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Review Article

Socioeconomic and Environmental Determinants of Opportunistic Viral Infections: Implications for Vulnerable Populations

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Abstract

The opportunistic viral infections (OVIs) disproportionately affect immunocompromised populations, including individuals living with HIV/AIDS, transplant recipients, and patients undergoing chemotherapy or immunosuppressive therapies. While host immunity is a primary determinant of susceptibility, socioeconomic and environmental factors critically influence exposure risk, infection severity, and clinical outcomes. This review synthesizes current evidence on how poverty, education, healthcare access, occupational and lifestyle factors, housing conditions, urbanization, climate, and environmental pollution impact the incidence and progression of OVIs in Nigeria and other developing countries. Socioeconomic deprivation often amplifies environmental risks, creating synergistic effects that elevate infection rates. Interventions targeting social determinants of health such as improving healthcare access, nutrition, sanitation, and education alongside environmental control measures, can reduce the burden of OVIs. Integrating socioeconomic and environmental considerations into clinical management and public health strategies is essential to mitigate morbidity and mortality associated with opportunistic viral pathogens, particularly in low- and middle-income countries.

Keywords: *Environmental Determinants; HIV/AIDS; Immunocompromised Populations; Opportunistic Viral Infections; Public Health; Risk Factors; Socioeconomic Factors; Transplant Recipients*

Introduction

Opportunistic viral infections (OVIs) occur primarily in individuals with impaired immunity, including people living with HIV/AIDS, organ transplant recipients, and patients receiving chemotherapy or other immunosuppressive therapies. In such hosts, viruses that normally remain latent or cause mild illness especially herpesviruses such as cytomegalovirus (CMV), Epstein–Barr virus (EBV), and varicella-zoster virus (VZV) can reactivate and cause severe disease. This pattern has been extensively described in global sero-epidemiologic reviews such as that of Redding *et al.,* (2019). Although immune suppression is the fundamental driver of susceptibility to OVIs, a substantial body of research indicates that socioeconomic determinants significantly influence exposure, seroprevalence, and outcomes. Large population analyses, including the work of Li *et al*, (2020), consistently demonstrate that individuals with lower Socioeconomic Status (SES) measured through income, education, and neighbourhood deprivation have markedly higher CMV seroprevalence and tend to acquire infection earlier in life. Further evidence from Yin and Couzin (2020) suggests that CMV seropositivity may act as a biological mediator through which socioeconomic disadvantage contributes to poorer long-term health and mortality.

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Socioeconomic context also shapes OVI outcomes in clinical populations. For example, Bisaga *et al*., (2025) found that solid-organ transplant recipients living in socially deprived areas exhibited higher CMV seropositivity rates and more adverse post-transplant outcomes, highlighting how social determinants interact with clinical vulnerability. Environmental conditions further modify OVI risk. Urbanization, household overcrowding, inadequate sanitation, and limited access to clean water increase viral exposure, particularly in low-income settings. Seasonal and climatic variables such as humidity, temperature, and ultraviolet radiation are also important (Aemiro *et al*., 2025). Studies such as Gona *et al.,* (2006) have shown distinct seasonal patterns in VZV and herpes zoster incidence, suggesting that environmental variability influences viral reactivation dynamics.

Growing evidence also links environmental pollution especially long-term exposure to fine particulate matter with impaired antiviral immunity and heightened susceptibility to viral infections. Recent mechanistic and epidemiological syntheses by Mohamud *et al.,* (2023) demonstrate that particulate matter disrupts immune pathways, reduces antibody responses, and increases vulnerability to respiratory viral infections. Findings from SARS-CoV-2 cohorts by Wakil, *et al.,* (2022) further reinforce the role of pollution as a modifier of viral infection severity. Overall, socioeconomic and environmental determinants do not act independently but instead reinforce one another, creating layered vulnerability. Poverty frequently coincides with overcrowding, poor sanitation, food insecurity, and limited healthcare access, thereby amplifying both exposure and susceptibility to opportunistic viruses (Graham & White, 2023). Consequently, interventions that focus solely on clinical treatment without addressing underlying social and environmental determinants are insufficient (Hellewell *et al*., 2020). As emphasized by researchers such as Bannister-Tyrrell, *et al.,* (2020), comprehensive strategies that integrate medical care with social support and environmental improvements are essential for reducing OVI burden among at-risk populations.

The major Socioeconomic determinants and their manifestations at the Global, African Continental and specific Nigerian context has been discussed below (Table 1)

Socioeconomic Determinants Income and Poverty

Income is one of the strongest predictors of vulnerability to opportunistic viral infections (OVIs). Individuals living in poverty face limited access to preventive healthcare, delayed diagnosis of underlying immunosuppressive conditions, and inconsistent treatment adherence. Studies in HIV care settings consistently show that people with lower income have a higher likelihood of uncontrolled viral load, which increases reactivation of latent viruses such as cytomegalovirus (CMV) and Epstein–Barr virus (EBV) (Bayissa & Techane, 2022). For example, work by Tufon *et al*., (2014) demonstrated that CMV seroprevalence is significantly higher among low-income groups, often reflecting earlier-life exposure in settings characterized by crowding and poor sanitation.

