frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 26 September 2025
DOI 10.3389/fenvs.2025.1561945

OPEN ACCESS

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*CORRESPONDENCE
Adela Socol,
adela.socol@uab.ro

RECEIVED 16 January 2025
ACCEPTED 18 August 2025
PUBLISHED 26 September 2025

CITATION
Tiron-Tudor A, Apostu SA, Socol A and Ivan O-R (2025) Cross-mapping interactions between access to water and sanitation, human and economic development in the least developed countries.
Front. Environ. Sci. 13:1561945.
doi: 10.3389/fenvs.2025.1561945

Cross-mapping interactions between access to water and sanitation, human and economic development in the least developed countries

Adriana Tiron-Tudor[1], Simona Andreea Apostu[2,3], Adela Socol[4]* and Oana-Raluca Ivan[4]

[1]Department of Accounting and Audit, Faculty of Economics and Business Administration, "Babes-Bolyai" University of Cluj-Napoca, Cluj-Napoca, Romania, [2]Department of Statistics and Econometrics, Bucharest University of Economic Studies, Bucharest, Romania, [3]Institute of National Economy, Romanian Academy, Bucharest, Romania, [4]Department of Finance and Accounting, Faculty of Economic Science, University "1 Decembrie 1918" of Alba Iulia, Alba Iulia, Romania

Introduction: Extensive research on human and economic development in the Least Developed Countries (LDC) signaled concerns about the critical barriers that impede sustainable growth in these nations. This study examines the dynamic relationship between the two indices of human development (Human Development Index and Human Assets Index) and the capacity of 22 LDCs, between 2003 and 2019, to attract FDI, the degree of urbanization, water and sanitation access, as well as fertility rate.

Methods: The methodological construct is based on panel VAR and Granger causality methods. By considering all variables endogenous and interdependent, a cross-sectional dimension is introduced. The lag length was found using the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and the Hannan-Quinn Information Criterion (HQIC). To analyse the changing relationship between variables, we used the 7-variable panel VAR for impulse response function analysis.

Results and discussion: The results show a strong cause-and-effect link between urbanization, access to sanitation, and human development. Subsidiary, human development, and water access affect the level of foreign investments. The findings have practical implications for LDC governments by revealing a possible pathway for the sustainable development of the region. The provision of water access and sanitation infrastructure are investments that positively affect economic growth and human development. The paper emphasized the importance of equal and non-discriminatory access to water and sanitation services, an objective otherwise configured in SDG 6 "Clean water and sanitation". Countries' higher levels of human development are linked to more people living in cities, as they lead to more social and economic progress. Research examining how investments, access to water and sanitation, and birth rates affect human development supports this. The mechanisms of such interaction reside in higher income levels in urban areas, employment opportunities, and increased access to educational and health services.

KEYWORDS

sustainable development goals, water access, sanitation access, least developed countries (LDC), foreign direct investment

1 Introduction

Achieving sustainable development represents a shared vision of all nations for global development toward a sustainable economy, society, and environment (United Nations, 2015). United Nations Conference on Trade and Development (UNCTAD) argues that the least developed countries (LDCs) are the battleground where the Sustainable Development Goals will be won or lost (Fojtikova et al., 2023). The LDC classification of the United Nations General Assembly reflects an acknowledgement by the international community that special support measures are needed to assist the least developed among the developing countries. LDCs are countries that have low levels of income and face severe structural impediments to achieving sustainable development (United Nations, 2025a), being the most exposed countries to economic, social, and environmental vulnerabilities. These nations possess the least amount of wealth and human capital because of this unfavorable environment (Peña and Hernández, 2018). Current criteria to be considered for LDC are an income *per capita* of below 1088 USD, a human assets index (HAI) of below 60, and an economic and environmental vulnerability index higher than 36 (United Nations, 2025a).

Extensive scholarly literature exists regarding the advancements made by LDCs in the direction of sustainable development. However, fundamental obstacles continue to endure and have escalated in complexity and immediacy (Lewis, 2000; Hong et al., 2021). The standard of living of the inhabitants of LDCs is below average. Along with the main problems of malnutrition and inadequate housing (Apostu et al., 2022), the problem of not having enough access to basic services like sanitation, healthcare, electricity, and education is seen around the world as a major problem that needs to be addressed. Human development research investigates a multitude of aspects, such as foreign direct investments (FDI), urbanization (Sahai and Kumar, 2021), access to water and sanitation (Amorocho-Daza et al., 2023), and fertility rate (Harttgen and Vollmer, 2014). In the past 10 years, there has been registered new research on LDCs. This study explores the connection between LDCs and certain SDGs, like SDG 6's water access, SDGs' health and education, or the whole set of SDGs (Guerrero-Ruiz et al., 2021; Hurley and Voituriez, 2016; Fojtikova et al., 2023; United Nations, 2018), by analyzing different financial, economic, and environmental factors.

