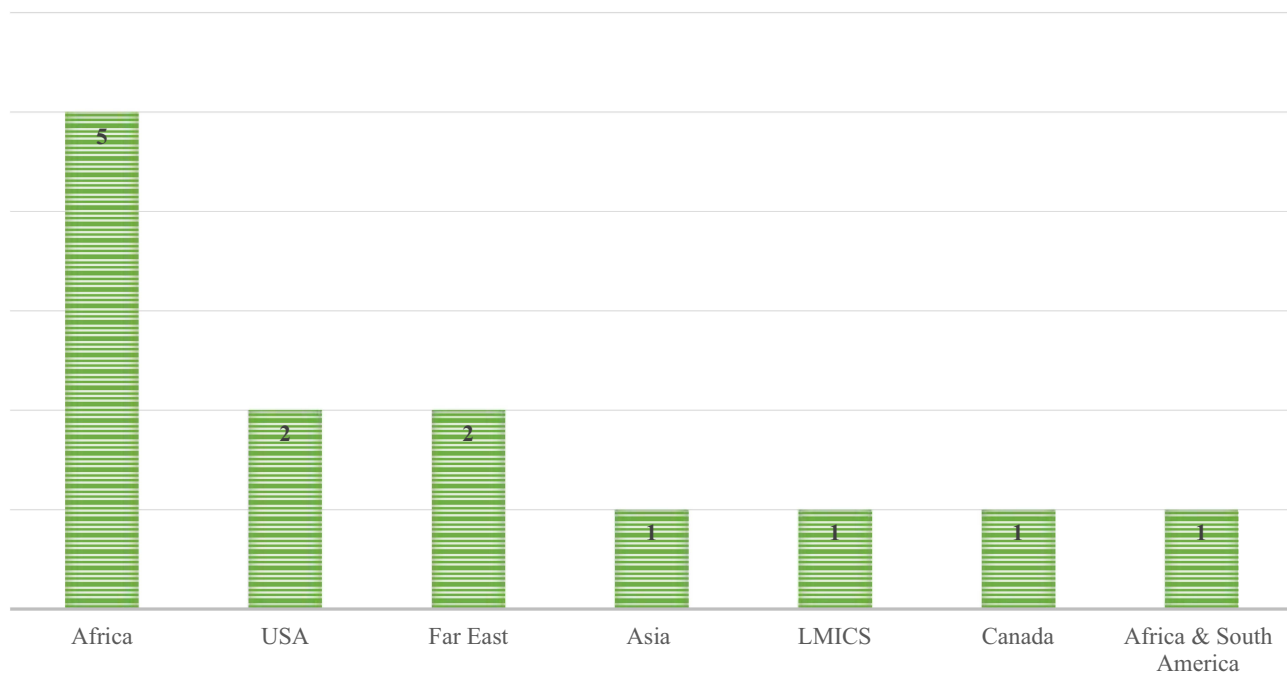


Figure 2 Regional distribution of published articles used for final analysis.

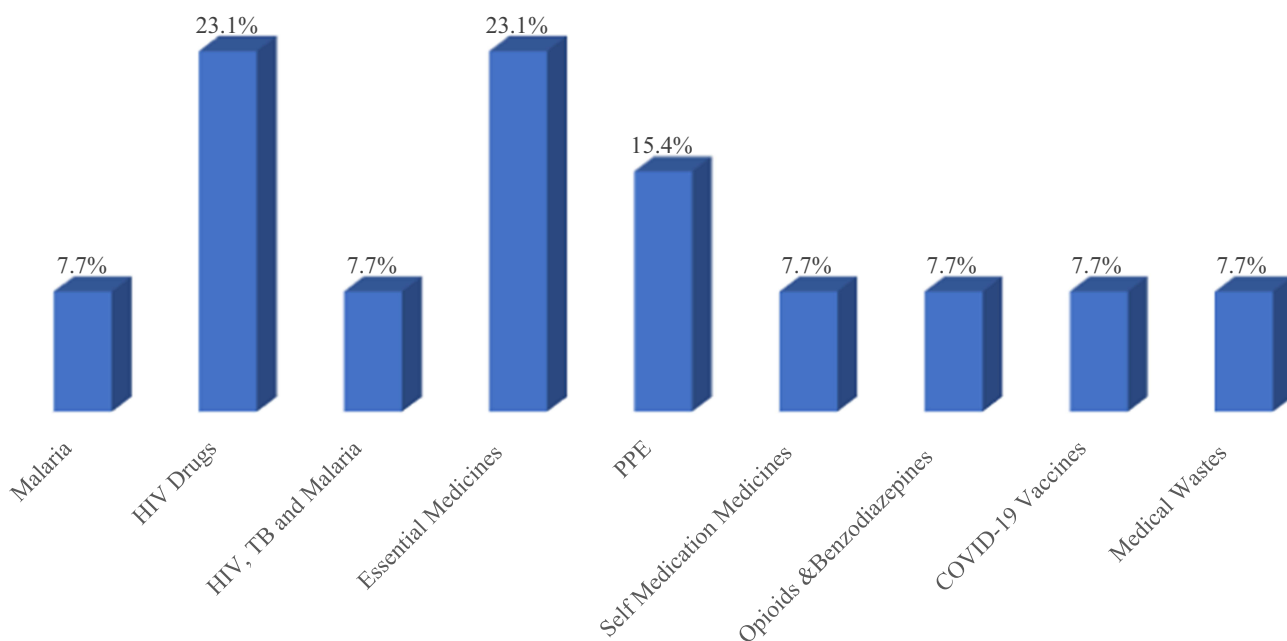


Figure 3 Class of essential medicines addressed in the reviewed articles.