Among HIV-positive individuals in resource-limited regions, delayed initiation of Antiretroviral Therapy (ART) is strongly associated with CMV disease and EBV related lymphoproliferative disorders. Amisu *et al*., (2023) further noted that CMV infection disproportionately affects socially disadvantaged groups and may amplify long-term morbidity by interacting with chronic immune activation. Poverty also restricts access to immunosuppressive therapy monitoring for transplant patients, increasing the risk of viral complications such as CMV syndrome, BK polyomavirus activation, and post-transplant lymphoproliferative disorder (Mateus, 2014; CDC, 2020).

Education and Health Literacy

Education and health literacy influence nearly every aspect of OVI risk, including preventive behaviour, treatment adherence, hygiene practices, and ability to recognize early symptoms (Cuadros *et al*., 2025). Caregivers with higher educational attainment are more likely to adopt behaviours that reduce viral exposure, such as proper sanitation, safer childcare practices, and adherence to vaccination schedules. Evidence from community-based intervention trials shows that health-literacy improvement programs significantly reduce the incidence of transmissible viral infections in household and school environments (Mohamud *et al.,* 2023; Feachem *et al.,* 2023).

Health literacy is particularly crucial in chronic disease management. For example, effective control of HIV, autoimmune diseases, and transplant-related complications requires understanding complex medication regimens (Farayibi & Asongu, 2020). As noted by Bisaga *et al*., (2025), in global viral-seroprevalence studies, populations with lower educational attainment exhibit higher rates of CMV and EBV exposure, likely due to both behavioural and environmental disadvantages. Limited literacy also leads to lower uptake of routine viral screening, delaying diagnosis of conditions such as HBV, HIV, and CMV reactivation.

Healthcare Access

Barriers to healthcare whether geographic, financial, or systemic significantly worsen OVI outcomes. Limited access to diagnostic tools such as quantitative PCR for CMV, EBV, or BK virus (BKV) prevents timely detection of viral reactivation in high-risk patients such as transplant recipients and oncology patients. Li *et al.,* (2020); Gorbalenya *et al*., (2020) highlighted that socially deprived transplant recipients were more likely to experience adverse CMV-related outcomes because of delayed monitoring and reduced access to specialized care.

In many low- and middle-income countries, routine screening for OVI-related complications is either unavailable or unaffordable. For example, BK virus nephropathy in kidney-transplant recipients often goes undetected until renal dysfunction becomes severe, increasing the risk of graft loss. Patients living in rural areas, where specialist services are scarce, frequently experience diagnostic delays that allow opportunistic viruses to progress unchecked. This gap in healthcare infrastructure further widens disparities between high- and low-income patient groups (Hellewell *et al*., 2020; Isaac, 2020; Moges & Kassa, 2014).

Occupational and Lifestyle Factors

Occupational environments characterized by crowding, poor ventilation, or high interpersonal contact such as markets, factories, and informal-sector jobs enhance exposure to airborne or contact-transmitted viruses (Liu *et al*., 2020). Workers in informal settlements or heavily populated urban centres are particularly vulnerable, as demonstrated in studies of respiratory and enteric viral transmission in densely populated settings. These risks are amplified for immunocompromised individuals whose ability to control viral replication is already diminished (Mateus *et al*., 2014; Saidu *et al*., 2009).

Lifestyle factors such as malnutrition, tobacco exposure, alcohol dependence, and chronic stress further compromise immune function (Merler and Ajelli, 2010). Malnutrition is especially influential: micronutrient deficiencies weaken both innate and adaptive immunity, thereby increasing susceptibility to OVI reactivation. Reviews such as those by Ishola and Phin, (2011) emphasize that undernutrition can impair antiviral responses, reduce vaccine effectiveness, and exacerbate severity of viral infections. Stress associated with poverty and precarious employment may also contribute to immune dysregulation, increasing the likelihood of herpesvirus reactivation.

***Table 1:** Categorizes the Key Determinants and Compares their Manifestations at the Global Level, the African Continental Level, and the Specific Nigerian Context*