This study highlights the presence of significant obstacles, such as key barriers and low human development conditions that hinder the achievement of sustainable progress in these nations. The objective of this study is to empirically investigate for the LDC nations the causal relationship between human development (captured by two indices, the Human Development Index and Human Assets Index) and factors stimulating economic growth, such as FDI, urbanization, water and sanitation access, as well as fertility rate.

Thus, we analysed four hypotheses:

Hypothesis 1: Human development and FDI generate a bidirectional causal relationship in LDC countries.

Hypothesis 2: Urbanization contributes to human development, which in turn influences the degree of urbanization in LDC nations.

Hypothesis 3: Access to water and sanitation in LDC countries has a mutual influence on the degree of human development.

Hypothesis 4: Fertility rate and human development have a reciprocal influence in LDC countries.

The results reveal factors that influence human development as the motor of sustainable development, but also how human development may stimulate economic growth, such as investment levels, urbanization, access to water or sanitation, and fertility rates, representing the novelty of the paper. To the best of our knowledge, there is no study that analyzes both indices of human development, the Human Development Index and the Human Assets Index together with FDI. Thus, the paper fills the gap in this direction. Our results contribute to the current state of knowledge about how LDCs may achieve sustainable development.

The rest of the study is structured as follows: The second section presents the nexus between human development, foreign investment, urbanization, water and sanitation access, as well as the fertility rate. The hypothesis is built around these. The third section describes the data and methodology used; the fourth part presents the empirical results and discussions; and the last part concludes the study.

2 Literature review

Sustaining human development is fundamentally the objective of sustainability advocates, and human development cannot be considered real without sustainability (Neumayer, 2010). If the goal of human development is to help people live longer, be healthier, get a better education, and be happy with their lives, then the goal of sustainable human development is to make sure that future generations can do the same (Neumayer, 2010). Thus, human resources are a determining factor in a country's success, and states with qualified and highly educated personnel have competitive advantages (Budiono and Purba, 2023). Education is recognized as a major factor in economic growth (Petrakis and Stamatakis, 2002), and high levels of human capital contribute to the development of foreign direct investment flows (Yamin and Sinkovics, 2014).

Given the breadth and complexity of the concept of human development, there has been some considerable effort devoted to developing some measurements for it. The United Nations Development Programme (UNDP) offers the Human Development Index (HDI), a widely acknowledged metric for assessing human development (Bartkute et al., 2023). It is composed of three elements: education, longevity, and income. An additional metric for assessing human development is the Human Assets Index, which the United Nations Conference on Trade and Development (UNCTAD) employs as a criterion for identifying LDCs and is a composite index of health and education.

Not only the people in LDC suffer from low-income levels, lack of education, poor health, and low life expectancy, but these indicate low levels of human development which may not even be sustainable into the future, even under the optimistic substitutability assumption of weak sustainability, not valid in these countries (World Bank, 2010).

To raise genuine savings and investment, a country needs to invest more and consume less. This policy recommendation is not feasible or compatible with human development in extremely impoverished and weakly sustainable nations, as it would place the onus of attaining a semblance of sustainability on the poorest and most vulnerable individuals. This is, of course, unless the necessary funds for supplementary investments can be procured externally (Neumayer, 2010). Integration into the international economy through both trade and financial relations can be a powerful instrument to advance structural transformation.

FDI is a key driver of sustainable economic development (Ofori I. K. et al., 2023; Cudjoe et al., 2023). An examination of the capacity of LDC to provide their citizens with sustainable human and economic development reveals that FDI is expected to affect human development directly or indirectly (Gökmenoğlu et al., 2018). Together, LDCs constitute 14% of the world's population, but at the same time, they account for less than 2% of world GDP and only 1% of world trade (United Nations Conference on Trade and Development, 2021).