have prolonged contact with infected individuals without wearing self-protection PPEs due to a critical shortage;²⁹ and they over-prescribed self-medications in order to manage different pain symptoms, including headaches, migraines, joint and muscle pains, and running nose.²⁵ A similar study by³⁶ indicated that many countries were worried about the unavailability of PPEs for frontline healthcare employees. The sudden rise in the volume of health-related waste generated and the absence of an adoptable reverse logistics network were also critical challenges at the time of the pandemic.²⁴

Table 2 Summary of Challenges, Opportunities, and Prospects for Global Health Commodities' Supply Chain

Authors	Targeted Health Commodities	Identified Challenges	Identified Impacts on Supply Chain	Future Prospects Indicated
[13]	HIV, TB and Malaria Treatments	<ul style="list-style-type: none"> • HIV interruption to antiretroviral therapy • Decrease timely diagnosis and treatment of TB • Malaria disruption of supply and planned net campaigns 	<ul style="list-style-type: none"> • Deaths due to HIV, TB, and malaria over five years could increase by up to 10%, 20%, and 36%, respectively, compared with if there was no COVID-19 pandemics 	<ul style="list-style-type: none"> • Improving the resilience of the health system • Long-term suppression and intervention for COVID-19 Pandemic
[22]	Malaria Treatments	<ul style="list-style-type: none"> • Supply chain disruption of effective antimalarial drug treatment 	<ul style="list-style-type: none"> • Disruption of medicines in Africa could almost double malaria mortality in 2020 and lead to even more significant increases in the forthcoming years 	<ul style="list-style-type: none"> • Fighting and averting the Pandemic must remain an integrated priority
[8]	HIV treatments	<ul style="list-style-type: none"> • International shipping interruption • Delay (increased lead times) • Rising costs • Shortage of workforce in manufacturing plants • Forecast for a return to normality • Lack of active pharmaceutical ingredients and excipients to manufacture HIV drugs 	<ul style="list-style-type: none"> • Inflate AIDS-related deaths worldwide • Transmission to someone else will increase due to high viral load in people receiving ART 	<ul style="list-style-type: none"> • Improve the resilience of the generic ARV drug supply system • Initiate long-term orders for multi-month dispensing • Consider safety stocks in the facilities • Use real-time information with computerized inventory management system • Stakeholders collaboration
[23]	Essential Medicines for Chronic & Acute Diseases Treatment	<ul style="list-style-type: none"> • Poor means of transportation availability • Income decrement • Increase in the price of drugs • Healthcare workers refusal to treat patients in fear of getting the virus. 	<ul style="list-style-type: none"> • 35.2% of participants with chronic diseases had challenges for getting essential drugs vs 10.6% before lockdown. • Due to problems in getting their medicines, 84% experience worsening chronic health conditions 	<ul style="list-style-type: none"> • If the people cannot get to healthcare facilities, design strategies such as community-based responses • Initiate sustainable and large-scale drug manufacturing initiatives
[24]	Medical Wastes	<ul style="list-style-type: none"> • An abrupt increase in the volume of generated medical wastes • Lack of adoptable reverse logistics network design for Infection Medical Waste (IMW) during pandemics 	<ul style="list-style-type: none"> • Decreasing per person Medical Waste to 15% can decrease the total cost and risk with 7.5% and 15%, respectively. • Installing Temporary Treatment Centers took up to 50% of the cost, and the transportation cost of IMW and the treated waste cost was 16% and 10%, respectively. 	<ul style="list-style-type: none"> • Efficiently forecast the amount of generated waste using real-time data to precisely predict. • Proper management of Covid-19 IMW can decrease the transmission and might have minimized an extra cost. • Using portable treatment machines to reduce transporting waste • The discovery of curative drugs or remedies can reduce the amount of total generated wastes

(Continued)

Table 2 (Continued).