S/N	Determinant Category	Global Context (Developed vs. Developing)	African Context (Continental)	Nigerian Context (National)	Impact on OVIs (e.g., CMV, EBV, HSV, HHV-8)
1	Poverty and income inequality	Poverty exists but often with social safety nets (welfare, universal healthcare) in the Global North.	High poverty rates (>40% in Sub-Saharan Africa) limit access to nutrition and healthcare. High Gini coefficients.	Despite GDP growth, extreme poverty is high; over 60% of Nigerians live in poverty. High cost of living	Malnutrition weakens cell-mediated immunity, increasing susceptibility to viral reactivation (e.g., Herpes Zoster).
2	Healthcare Infrastructure	Universal or subsidized healthcare; widespread access to antivirals and diagnostic labs (PCR, CD4 count).	Fragmented systems; reliance on NGOs and foreign aid. Shortage of specialized virology labs.	Decayed public health infrastructure; "brain drain" of healthcare workers; out-of-pocket payment limits access to viral load testing.	Late diagnosis of HIV leads to late presentation of OVIs (e.g., CMV retinitis).
3	Sanitation and water quality	Generally regulated; low faecal-oral transmission of enteric viruses.	Rapid urbanization leads to slums; open defecation still practiced in rural areas.	Poor solid waste management (especially in cities like Lagos); contaminated water sources.	Increases exposure to enteric viruses (e.g., Adenovirus) which become opportunistic in malnourished children.
4	Overcrowding and housing	Overcrowding is limited to specific urban pockets or homeless shelters.	High population density in informal settlements; poor ventilation.	Congested urban slums (Makoko, Ajegunle); multi-generational living in small spaces.	Facilitates airborne transmission (e.g., Varicella, Measles) and salivary exchange (EBV, CMV) in early childhood.
5	HIV Co-epidemic	HIV managed as a chronic disease with ART; low OVI incidence.	Highest burden of HIV in the world (Eastern and Southern Africa).	Nigeria has the 4th largest HIV epidemic globally. High rate of late presentation.	HIV-induced CD4 depletion is the primary trigger for OVIs (Kaposi Sarcoma/HHV-8, CMV).
6	Malnutrition	Rare in general population; usually linked to specific eating disorders.	Widespread stunting and wasting in children due to food insecurity.	Chronic food insecurity in the North-East (conflict zones) and South-South (poverty).	Protein-energy malnutrition suppresses cytotoxic T-cell function, allowing latent viruses (EBV) to reactivate.
7	Climate and Geography	Temperate climates lead to seasonal viral peaks (winter).	Tropical climate allows year-round transmission of arboviruses and some herpesviruses.	Tropical climate with diverse ecological zones (rainforest to Sahel).	High heat and humidity can affect virus survival on fomites; impacts vector ecology for certain viruses.
8	Armed conflict and displacement	Minimal impact.	High displacement due to civil wars (DRC, Sudan, etc.).	Boko Haram insurgency in the North-East; Farmer-Herder crises; millions of IDPs.	Displacement disrupts vaccination schedules (Measles) and increases exposure in overcrowded IDP camps.

(Ochube & Usman, 2023; Aemiro *et al., 2025; Bisaga et al., 2025;* Angell *et al., 2022; Phillips et al., 2025; Chiziba et al., 2024; Kabalimu et al., 2025; Onsongo & Kagothe, 2024)*

Environmental Determinants

Urbanization and Population Density

Urbanization substantially reshapes viral transmission dynamics, particularly in rapidly growing cities where population density outpaces infrastructure development. High-density urban environments facilitate more frequent person-to-person contact, increasing the spread of both respiratory and enteric opportunistic viral infections (OVIs). Crowded transport systems, informal settlements, and densely populated markets are key hotspots for viral circulation (Ishola & Phin, 2011; Mequanente *et al*., 2022; Bhatt *et al*., 2024).

Poor sanitation and inadequate waste management in disadvantaged urban neighbourhoods further heighten exposure to enteric viruses such as adenoviruses, rotavirus, and norovirus. Studies of low-income urban communities consistently show higher rates of latent virus exposure and earlier seroconversion (Pigott *et al*., 2017). For example, research from Saidu *et al*., 2009, Mohamud *et al*., 2023 on global CMV seroprevalence illustrates how urban overcrowding and sanitation deficits correlate with earlier-life CMV infection. Additionally, rapid urban growth in low-resource settings often results in informal housing with minimal access to clean water, amplifying OVI risk among immunocompromised populations.

Climate and Seasonal Variation

Climate factors including temperature, humidity, rainfall, and ultraviolet (UV) exposure directly influence viral persistence in the environment and the likelihood of seasonal surges in opportunistic infections (Zsichla & Muller, 2023). Herpesviruses are especially sensitive to environmental fluctuations: epidemiological studies, including work by Woldegeorgis *et al.,* (2023), have documented seasonal patterns in varicella-zoster virus (VZV) reactivation, with incidence peaking in periods associated with environmental stressors such as reduced UV exposure and cooler temperatures.

Temperature and humidity affect viral stability on surfaces and in aerosols, altering the efficiency of respiratory transmission. In many tropical regions, heavy rainfall and flooding increase exposure to contaminated water sources, leading to spikes in enteric viral infections risks that disproportionately affect immunocompromised children and adults (Tegegne *et al*., 2022; DigitalUHC Consortium *et al*., 2022). Seasonal immunologic changes, including shifts in vitamin D status linked to sun exposure, may also influence susceptibility to herpesvirus reactivation and other OVIs (Adebayo *et al*., 2021).

Environmental Pollution

Exposure to air pollutants particularly fine particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, and industrial chemical residues have profound effects on mucosal immunity (Tavares, 2021; Shekar *et al*., 2021). Pollutants damage epithelial barriers, impair macrophage function, and reduce the efficiency of innate antiviral responses. Reviews conducted by Bello *et al*., (2020), outline how chronic exposure to particulate matter weakens antiviral immunity and increases severity of both primary and opportunistic viral infections.

Emerging evidence from immunocompromised patient cohorts suggests that pollution may exacerbate the risk of viral reactivation (Popoola, 2018). For example, observational studies summarized by Olatunji *et al.,* (2024) reported associations between long-term particulate matter exposure and higher levels of viral markers, including evidence suggesting more frequent CMV reactivation in individuals with compromised immunity. Pollution also increases susceptibility to respiratory viruses such as adenoviruses and polyomaviruses, which can cause severe disease in transplant recipients and oncology patients as in figure 1.