In LDCs, FDI inflows were often responsible for the increase in capital formation. However, there are several reasons for LDC policymakers not to overestimate the potential of FDI for accelerating the process of structural transformation. First, FDI flows have been concentrated in only a few LDCs and did not always lead to faster output growth (United Nations Conference on Trade and Development, 2013). Second, a large part of FDI in LDCs is usually undertaken in capital-intensive extractive industries, which typically have very few linkages with the rest of the economy. In this case, it is often difficult for the State to appropriate a fair share of the considerable rents that have been generated (United Nations Conference on Trade and Development, 2013). Exploiting other states' ecological and social resources (LDCs) in achieving sustainability goals would depart from the basic ethos of the 2030 Agenda: "Leave No One Behind" (Chen, 2024). In the same way, FDI that comes to LDCs' manufacturing industries because of their low labor costs usually stays in areas that are geared toward exports, like export processing zones, where imported materials are put together to be sent back to other countries. The same applies to tourism enclaves, which are often supplied through imports (United Nations Conference on Trade and Development, 2013).

Unlike the abundant literature on links between FDI and economic growth, studies examining FDI's influence on human development are relatively rare (Gökmenoğlu et al., 2018). Previous studies on the relationships between human development and countries' capacity to attract FDI show mixed results. The first group of empirical studies shows that high HDI scores make FDI less likely to come in. These studies looked at 161 countries (109 low-to middle-income and 52 high-income) from 2006 to 2018 and found that higher levels of social and human development led to less FDI (Chipalkatti et al., 2021).

Primary education as a measure of human development in 124 countries between 1971 and 2010 did not draw FDI (Iamsiraroj, 2016). Still, earlier research has shown that FDI and HDI are linked in both directions. FDI has a positive effect on HDI (a measure of welfare), especially in Asia, which had less developed and poorer countries from 1990 to 2014 (Ahmad et al., 2019). The HAI (used to classify LDCs) has not been talked about as much in the literature since the 1970s as the HDI (Feindouno and Goujon, 2019). This is because it covers important health and education issues that affect human development and has a series available for 147 developing countries.

Thus, the following hypothesis was developed based on the potential of human development to generate conditions for attracting foreign investment and on the role of FDI in human development:

Hypothesis 1: Human development and FDI present a bidirectional causal relationship in LDC countries.

The degree of urbanization, which is another indicator thought to be highly correlated with human development, is the subject of this study. SDG 11: Sustainable cities and communities aim to make cities and human settlements inclusive, safe, resilient, and sustainable. Sustainable urbanization cannot be addressed without basic access to water and sanitation (Yeyouomo and Asongu, 2024). In recent years, there has been a proliferation of research examining the effects of urbanization on human development; however, the reciprocal relationship between urbanization and human development has received comparatively less attention.

While previous research has examined various types of interactions among the indicators, the prevailing emphasis has been on the favorable consequences of urbanization for human development. An in-depth study of 187 states from 1990 to 2017 found that urbanization has a positive effect on human development. Several numbers, including the total number of people living in cities, the rate of urban population growth, and the percentage of people living in agglomerations with a population of one million or more, confirmed this (Tripathi, 2021). However, the extent of this influence is contingent on different income levels.

The next hypothesis was formulated in light of the following observations: Most LDCs face considerable challenges posed by demographic developments, rising inequality, and persistent poverty (Olaoye et al., 2023), combined with accelerated urbanization (United Nations Conference on Trade and Development, 2013). Income inequalities arise especially due to the ability to access development opportunities (such as capital, land, health, and education) among the population groups in society (Ho et al., 2023). The population living in the present LDCs is projected to almost double to 1.9 billion by 2050. With a soaring youth population, an additional 630 million people (equivalent to about one-third of the estimated LDC population in 2050) will have entered the labour market by 2050. Moreover, it is the most vulnerable country among LDCs that is most affected by these demographic trends (United Nations Conference on Trade and Development, 2013). Insufficiently paid employment creation has the potential to become a source of significant social and political tension and can weaken domestic demand growth.

Based on these considerations, we developed:

Hypothesis 2: Urbanization contributes to human development, which in turn influences the degree of urbanization in LDC nations.

On the other hand, economic growth is linked to better access to water and sanitation. The issue of poor access to water and sanitation in LDC countries has received a lot of attention, especially in light of the Millennium Development Goals, as diseases linked to improper water use have caused a lot of deaths

in those states (Jeuland et al., 2013). Many diseases (e.g., malaria, diarrhea, cholera, hepatitis, and typhoid) and child mortality can be managed through access to drinking water and good sanitation (Ofori I. et al., 2023).