Authors	Targeted Health Commodities	Identified Challenges	Identified Impacts on Supply Chain	Future Prospects Indicated
[25]	Drugs for self-medication	<ul style="list-style-type: none"> Professionals are working in stressful Covid-19 treatment centers Feeling different pain symptoms including headache, migraine, joint, and muscle pains, and running nose 	<ul style="list-style-type: none"> Self-medication prevalence increased to 60.4% (n = 229) as compared to 36.2% (n = 137) before the pandemic. Perceived adverse drug reactions reported from 22.4% (n = 85) of self-medication users. 	<ul style="list-style-type: none"> Sensitization and awareness creation could help to reduce self-medication practices among health professionals in panic pandemics.
[26]	Opioids and Benzodiazepines	<ul style="list-style-type: none"> Restriction on routine outpatient procedures and other medical procedures Supply interruption opioid or benzodiazepine treatments 	<ul style="list-style-type: none"> A substantial decrease in patients filling new opioid prescriptions ($\beta = -6029$, 95% CI = $-8810.40, -3246.72$). Decrease number of new opioid prescriptions following the executive order ($\beta = -2784$, 95% CI = $-3671.09, -1896.19$) Patients' quality of life decrement Healthcare systems, and economies had significant cost burden to patients 	<ul style="list-style-type: none"> Monitor Controlled Substance Prescription filling and patients' access to care in a pandemic disaster. Public health officials must access Prescription Drug Monitoring data in real-time for rapid policy change
[27]	ART drugs	<ul style="list-style-type: none"> Overstretched health systems due to Covid-19 Supply interruption of ART drugs Interruption of other HIV prevention programs 	<ul style="list-style-type: none"> Supply disruption for 50% of people for six months is expected to lead to a 1.63 times [1.39; Optimal HIV model–1.87; HIV Synthesis model] increase in HIV-related deaths over 1 year compared with no disruption. The six months of HIV disruption for 50% of persons are projected to increase 1.15–1.29 times the current annual number of deaths for the next five years. Transmission of HIV from mother-to-child may increase due to interruption of ART drugs by approximately .16 times. 	<ul style="list-style-type: none"> Governments, donors, suppliers, and communities should focus on maintaining a continuous supply of ART drugs at the time of pandemics to avoid additional HIV-related deaths. To prevent any increase in HIV incidence, other HIV prevention measures are also essential.
[28]	ART drugs	<ul style="list-style-type: none"> Disruption of HIV drug supply No new ART enrolments Decrease in viral suppression 	<ul style="list-style-type: none"> Interruption for 3 months to 40% of those on ART could lead to a similar number of additional deaths compared to those saved from COVID-19 via social distancing. Disruption to ART for 9 months could lead HIV deaths to exceed the number of COVID-19 deaths for 60–90%. If ART supply is maintained and other HIV prevention methods cease for three months, rises in HIV deaths would be limited to <2% over 5 years. 	<ul style="list-style-type: none"> Under reasonable worst-case assumptions, HIV deaths could increase substantially during the COVID-19 Pandemic High-burdened countries should give urgency to ensure steadiness of ART during the pandemics.

[29]	Infection Prevention Supplies and Personal Protective Equipment (PPE)	<ul style="list-style-type: none"> • Health professionals have lengthy exposure with infected patients without wearing PPE. • In the first month of the pandemic, there was lack of sufficient infection prevention supplies • The critical shortage of masks, N95 respirators, isolation gowns, face shields, goggles, hand sanitizer, and disinfection supplies • Less than half (45.4%) have adequate disinfection supplies • Only 13.6% and 18.2% of health professionals had sufficient Face shields and N95 respirators, respectively (P < 0.001 for all) 	<ul style="list-style-type: none"> • High risk of illness for healthcare workers when providing care to COVID-19 patients • Healthcare-acquired infection transmission increased • Causing unsafe patient care and work environments. 	<ul style="list-style-type: none"> • Before the next major pandemic wave, gaps in stockpiling and planning need to be addressed • Failure to do so will result in excess occupational exposures and healthcare-associated infections
[30]	COVID-19 Vaccines	<ul style="list-style-type: none"> • Inadequate number of vaccine manufacturing industries • Infrastructure problems for transportation and cold chain system • Tracking vaccinated population is difficult • Inappropriate local organization coordination • Absence of vaccine monitoring bodies • Financial constraint • Challenges in vaccine demand forecast accuracy • Lack of willingness to vaccinate • Volunteers are not interested in vaccine trials 	<ul style="list-style-type: none"> • Low vaccine coverage and access, which in turn affects at least 9 of the 17 SDGs. 	<ul style="list-style-type: none"> • Stakeholders should define, map, and give significant attention to key challenges for the successful execution of VSC. • Study challenges of COVID-19 vaccine development, production, distribution, and administration both from developed and LMIC perspectives.
[31]	All Medicines	<ul style="list-style-type: none"> • Shortage of an active and inactive ingredient • Challenges related to good manufacturing practices • Shipping of the drugs delay • Critical medical supplies temporary export restrictions 	<ul style="list-style-type: none"> • Two months shortage increased by 32% compared from the previous years • Demand increased for the drug by 108% • Disruption of drug supply by the manufacturer increased by 65% 	<ul style="list-style-type: none"> • To re-establish supply chains, stakeholders should work together • Give the greatest focus for single-source non-patented medicines and patented medicines • Strengthen supply chain resilience in the face of global shockwaves

(Continued)

Table 2 (Continued).