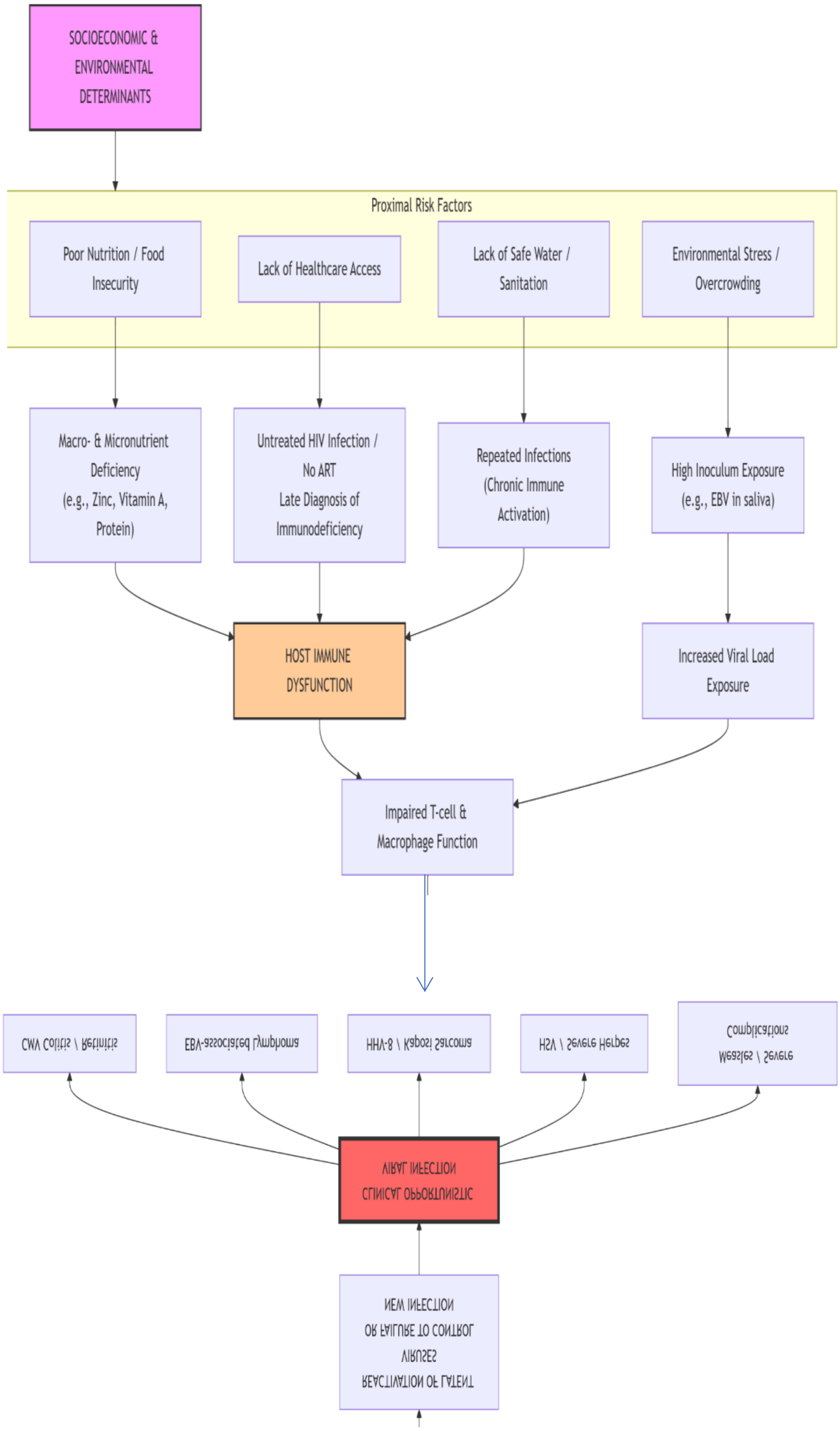

Figure 1: *Pathway from Socioeconomic Determinants to Clinical Opportunistic Viral Infection (The chart illustrates the cascade of how distant socioeconomic factors translate into biological vulnerability)* (*Bisaga et al., 2025; Phillips et al., 2025)*

Housing Conditions and Sanitation

In many low-income settings, households rely on shared or unsafe water sources, increasing the risk of gastrointestinal OVIs such as norovirus and adenovirus. Studies of household transmission dynamics consistently show higher secondary attack rates in overcrowded, multigenerational homes. Children and adults with weakened immunity such as those living with HIV, transplant patients, and people undergoing chemotherapy experience more severe outcomes when exposed in such settings (Olatunji *et al.,* 2024).

Lack of sanitation infrastructure compounds the problem: limited access to latrines, improper waste disposal, and shared washing facilities contribute to environmental contamination and ongoing viral circulation. These risks are amplified in urban slums and refugee settlements, where environmental and socioeconomic vulnerabilities intersect (Akintunde *et al*., 2022).

The Interaction between Socioeconomic and Environmental Factors

Socioeconomic and environmental determinants of opportunistic viral infections (OVIs) rarely act in isolation; instead, they interact in complex, mutually reinforcing ways that exacerbate vulnerability (Sabin *et al*., 2020). Socioeconomic deprivation characterized by low income, limited education, poor housing, and inadequate healthcare access often coincides with environmental risks such as overcrowding, poor sanitation, and exposure to pollution. This convergence creates a synergistic effect that significantly elevates *b*oth incidence and severity of OVIs (Akintunde *et al*., 2022).