There are still billions of people in the world without access to safe drinking water and sanitation. Thus, Sustainable Development Goal 6 (SDG 6) "Clean water and sanitation" is essential in achieving SDG's aims in social, economic, and environmental sustainability (Venkatesh and Velkennedy, 2023). Environmental degradation profoundly influences the quality of drinking water, that makes this crucial in sustainable development, to which FDI could contribute (JinRu et al., 2022). SDG 6 proposes integrated and holistic water management strategies to achieve universal and equitable access to safe and affordable drinking water and sanitation for all by 2030. SDG 6 is critical about connecting it to human development and interlinking other elements covered by the SDGs, as follows: SDG 1: eradicate all forms of poverty; SDG 3: health and wellbeing; SDG 3: promote economic growth with decent jobs; and SDG 10: reduce inequalities (García-Lopez et al., 2024).

Although between 2015 and 2022 (United Nations, 2024), the proportion of the global population with access to safe drinking water services improved by 4% (from 69% to 73%) and the proportion of those with access to sanitation services increased by 8% (from 67% to 75%), in 2022, approximately 2.2 billion people did not benefit from safe drinking water. LDCs are the most affected by the global water crisis, especially those in Sub-Saharan Africa (Dos Santos et al., 2017). Providing everyone with safe drinking water appears to be an acute topic in the contemporary world, concerned with population growth and climate change (Abdiyev et al., 2023).

Access to water and sanitation serve as fundamental prerequisites for the individuals wellbeing and education (Moreira et al., 2024; Kirschke et al., 2020) and sustainable sanitation practices are essential in less developed countries (Ejigu and Yeshitela, 2024). Regarding access to water and sanitation, Least Developed Countries (LDCs) face a critical predicament (Ferdous et al., 2022). Extensive research has been conducted on the consequences of insufficient water security, which include but are not limited to mortality, morbidity, economic hardship, and social unrest (Mason, 2014).

Even countries with substantial natural resources experience reductions in welfare due to reduced access to water and sanitation (Mpuure and Mengba, 2024). The technical obstacles that are inherent in the task of guaranteeing universal access to water and sanitation in least-developed countries (LDCs) have been the subject of substantial academic discussion. Nevertheless, scholarly investigations into the relationship between this issue and challenges in human development are scarce (Goswami and Ghosal, 2022; Ladi et al., 2021). A study from 2023 that used the causality method and data from 188 states between 2000 and 2017 (Amorocho-Daza et al., 2023) indicated a connection between water and human development.

This supported the hypothesis:

Hypothesis 3: Access to water and sanitation in LDC countries has a mutual influence on the degree of human development.

Rapid population growth, fueled by high fertility, presents a barrier to reducing poverty levels and reaching other internationally agreed development goals (Cheng et al., 2022). In LDCs, fertility rates are higher due to the lack of access to contraceptives and generally lower levels of female education (Bado et al., 2020). Reducing population growth through cutting fertility rates, versus increasing mortality or restricting migration, is beneficial to the economy, as low fertility increases the number of people of working age *per capita* as well as output *per capita* (Ashraf et al., 2013). Benefits to economic growth also occur as lowering fertility leads to an increase in the supply of female labor, particularly in urban areas in developing countries. In addition, smaller family sizes allow for greater investment in the health and education of children in the long term, both from the family and from the government (Foley, 2022). Despite the steady decline in the fertility rate in LDCs since the 1980s, their populations are the fastest growing.

There are good reasons in the literature to investigate how this indicator, the fertility rate, and human development are all connected. Previous research has shown mixed but strong results for fertility rate interaction and human development. Noteworthy is the study of Myrskylä et al. (2009), which documents (for the period 1975–2005) that increasing levels of human development led to a decreased fertility rate, and if human development exceeds a specific limit, then its growth leads to increased fertility rate. Studies are showing that fertility rates rise after a certain level of human development (Cheng et al., 2022; Harttgen and Vollmer, 2014).

This leads to the following hypothesis:

Hypothesis 4: Fertility rate and human development have a reciprocal influence in LDC countries.

Figuring out the cause-and-effect link between human development and things that might affect it (like investments, urbanization, access to water and sanitation, and fertility rate) lets us make cross-mapping interactions that help us learn more about the economies of LDCs and their level of human development.