Authors	Targeted Health Commodities	Identified Challenges	Identified Impacts on Supply Chain	Future Prospects Indicated
[32]	Essential medicines and PPE	<ul style="list-style-type: none"> • Shortage of essential medicines and PPE • There is poor communication among public and private health institutions • Local drug manufacturers were unable to meet the local need 	<ul style="list-style-type: none"> • Highly increased the price of PPE • Healthcare workers at the front are at danger of catching transmittable infections • Reuse of disposable PPE 	<ul style="list-style-type: none"> • Price gouging needs implementation of policy changes • To inform concerned parties, establish warning systems of expected shortages proactively • Incentivize local industries • Establish national stockpile for essential health commodities • Create multilateral communication • Establishing centralized procurement • Design medication sharing and exchange network • Initiate reconciliation and medication education by pharmacists

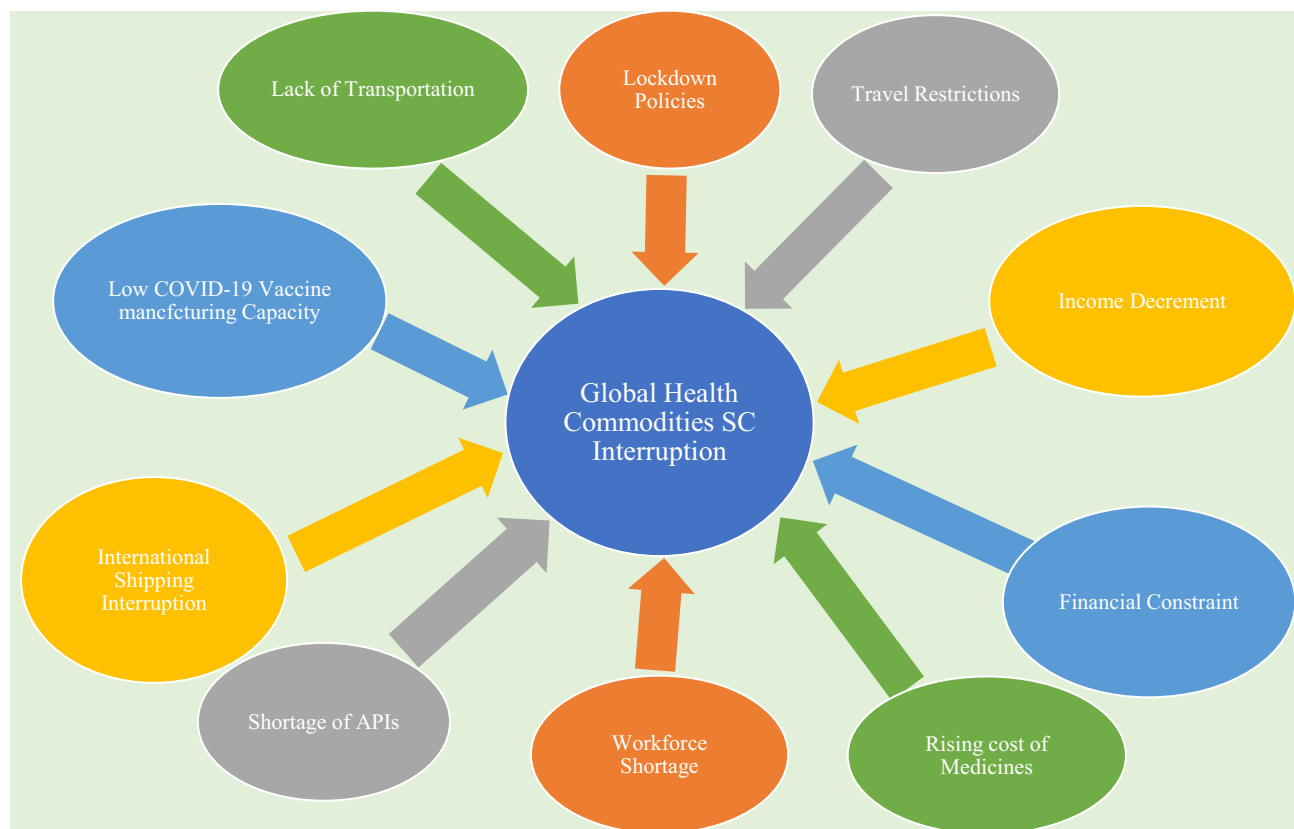


Figure 4 Challenges for global health commodities' supply chain interruption during COVID-19 Pandemic.

The modeling study, utilizing the Decision-Making Trial and Evaluation Laboratory with Intuitionistic Fuzzy Sets (DEMATEL-IF), identified 15 challenges for the COVID-19 vaccine supply system in low- and middle-income countries (LMICs), with the prominence-relation map illustrated below³⁰ (Figure 5).