Research by Akintunde *et al*., 2022 shows that low-income urban communities experience earlier-life CMV exposure due to overcrowding and sanitation deficits. At the same time, limited healthcare access delays diagnosis and management of viral reactivation in immunocompromised individuals, as noted in transplant-focused**.**

These synergistic interactions mean that interventions targeting only clinical or biomedical factors often fall short. Instead, effective OVI prevention requires addressing broader structural inequities influencing viral exposure, immune competence, and care-seeking patterns. Populations living in informal settlements, for example, routinely face multiple simultaneous determinants: high density housing, inadequate sanitation, poor air quality, food insecurity, and low health literacy.

Public Health and Clinical Implications

Given the intertwined nature of socioeconomic and environmental determinants, effective management of opportunistic viral infections requires a multisectoral approach spanning clinical practice, community-level intervention, and policy reform.

Healthcare Interventions

Strengthening healthcare systems is essential for reducing OVI-associated morbidity and mortality through the following;

i. Improved diagnostic access: Expanding availability of sensitive molecular diagnostics especially for CMV, EBV, BK virus, JC virus, and adenoviruses can facilitate earlier detection. This is particularly critical in transplant recipients and oncology patients, where delayed diagnosis worsens outcomes.

ii. Expanded access to antiviral therapy: Ensuring availability of drugs such as ganciclovir, valganciclovir, cidofovir, and novel CMV-targeting agents is vital in low-resource settings.

iii. Strengthening routine monitoring: Regular viral load monitoring for CMV in HIV-positive individuals and BK virus screening in kidney transplant recipients can prevent severe disease.

iv. Integration with primary care: Embedding OVI screening into routine HIV care, oncology follow-up, and post-transplant clinics improves early detection and continuity of care (Akintunde *et al*., 2022).

Community Level Interventions

Community based strategies are crucial for reducing environmental exposure and enhancing host resilience through the following;

i. Nutrition support programs: Malnutrition is a major immunosuppressive factor in disadvantaged populations. Community nutrition interventions improve immune function and reduce viral reactivation risk.

ii. Health education and literacy programs: Studies such as those by Contento, (2016) show that improved health literacy enhances preventive behaviors, adherence to antiviral therapies, and early care-seeking.

iii. Sanitation and hygiene improvements: clean water access, improved waste disposal, and hygiene education reduce transmission of enteric and respiratory viruses, particularly in children and immunosuppressed adults.

iv. Strengthening community health workers: In resource-limited settings, community health workers can provide critical support for surveillance, early detection, and referral (Akintunde *et al*., 2022).

Policy Implications

To achieve sustainable reductions in OVI incidence, policymakers must integrate socioeconomic and environmental determinants into long-term planning through the following;

i. Urban development policies that address overcrowding, ventilation, and sanitation can mitigate exposure.

ii. Environmental regulations targeting pollution reduction may improve baseline antiviral immunity, as supported by environmental epidemiology work.

iii. Equitable health financing models can ensure that vulnerable populations receive timely diagnosis and treatment.

iv. Social protection programs including housing support, income assistance, and nutritional subsidies may indirectly reduce OVI risk by improving overall living conditions shown in figure 1 (Bisaga *et al*., 2025; Phillips *et al*., 2025).

Knowledge Gaps and Future Directions

Despite growing interest in the social and environmental determinants of OVIs, several critical gaps remain and these includes;

Limited Longitudinal and Multidimensional Data

Most existing studies analyze socioeconomic or environmental factors independently. More long-term, multi-factorial cohort studies are needed to clarify how these determinants interact over time to influence viral reactivation and disease severity. For example, longitudinal data linking pollution exposure to herpesvirus reactivation in immunocompromised patients remain sparse (Althaus, 2014).

Underrepresentation of low- and middle-income countries (LMICs)

Research from LMICs where socioeconomic and environmental risks are often most intense remains limited. Region-specific data are essential to better understand variations in CMV, EBV, BK virus, and adenovirus epidemiology. Local studies can also reveal unique environmental exposures, cultural practices, and healthcare constraints influencing OVI risk (Wakil, *et al*., 2022; Mohamud *et al*., 2023).

Emerging Technologies to Identify High Risk Population

Advances in technology offer new avenues for understanding and predicting OVIs through the following;

i. Metagenomics and next-generation sequencing can uncover undetected viral reservoirs and rare viral co infections.

ii. Artificial intelligence (AI) can integrate socioeconomic, clinical, and environmental data to predict viral reactivation in high-risk patients.

iii. Wearable health monitoring devices may help track environmental exposures (e.g., pollution, temperature) and physiological stressors that trigger viral reactivation (Wakil, *et al*., 2022; Mohamud, *et al*., 2023).

Climate Change and Future OVI Patterns

The climate driven changes including rising temperatures, altered rainfall patterns, and increased pollution are expected to influence viral ecology and host susceptibility. Future research should examine how global warming may reshape the geography and seasonality of OVI risk (Nansseu & Bigna, 2017; Wakil, *et al*., 2022; Mohamud *et al*., 2023).

Conclusion

The socioeconomic and environmental factors are not merely background variables but rather critical determinants of susceptibility, transmission, and clinical severity of opportunistic viral infections (OVIs). For vulnerable populations, particularly in resource-limited settings like Nigeria and sub-Saharan Africa, poverty, malnutrition, and inadequate housing create a biological vulnerability where latent viruses reactivate and novel pathogens cause severe disease. Addressing these determinants requires a paradigm shift beyond individual medical management. While global frameworks increasingly recognize the link between environmental stability and health, the immediate priority for OVI control must be integrated interventions that combine clinical care (such as antiretroviral therapy and vaccination) with social risk mitigation (food security, housing, and sanitation). Future research and policy efforts must bridge the gap between the virologist's laboratory and the community's social reality, ensuring that the fight against viruses includes the fight against the inequities that enable them.