3 Data and methodology

To identify the factors influencing human development and determinants stimulating economic growth in LDC countries, we used the following variables: HDI (Human Development Index), Human Assets Index (HAI), FDI, net inflows, % of GDP (FDI), Urbanization, Water and Sanitation access, as well as Fertility rate.

The variable description is presented in Table 1. The sample consists of 22 countries from 44 least-developed countries (classified by UNCTAD, the United Nations Conference on Trade and Development), due to data availability between 2003 and 2019. The study proposes the analysis prior to the COVID-19 pandemic period, to understand how human and economic development evolved in these countries, without being influenced by the global pandemic crisis, when many countries changed policies and regulations in 2020, which could affect the results. The studied countries are: Angola, Bangladesh, Burundi, Cambodia, Comoros, the Democratic Republic of Congo, Benin, Gambia, Guinea, Haiti, Madagascar, Mali, Mauritania, Mozambique, Nepal, Niger, Rwanda, Senegal, Sierra Leone, Togo, Uganda, and the United Republic of Tanzania.

As previous literature has shown, human capital proves to be an essential criterion of a country's degree of development. This study

TABLE 1 Variables description.

Variables	Description	Source
HDI	Human Development Index	The Human Development Report of the United Nations Development Programme (https://hdr.undp.org) (United Nations Development Programme, 2025)
HAI	Human Assets Index	The United Nations (UN) (https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-data-retrieval.htm) (United Nations, 2025b)
FDI	Foreign Direct Investment, net inflows, % of GDP	The World Bank's World Development Indicators (WDIs) (https://data.worldbank.org/indicator?tab=all) via the International Monetary Fund Balance of Payments Statistics database (World Bank, 2025)
Urbanization	Urban population (% of total population)	The World Bank's World Development Indicators (WDIs) (https://data.worldbank.org/indicator?tab=all) via United Nations Population Division (World Bank, 2025)
Water Access	Access to basic drinking water (% of population)	The United Nations (UN) (https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-data-retrieval.htm) (United Nations, 2025b)
Sanitation access	Access to basic sanitation (% of population)	The United Nations (UN) (https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-data-retrieval.htm) (United Nations, 2025b)
Fertility rate	Fertility rate, total (births per woman)	The World Bank's World Development Indicators (WDIs) (https://data.worldbank.org/indicator?tab=all) (World Bank, 2025)

uses two indices of the degree of human development: the Human Development Index and the Human Assets Index. The Human Development Index (HDI) summarizes three dimensions of human development: health (life expectancy at birth), education (mean of years of schooling for adults aged 25 years and older, expected years of schooling for children of school age), and standard of living (gross national income *per capita*). The Human Assets Index (HAI) is composed of six health and education indicators: the death rate for children under five, the death rate for mothers, the number of children who are stunted, the number of adults who can read and write, and the gender parity index for lower secondary school completion. For robustness of estimates, both indices of human development are used in this study. To the best of our knowledge, there is no study that analyzes both indices of human development, the Human Development Index and the Human Assets Index.

Foreign direct investment represents an external investment into a business from outside the investor's own country to get a long-term management stake (10% or more of the voting stock). It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments.

Urbanization captures a percentage of the urban population from the total population and is considered a major proxy impacting human wellbeing. Access to public services and infrastructure, education, and the quality of working and living conditions all impact the quality of life of individuals residing in urban agglomerations. Water and sanitation access shows the percentage of the population with access to such services, considered essential for sustainable development, while the fertility rate quantifies the number of births per woman, the main indicator of the degree of human development.

In the case of panel data, before running the panel Granger causality, it is necessary to ascertain cross-section dependence and unit root tests (Akbaş and Lebe, 2016; Onuoha et al., 2018).

There are several alternatives available for examining cross-section dependence (De Hoyos and Sarafidis, 2006). The most prevalent are Friedman (1937), the Lagrange Multiplier (LM) developed by Frees (1995), Frees (2004), Pesaran's CD test proposed by Pesaran (2004), and Friedman (1988). The panel VAR model, Levin, Lin, and Chu LLC (Levin et al., 2002), Im, Pesaran, and Granger causal analysis are used to analyze the stationarity. The panel VAR model is utilized in this paper since Granger's causal analysis can detect minute improvements in the model's structure. The PP-Fisher Chi-Square test, Shin W-Stat IPS (Im et al., 2003), and ADF-Fisher Chi-Square tests were utilized. The panel-unit root test shows that all variables support the alternative hypothesis, so the variables are stationary at this level.