Impacts of COVID-19 on Global Health Commodities Supply Chain

All modeling studies conducted on supply interruption of drug treatments for communicable diseases indicated the abrupt increase in deaths due to malaria, HIV, and TB due to the pandemic crisis. Research conducted by¹³ projected that in comparison to a scenario without the COVID-19 pandemic, fatalities from HIV, TB, and malaria could surge by as much as 10%, 20%, and 36%, respectively, over the upcoming five years. This is supported by additional studies suggesting that TB, HIV, and malaria could potentially trigger another global outbreak and contribute to loss of life during the pandemic.¹³ Research conducted by Jewell et al also indicated that a 50% interruption in ART drugs for six months could result in a 1.63 times increase [1.39 in the optimal HIV model; 1.87 in the HIV synthesis model] in HIV-related deaths over the course of one year due to medication shortages. Additionally, it is forecasted that there will be a 1.15–1.29 times increase in the number of deaths over each of the next five years compared to the current annual count.²⁷

Another modeling study indicated that

Interruption of Antiretroviral Therapy (ART) for three months for 40% of patients could cause a similar number of additional deaths as those that might be saved from COVID-19 through social distancing.

In the same study, it is suggested that HIV-related deaths could surpass the number of COVID-19 fatalities if treatment is disrupted for nine months among 6–90% of individuals on ART.²⁸ Rewari et al study supports this finding.⁸ This is also in parallel with a study finding in China in which travel restrictions affected 26.9% of TB patients to miss or postpone their follow-up.³⁷

		Minor Key Challenges	Key Challenges
Relation	High	<ul style="list-style-type: none"> • Long-distance between vaccine stores and vaccination camps 	<ul style="list-style-type: none"> • Lack of vaccine monitoring bodies • Challenges in controlling and vaccine temperature monitoring • The difficulty of tracking vaccinated population • Inadequate positive vaccine marketing • Absence of local organizations coordination • Vaccine manufacturing companies are limited in number
	Low	<ul style="list-style-type: none"> • Lack of volunteers for trials of vaccines 	<ul style="list-style-type: none"> • Absence of valid forecast for vaccine demand • Lack of willingness of consumers to vaccinate • Lack of correspondence between the COVID-19 vaccine supply chain (VSC) members • Absence of appropriate storage systems • Absence of efficient scheduling and planning • High procurement lead time • High vaccination cost and absence of financial support for vaccine purchase
		Low	High

Figure 5 Challenges of COVID-19 vaccines' supply system presented with the prominence-relation map.

Note: Adapted from Int J Prod Econ, volume 239 (April), Alam ST, Ahmed S, Ali SM, Sarker S, Kabir G, ul-Islam A. Challenges to COVID-19 vaccine supply chain: implications for sustainable development goals. 108193, copyright 2021, with permission from Elsevier.³⁰

Similarly, the other modeling study suggested that interruptions in malaria treatment due to the pandemic in Africa might double malaria deaths in 2020 and possibly result in a more significant rise in the coming years.²²

Likewise, 35.2% of study participants with chronic diseases in Nigeria had challenges acquiring essential medicines compared to 10.6% before the lockdown. Of these, 84% of respondents claimed that their chronic health condition deteriorated due to supply interruptions due to the pandemic crisis.²³ In Canada, a two-month shortage of essential medicines increased by 32% compared to the previous years, and demand increased to 108% due to the pandemic.³¹ Likewise, Downs et al noted a significant decrease in the number of clients initiating new opioid treatments ($\beta = -6029$, 95% CI = $-8810.40, -3246.72$) and in the number of healthcare professionals issuing new opioid prescriptions ($\beta = -2784$, 95% CI = $-3671.09, -1896.19$) following elective restrictions within the healthcare system.²⁶

In parallel with the critical shortage of PPE, the pandemic crisis badly impacted healthcare workers, as they are at high risk of illness as front-line workers in providing care to COVID-19 patients.²⁹ The pandemic also highly increased the price of PPE and pushed for reuse of disposable PPE.³² They were also pushed to self-medication's over prescription, which increased to 60.4% (n = 229) as compared to 36.2% (n = 137) before the pandemic. As a result, perceived adverse drug reactions occurred in 22.4% (n = 85) patients due to self-medication.²⁵

This pandemic also affected the reverse logistics system due to overproduction of medical wastes and increased cost of installing temporary treatment centers, transportation, and waste treatment with 50%, 16%, and 10%, respectively.²⁴

Various studies documented the notion that global drug shortages resulting from the pandemic crisis could have profoundly detrimental effects on patient outcomes in the future and may also have enduring implications for Antimicrobial Resistance (AMR), which is another critical aspect of ongoing global health security agenda.^{9,12,38}

Although a few COVID-19 vaccine approvals are considered as a light in the dark, access and supply chain-related problems impacted the green light for fighting the Pandemic. The limited capacity for vaccine production, along with issues of access and supply chain challenges, impedes efforts to swiftly attain herd immunity against the infection

through vaccination. Consequently, this impacts progress toward achieving at least 9 out of the 17 sustainable development goals (SDGs).^{19,30}

In summary, the effects of the virus on the global health commodities' supply chain can be classified into four main thematic areas: health impact, economic impact, health system impact, and environmental impact (Figure 6). Significantly, the pandemic had a profound and far-reaching effect on both the global health system and the world economy, as evidenced by various studies.^{3,39}

Identified Future Prospects

The reviewed articles suggested different prospects for the global health commodities' supply system at the time of the pandemic era and beyond. The prospects are categorized thematically as follows (Figure 7).