Author's Contributions

Sheriff Wakil and Ijudigal Musa Papka participated in supervision, writing, review, and editing. Each author had reviewed and approved for publication.

Conflicts of Interest

The authors declare no conflict of interest.

References

Adebayo, F. A., Itkonen, S. T., Öhman, T., Kiely, M., Cashman, K. D., Lamberg-Allardt, C., & Odin Consortium. (2021). Safety of vitamin D food fortification and supplementation: evidence from randomized controlled trials and observational studies. *Foods*, *10*(12), 3065. https://doi.org/10.3390/foods10123065

Aemiro, A., Girma, A., & Beletew, D. (2025). Prevalence of Opportunistic Infections and Determinants Among HIV-Positive Patients in Ethiopia: A Systematic Review and Meta-Analysis. *Health Science Reports*, *8*(2), e70418. https://doi.org/10.1002/hsr2.70418

Akintunde, T. S., & Olaniran, O. D. (2022). Financial development, public health expenditure and health outcomes: evidence from Nigeria. *Journal of Economics and Allied Research*, *7*(1), 13-24. ISSN: 2536-7447

Althaus, C. L. (2014). Estimating the reproduction number of Ebola virus (EBOV) during the 2014 outbreak in West Africa. *PLoS Currents*, *6*, ecurrents-outbreaks. https://doi.org/10.1371/currents.outbreaks.91afb5e0f279e7f29e7056095255b288

Amisu, B. O., Oksanna, O. J., Olaleke, N. O., Ologun, C. O., Lucero-Prisno, D. E., Ogunwale, V. O., ... & Mewara, A. (2023). Socio-environmental determinants of parasitic intestinal infections among children: A cross-sectional study in Nigeria. *Journal of Global Health Science*, *5*(1). https://doi.org/10.35500/jghs.2023.5.e6

Angell, B., Sanuade, O., Adetifa, I. M., Okeke, I. N., Adamu, A. L., Aliyu, M. H., ... & Abubakar, I. (2022). Population health outcomes in Nigeria compared with other west African countries, 1998–2019: a systematic analysis for the

Global Burden of Disease Study. *The Lancet*, *399*(10330), 1117-1129. https://www.thelancet.com/journals/lancet/article/piis0140-6736(21)02722-7/fulltext

Bannister-Tyrrell, M., Meyer, A., Faverjon, C., & Cameron, A. (2020). Preliminary evidence that higher temperatures are associated with lower incidence of COVID-19, for cases reported globally up to 29th February 2020. *MedRxiv*, 2020-03. https://doi.org/10.1101/2020.03.18.20036731

Bayissa, M. W., & Techane, D. (2022). Multi-Lingual Mobile Application to Improve the Pharmaceutical Care of Patients in Ethiopia. *International Journal of Computer and Information Technology*, *11*(5), 184-189. https://doi.org/10.24203/ijcit.v11i5.290

Bello-Morales, R., Ripa, I., & López-Guerrero, J. A. (2020). Extracellular vesicles in viral spread and antiviral response. Viruses, 12(6), 623. https://doi.org/10.3390/v12060623

Bhatt, P., Padhi, A., Agarwal, A., & Katoch, C. D. S. (2024). Global environmental and socioeconomic drivers influencing contemporary viral disease emergence and transmission. *Discover Viruses*, *1*(1), 4. https://doi.org/10.1007/s44370-024-00004-7

Bisaga, W., Wieczorek, M., Pawlinski, J., Jonczyk, K., Malicki, D., Starnawski, P., Janczura, J. (2025). Environmental and socioeconomic factors influencing hepatotropic virus transmission. *Medical Science Pulse*, *19*. https://doi.org/10.5604/01.3001.0055.1648

Centers for Disease Control and Prevention. (2020). *Coronavirus disease 2019 (COVID-19)* https://www.cdc.gov/coronavirus/2019-ncov/cdcresponse/about-COVID-19.html

Chiziba, C., Mercer, L. D., Diallo, O., Bertozzi-Villa, A., Weiss, D. J., Gerardin, J., & Ozodiegwu, I. D. (2024). Socioeconomic, demographic, and environmental factors may inform malaria intervention prioritization in urban Nigeria. *International Journal of Environmental Research and Public Health*, *21*(1), 78. https://doi.org/10.3390/ijerph21010078

Cuadros, D. F., Kiragga, A., Tu, L., Awad, S., Bwanika, J. M., & Musuka, G. (2025). Unpacking social and digital determinants of health in Africa: a narrative review on challenges and opportunities. *Mhealth*, *11*, 41. https://doi.org/10.21037/mhealth-24-73

Farayibi, A., & Asongu, S. (2020). The economic consequences of the COVID-19 pandemic in Nigeria. *European Xtramile Centre of African Studies, WP/20/042 (2020)*. https://dx.doi.org/10.2139/ssrn.3637668

Feachem, R. G., Bradley, D. J., Garelick, H., & Mara, D. D. (2023). *Sanitation and disease: Health aspects of excreta and wastewater management*. John Wiley & Sons, Singapore. https://documents1.worldbank.org/curated/en/704041468740420118/pdf/multi0page.pdf .