By differencing, the VAR method achieves stationarity. This means that important information about the co-movements is taken out of the time series. To maintain a uniform specification, all variables were included in the PVAR in their level forms (Kireyev, 2000).

The Akaike information criterion, the Bayesian information criterion, or the Hannan-Quinn information criterion were used to find the smallest number of lags that should be in the model. This was done to check for Granger causality in panel datasets. P-values and critical values were computed using a bootstrapping procedure (Lopez and Weber, 2017).

Sims first proposed the Panel-Data VAR method in 1980 (Sims, 1980), which is a hybrid econometric approach. It uses the panel unit-root test to look at the time-series characteristics of individual variables (Jouida, 2018). The method combines the standard VAR method, which sees every variable in the structure as endogenous, with the panel-data method, which lets you add a fixed effect to the model in a clear way (Shank and Vianna, 2016).

By considering all variables endogenous and interdependent, a cross-sectional dimension is introduced. The VAR for the panel may be extpressed as follows, as shown in Equation 1:

$$Y_{it} = A_{0i}(t) + A_i(l)Y_{t-j} + u_{it} \quad (1)$$

where country i = 1, . . . , 22, time t = 2003, . . . , 2019, Y_{it} is a vector of G X 1, in which G is the number of variables for country i and Y_t is the stacked version of y_{it}.

The lag length was found using the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and

TABLE 2 Summary statistics of dependent and explanatory variables.

Variables	HDI	HAI	FDI	Urbanization	Water access	Sanitation access	Fertility rate
Mean	0.4498	44.1264	4.0307	33.8838	59.0425	27.9282	5.0460
Min	0.2630	11.4774	−11.199	8.9080	21.4030	4.8613	1.9170
Max	0.6090	73.6211	39.4562	66.1770	97.0160	66.5738	7.6580
Std. Dev	0.0678	14.1748	5.6896	13.3291	16.7634	15.0355	1.2963

the Hannan-Quinn Information Criterion (HQIC). The parsimonious principle says that the third-period lag is the best lag length (Lin and Wang, 2019).

To analyze the dynamic relationship between variables, we used the 7-variable panel VAR for impulse response function analysis. This indicated how a standard random perturbation shock affected the other variables since those variables were mostly static. It can be used to look at the changing relationship and interaction between variables (Lin and Wang, 2019).

Observing the impulse responses, their 5% and 95% percentile bounds are visible. These were found through Monte Carlo simulations with 200 and 1,000 replications, respectively. In cases where the zero line lies outside the confidence bands, there is evidence of a statistically significant response to the shock inflicted (Jouida, 2018).

The analysis was performed using EViews 12 Student Version.

4 Empirical results and discussion

In order to respond to the study aim, we analysed four hypotheses, according to the extant literature:

Hypothesis 1: Human development and FDI generate a bidirectional causal relationship in LDC countries.

Hypothesis 2: Urbanization contributes to human development, which in turn influences the degree of urbanization in LDC nations.

Hypothesis 3: Access to water and sanitation in LDC countries has a mutual influence on the degree of human development.

Hypothesis 4: Fertility rate and human development have a reciprocal influence in LDC countries.

The panel VAR model is used in this paper since Granger's causal analysis can pick up on small changes in the structure of the model. Panel VAR is suitable for dealing with interdependent economic questions because it is based on standard VAR. With its conceptual framework firmly grounded in standard VAR, panel VAR is exceptionally well-suited for examining interdependent economic inquiries. One advantage of this method is its cross-sectional design (Polemis, 2017). This means that the panel data may include individual heterogeneity and heteroscedasticity that was not seen (Du et al., 2018). It is not necessary to know about the economy of the panel data (Acheampong, 2018; Juodis, 2018; Lin and Wang, 2019).

Table 2 displays the descriptive statistics about the data that were utilized in the research. As it can be observed, HDI registers an average value of 0.4498, oscillating between 0.26 and 0.61, standard deviation being 0.07. For HAI was registered a mean of 44.13, a minimum of 11.48, a maximum of 73.62, and a standard deviation of 14.17. FDI has a medium value of 4.03, varying between −11.2 and 39.46, with standard deviation of 5.69. The values for Urbanization are included between 8.91 and 66.18, the average being 33.88 and standard deviation 13.33. For water access the mean is 59.04, the standard deviation is 16.76, the minimum being 21.4 and maximum being 97.02. Sanitation access presents a mean of 27.93, a minimum of 4.86, a maximum of 66.57, and a standard deviation of 5.04. For fertility rate was registered values between 1.92 and 7.66, a mean of 5.05 and standard deviation of 1.3.