Those themes identified as a prospect in other literatures, including evidence-based decision, policy, regulation, and legal framework; technology and artificial intelligence; end-to-end (E2E) supply data visibility; stakeholder collaboration, and advancing communication, not addressed in these reviewed studies. On the other hand, new themes, including designing resilient global health systems, backing local manufacturing, and designing efficient reverse logistics systems, were identified in the reviewed studies. This is in line with the fact that the Pandemic disrupted the global health system and increased the demand for health commodities. These, in turn, initiated countries to foster their local manufacturing capacity. The additional medical waste produced due to the Pandemic and the routine medical waste backlog are direct pointers for designing an efficient reverse logistics system.

Design Resilient Global Health System

The pandemic clearly showed that our global health system is fragile and unable to absorb severe shocks. Countries should work hard in revising and designing more resilient healthcare systems in a forward-looking approach.¹³

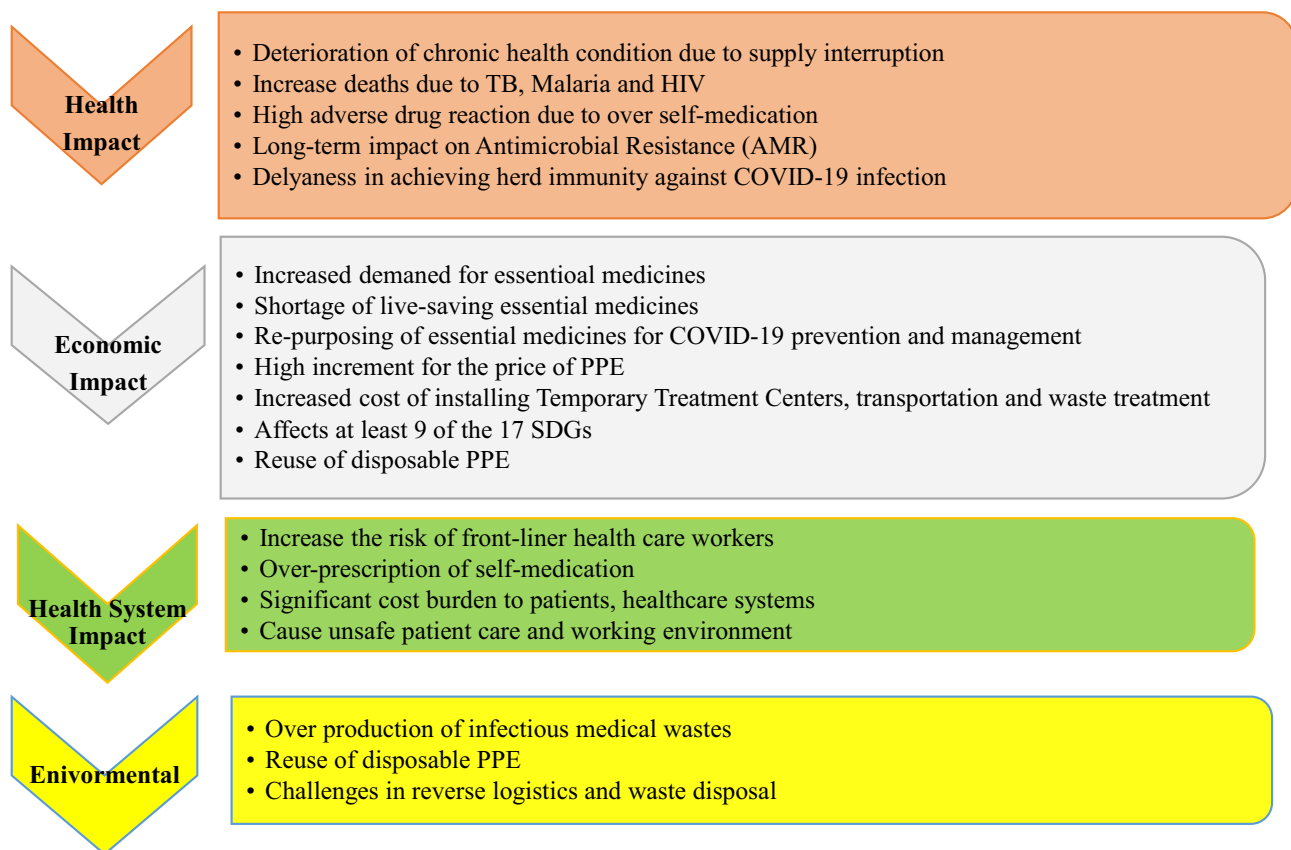


Figure 6 Impacts of COVID-19 Pandemic on the global health commodities' supply chain system.