Gona, P., Van Dyke, R. B., Williams, P. L., Dankner, W. M., Chernoff, M. C., Nachman, S. A., & Seage, G. R. (2006). Incidence of opportunistic and other infections in HIV-infected children in the HAART era. *Jama, 296*(3), 292-300. https://doi.org/10.1001/jama.296.3.292

Gorbalenya, A. E., Baker, S. C., Baric, R. S., de Groot, R. J., Drosten, C., Gulyaeva, A. A., ... & Ziebuhr, J. (2020). Severe acute respiratory syndrome-related coronavirus: The species and its viruses–a statement of the Coronavirus Study Group. *BioRxiv*. http://dx.doi.org/10.1038/s41564-020-0695-z

Graham, H., & White, P. C. (2016). Social determinants and lifestyles: integrating environmental and public health perspectives. *Public Health*, *141*, 270-278. https://doi.org/10.1016/j.puhe.2016.09.019

Hellewell, J., Abbott, S., Gimma, A., Bosse, N. I., Jarvis, C. I., Russell, T. W., ... & Eggo, R. M. (2020). Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. *The Lancet Global Health*, *8*(4), e488-e496. https://doi.org/10.1016/S2214-109X(20)30074-7

Isaac, O. N. (2020). Africa: COVID 19 and the future of economic integration. *Available at SSRN 3607305*. https://dx.doi.org/10.2139/ssrn.3607305

Ishola, D. A., & Phin, N. (2011). Could influenza transmission be reduced by restricting mass gatherings? Towards an evidence-based policy framework. *Journal of Epidemiology and Global Health, 1*(1), 33-60. https://doi.org/10.1016/j.jegh.2011.06.004

Kabalimu, T. K., Kibwengo, C. F., Sungwa, E. E. (2025). Opportunistic infections and associated factors among HIV infected patients on anti-retroviral treatment at Bombo hospital in tanga region, Tanzania. *African Journal of Health Sciences*, *35*(3), 252-262. https://ojs.ajhsjournal.or.ke/index.php/home/article/view/267

Li, Q., Guan, X., Wu, P., Wang, X., Zhou, L., Tong, Y., ... & Feng, Z. (2020). Early transmission dynamics in Wuhan, China, of novel coronavirus–infected pneumonia. *New England Journal of Medicine, 382*(13), 1199-1207. https://doi.org/10.1056/NEJMoa2001316

Liu, P., Jiang, J. Z., Wan, X. F., Hua, Y., Li, L., Zhou, J., ... & Chen, J. (2020). Are pangolins the intermediate host of the 2019 novel coronavirus (SARS-CoV-2)?. *PLoS pathogens*, *16*(5), e1008421. https://doi.org/10.1371/journal.ppat.1009664

Mateus, A. L., Otete, H. E., Beck, C. R., Dolan, G. P., & Nguyen-Van-Tam, J. S. (2014). Effectiveness of travel restrictions in the rapid containment of human influenza: a systematic review. *Bulletin of the World Health Organization*, *92*, 868-880D. http://dx.doi.org/10.2471/BLT.14.135590

Mequanente, D. A., Srinivasan, P., Mallika, G., Thamimul Ansari, P. M., & Wale, M. (2022). Incidence of opportunistic infections among HIV-infected children on ART at Gondar University Specialized Hospital, Ethiopia. *Indian Journal of Science and Technology*, *15*(34), 1675-1682. https://doi.org/10.17485/IJST/v15i34.1073

Merler, S., & Ajelli, M. (2010). The role of population heterogeneity and human mobility in the spread of pandemic influenza. *Proceedings of the Royal Society B: Biological Sciences*, *277*(1681), 557-565. https://doi.org/10.1098/rspb.2009.1605

Moges, N. A., & Kassa, G. M. (2014). Prevalence of opportunistic infections and associated factors among HIV positive patients taking anti-retroviral therapy in DebreMarkos Referral Hospital, Northwest Ethiopia. *Journal of AIDS and Clinical Research* *5*(5), 1–300. https://doi.org/10.4172/2155-6113.1000301

Mohamud, A. K., Ahmed, O. A., Mohamud, A. A., & Dirie, N. I. (2023). Magnitude of opportunistic infections and associated factors among adult people living with human immune deficient virus on art at selected public hospital, mogadishu somalia: cross-sectional study. *Annals of Medicine and Surgery*, *85*(7), 3364-3371. https://doi.org/10.1097/MS9.0000000000000880

Nansseu, J. R. N., & Bigna, J. J. R. (2017). Antiretroviral therapy related adverse effects: Can sub-Saharan Africa cope with the new “test and treat” policy of the World Health Organization?. *Infectious Diseases of Poverty, 6*(1), 24. https://doi.org/10.1186/s40249-017-0240-3

Ochube, G. A. & Usman, U. (2023). Globalization and its implications on the nigerian health system. *International Journal of Law, Politics & Humanities Research Published by Cambridge Research and Publications,* 27(6). https://www.cambridgenigeriapub.com/wp-content/uploads/2023/04/CJLPHR_VOL27_NO6_MAR-2023-1.pdf

Onsongo, S., & Kagotho, E. (2024). Applications, Opportunities, and Challenges. *A Comprehensive Overview of Telemedicine*, *26*, 1-18. https://doi.org/10.5772/intechopen.1005094