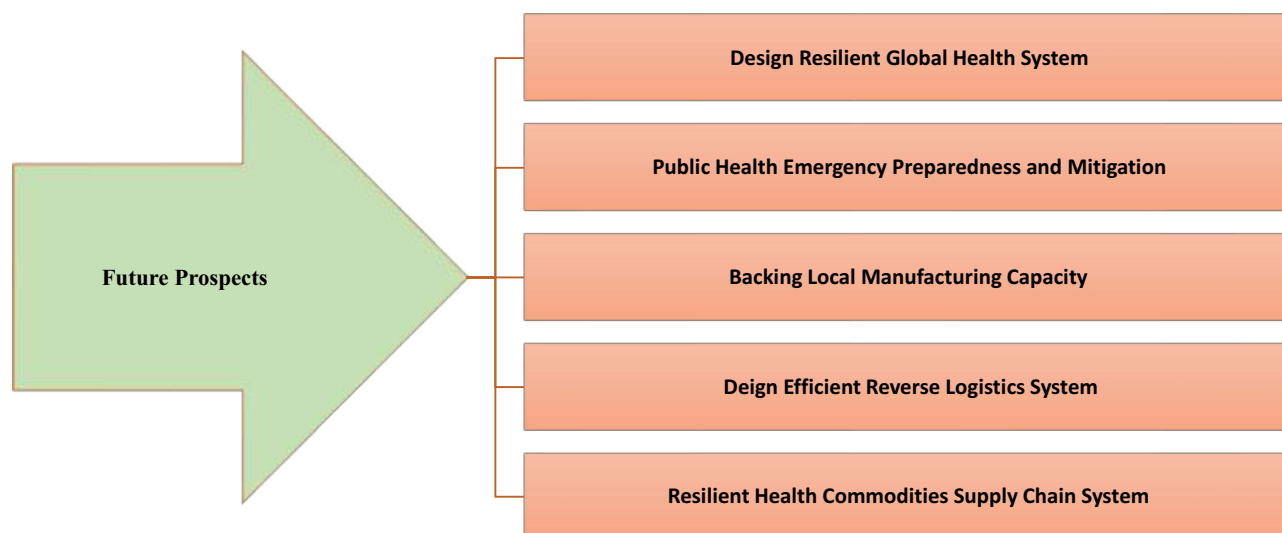


Figure 7 Prospects indicated by researchers for improving the global health commodities' supply chain system.

Public Health Emergency Preparedness and Mitigation

Averting the ongoing public health crisis and unforeseen public health disasters with an integrated emergency preparedness plan and mitigation strategy. Before the next major pandemic wave comes, proper planning and averting healthcare-associated damages are crucial steps for the world. Long-term suppression interventions, coupled with the discovery of curative drugs or remedies, have the potential to enhance patients' recovery rates from the COVID-19 pandemic. Parallel to this, developing strategies to facilitate COVID-19 vaccine coverage can aid in reaching the herd immunity threshold before the loss of many lives worldwide.^{13,22,24,29}

Backing Local Manufacturing Capacity

Initiating large-scale and sustainable local pharmaceutical manufacturing initiatives can heal the current broken global supply chain and will help mitigate future public health catastrophes.²³ Nurturing local manufacturing capacity and creating production, research, and marketing partnerships with international industries will improve the local supply chain disruption and decrease countries' dependence on other international production sites. Incentivizing COVID-19 vaccine development, production, distribution, and administration may also curtail the global impact of the Pandemic.³⁰

Design Efficient Reverse Logistics System

Designing an efficient reverse logistics system with forecasting the amount of generated waste using real-time data will help properly manage COVID-19 Infection Medical Waste. Employing portable treatment equipment can reduce virus transmission and minimize additional costs.²⁴

Resilient Health Commodities Supply Chain System

Responsible stakeholders should take measures to improve supply chain interruption of essential medicines used to treat communicable and non-communicable diseases. Public health officials should monitor the ongoing essential health commodities' supply interruption and propose strategies, including; community-based interventions, awareness creation programs, and multi-month dispensing.^{23,25,26} In general, scholars strongly suggested the need for designing a resilient supply chain system with efficient forecasting, procurement, inventory management, and distribution systems.²⁷ A resilient supply chain system supported by technology and stakeholder collaboration can cope with the interruption of essential health commodities and future crises.^{8,28} As supported by fellow scholars, the future-focused supply chain should adopt a strategic approach encompassing various dimensions such as personnel, procedures, and technological advancements.^{36,40}

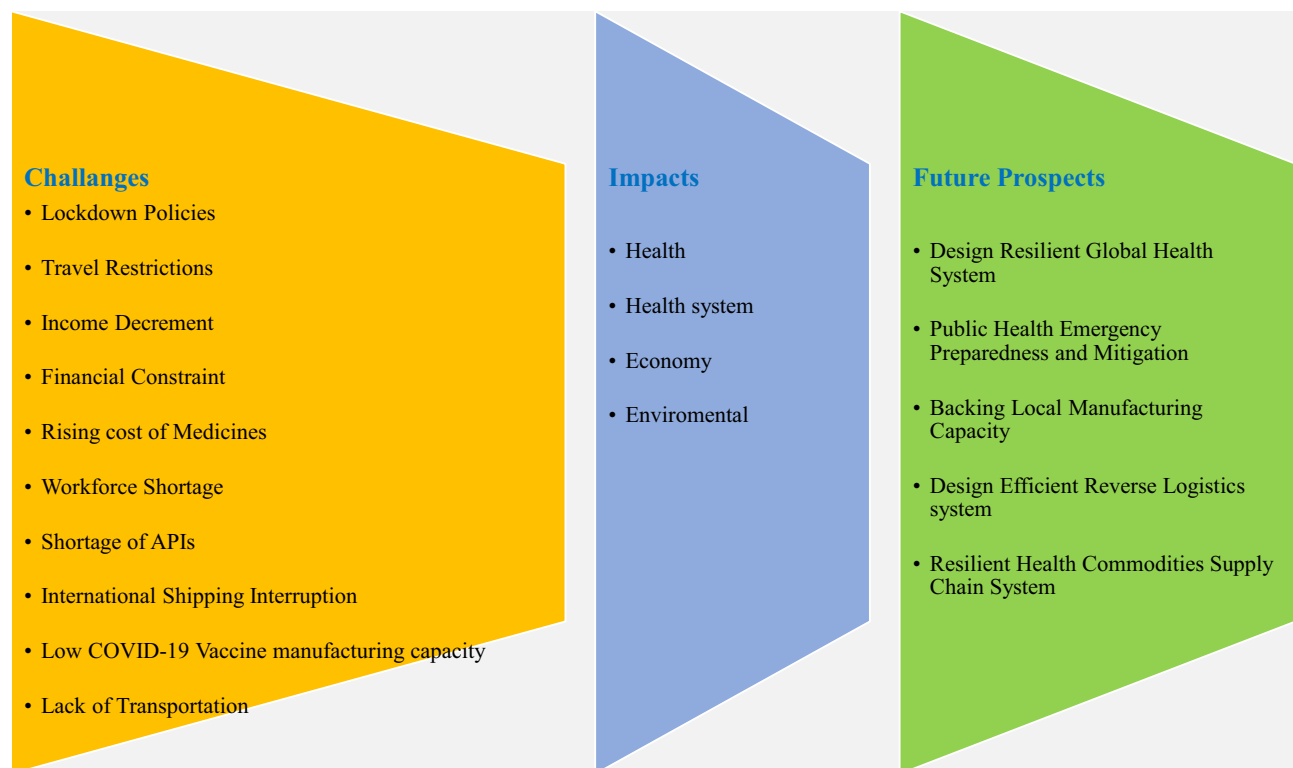


Figure 8 Challenges, impacts, and prospects of COVID-19 pandemic on global health commodities' supply system.

In summary, the reviewed studies listed many challenges of the global health commodities' supply chain due to the Pandemic. The effects of the pandemic on the global health commodities' supply chain have been classified into four main themes: health, healthcare systems, economy, and environment. These studies also indicated the prospects for improving the supply chain system as depicted below (Figure 8).

Limitations

This systematic review was compiled based on online available peer-reviewed articles in selected databases. Reviewed articles included in this study mentioned their limitations, especially modeling studies indicating that the reports should be interpreted cautiously due to different uncertainties. In addition to these, most of the reviewed articles address the consequences of the pandemic on health commodities' supply chain interruption from the perspective of end-users. Its effect on the other supply system corridors, including raw material supply, drug development, manufacturing, transportation, inventory, and warehouse management, was not well addressed.

Conclusion

The majority of literature mentioned supply interruption of vital healthcare commodities during the period of the pandemic due to different challenges. Supply chain interruption of essential medicines used for management of communicable diseases, including Malaria, HIV, and TB, led to an abrupt increase in deaths and is expected to continue over the next five years. Global drug shortages due to the pandemic crisis can have a devastatingly harmful impact on patient outcomes and might have a long-term impact on AMR. The global challenges associated with the supply chain of COVID-19 vaccines are impeding countries' ambitions to swiftly achieve herd immunity against the infection, consequently hindering progress towards the majority of Sustainable Development Goals (SDGs). The frequently suggested prospects were a resilient global health system, public health emergency preparedness and mitigation, the backing of local manufacturing capacity, designing an efficient reverse logistics system, and designing resilient health commodities' supply chain system. Hence, countries, researchers, and public health officials have to monitor the pandemic's effect on

the health commodities supply system and design a short-term and long-term resilient health supply chain system that can cope with the current and future health catastrophes.

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Author Contributions

All authors contributed significantly to the conception, design of the study, data extraction, analysis, and interpretation. They were involved in either drafting the manuscript, revising it, or providing editorial support. Additionally, all authors critically reviewed the article, granted final approval of the version to be published, selected the journal for submission, and consented to be accountable for all aspects of the work.

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