Olatunji, O. A., Omoruyi, E. C., Olisa, O., & Fowotade, A. (2024). The Diagnostic Performance of an HBeAg-based Test for HBV Infection. *African Journal of Biological Sciences*. 6 (4) ISSN: 2663-2187

DigitalUHC Consortium, & Quentin, W., & Kyobuutungi, C. (2022). Round table: Digital innovations in health financing: Experiences from sub-Saharan Africa. *European Journal of Public Health, 32*(Supplement_3), ckac129-496. https://doi.org/10.1093/eurpub/ckac129.496

Phillips, P., Nazari, N., Dharwadkar, S., Filion, A., Akaribo, B. E., Stephens, P., & Sundaram, M. (2025). Socioeconomic and Eco-Environmental Drivers Differentially Trigger and Amplify Bacterial and Viral Outbreaks of Zoonotic Pathogens. *Microorganisms*, *13*(3), 621. https://doi.org/10.3390/ microorganisms13030621

Pigott, D. M., Deshpande, A., Letourneau, I., Morozoff, C., Reiner, R. C., Kraemer, M. U., ... & Hay, S. I. (2017). Local, national, and regional viral haemorrhagic fever pandemic potential in Africa: a multistage analysis. *The Lancet*, *390*(10113), 2662-2672. https://www.thelancet.com/journals/lancet/article/piis0140-6736(17)32092-5/fulltext

Popoola, T. O. (2018). Health outcomes in sub-Saharan Africa Countries: an analysis of key determinants. *Modern Health Science*, *1*(1), p8-p8. https://doi.org/10.30560/mhs.v1n1p8

Redding, D. W., Atkinson, P. M., Cunningham, A. A., Lo Iacono, G., Moses, L. M., Wood, J. L., & Jones, K. E. (2019). Impacts of environmental and socio-economic factors on emergence and epidemic potential of Ebola in Africa. *Nature Communications*, *10*(1), 4531. https://doi.org/10.1038/s41467-019-12499-6

Sabin, N. S., Calliope, A. S., Simpson, S. V., Arima, H., Ito, H., Nishimura, T., & Yamamoto, T. (2020). Implications of human activities for (re) emerging infectious diseases, including COVID-19. *Journal of Physiological Anthropology*, *39*, 29. https://doi.org/10.1186/s40101-020-00239-5

Saidu, A. S., Bunza, M., Abubakar, U., Adamu, T., Ladan, M., & Fana, S. (2009). A survey of opportunistic infections in HIV seropositive patients attending major hospitals of Kebbi State, Nigeria. *Bayero Journal of Pure and Applied Sciences, 2*(1), 70-74. https://doi.org/10.4314/bajopas.v2i1.58466

Shekar, M., McDonald, C., Okorosobo, T., Subandoro, A., Eberwein, J. D., Mattern, M., ... & Karamba, W. (2015). *Costed plan for scaling up nutrition in Nigeria* (No. 98286). The World Bank. https://ideas.repec.org/p/wbk/hnpkbs/98286.html

Tavares, J. (2021). Electronic health record patient portals and the blockchain technology. In *Political and Economic Implications of Blockchain Technology in Business and Healthcare* (pp. 218-227). IGI Global. https://doi.org/10.4018/9781-7998-7363-1.ch008

Tegegne, K. D., Cherie, N., Tadesse, F., Tilahun, L., Kassaw, M. W., & Biset, G. (2022). Incidence and predictors of opportunistic infections among adult HIV infected patients on anti-retroviral therapy at Dessie comprehensive specialized hospital, Ethiopia: A retrospective follow-up study. *HIV/AIDS-Research and Palliative Care, 14,* 195-206. https://doi.org/10.2147/HIV.S346182

Tufon, E. N., Bih, A. D., & Alice, M. (2014). Occurrence and Risk Factors for Opportunistic Infections in HIV Patients Attending the Bamenda Regional Hospital, Cameroon. *International Journal of Nursing Education and Research, 2*(4), 381-384. https://ijneronline.com/AbstractView.aspx?PID=2014-2-4-24

Wakil, S., Isa M. A., Mustafa A., GIde, S., ……….. Ali, M. U. (2022). The Non-Pharmaceutical Interventions to Control the Spread of Covid-19. *Arid Zone Journal of Basic and Applied Research, 1*(1), 133-143. https://azjournalbar.com/the-non-pharmaceutical-interventions-to-control-the-spread-of-covid-19/

Woldegeorgis, B. Z., Zekarias, Z., Adem, B. G., Obsa, M. S., & Kerbo, A. A. (2023). Prevalence and determinants of opportunistic infections among HIV-infected adults receiving antiretroviral therapy in Ethiopia: A systematic review and meta-analysis. *Frontiers in Medicine*, *10*, 1087086. https://doi.org/10.3389/fmed.2023.1087086

Yin, W., & Couzin, O. (2019). HIV-Related Stigma and Discrimination in China. In: Wu, Z., Wang, Y., Detels, R., Bulterys, M., McGoogan, J. (eds) HIV/AIDS in China. Springer, Singapore. https://doi.org/10.1007/978-981-13-8518-6_28

Zsichla, L., & Mueller, V. (2023). Risk factors of severe COVID-19: a review of host, viral and environmental factors. *Viruses*, *15*(1), 175. https:/ /doi.org/10.3390/v15010175