We used LLC test (Levin, Lin, and Chu), IPS test (Im), and Panel VAR, which is highly suitable for investigating interdependent economic inquiries owing to its conceptual framework rooted in standard VAR. Pesaran and Shin W-Stat, Fisher ADF test, and Fisher PP test are all suitable due to the assumption of individual processes in each cross-section series. The results of the unit root test are listed in Table 3, according to which we claim that the variables are stationary at level.

The cointegrating relationship among the variables was tested using the Pedroni and Kao cointegration tests. The results are presented in Table 4 and confirm there is a cointegration relationship between the variables in the study: HDI, HAI, FDI, Urbanization, Water access, Sanitation access, and Fertility rate.

To select the appropriate model, we use likelihood-based criteria, the results being presented in Table 5. Our model has the smallest likelihood-based criteria (AIC, SC, and HQ values), the model with the three lags model is more stable than the other potential models.

In Table 6 we present the coefficients from the PVAR, all variables are not transformed and are treated as endogenous.

We use the postestimation tests PVAR Granger causality Wald test (Table 7), whose findings indicate that human development (as is captured by HDI and HAI) is caused by Urbanization and Sanitation access. HDI and Water access cause FDI, while Urbanization is caused by FDI, Water access, Sanitation access and Fertility rate. Urbanization causes Water access and Sanitation access is caused by Water access. For Fertility rate, none of the indicators in the analysis indicate a causal relationship.

Empirical evidence demonstrates that there is only an unidirectional relationship between selected variables and human development. This means that some hypotheses are partially supported (and one is not supported), which is in line with previous research. *Hypothesis* H_1, according to which Human development and FDI generate bidirectional causal relationships in LDC has been partially validated by proving that HDI causes FDI, which is in line with Gökmenoğlu et al. (2018). Similar results are

TABLE 3 Unit root tests.

Variables	Levin, Lin and Chu		Im, Pesaran and Shin W-Stat		ADF-Fisher Chi-Square		PP-Fisher Chi-Square	
	Statistic	Prob	Statistic	Prob	Statistic	Statistic	Statistic	Prob
HDI	−6.4150	0.0000	0.0309	0.5123	55.8267	0.1089	272.988	0.0000
HAI	−4.6278	0.0000	2.6551	0.9960	34.2342	0.8548	119.190	0.0000
FDI	−3.5055	0.0002	−3.5585	0.0002	80.7027	0.0006	118.198	0.0000
Urbanization	−2.2296	0.0129	7.6212	1.0000	64.8944	0.0218	29.7751	0.9502
Water Access	−1.5659	0.0587	5.9325	1.0000	74.0578	0.0031	694.504	0.0000
Sanitation access	−5.5989	0.0000	−2.1948	0.0141	89.1699	0.0001	546.609	0.0000
Fertility rate	−4.5933	0.0000	−2.0611	0.0196	142.901	0.0000	779.693	0.0000

TABLE 4 Cointegration tests.

Test	Statistic	Prob
Pedroni cointegration test		
Panel v statistic	−4.6341	1.0000
Panel Rho statistic	4.4875	1.0000
Panel PP statistic	−6.4412	0.0000***
Panel ADF statistic	−5.3539	0.0000***
Group Rho statistic	6.6651	1.0000
Group PP statistic	−13.2607	0.0000***
Group ADF statistic	−7.0583	0.0000***
Kao cointegration test		
ADF	3.8062	0.0001***

Note: ***, ** and * denote significance at 1, 5 and 10 percent level respectively.

highlighted by Sharma and Gani (2004), Majeed and Ahmad (2008), and Colen et al. (2012), according to whom HDI significantly and positively influence FDI in LDC. As the HDI reflects a composite measure of health outcomes (reflected by life expectancy), education attainment (measured by mean and expected years of school) and a decent standard of living (proxied by GNI *per capita*), it significantly influences a country's investment climate through multiple economic and institutional mechanisms. Human capital is the key for attracting FDI (Acheampong and Opoku, 2025) and the higher HDI scores could indicate a healthier and more educated population, which translates into a more skilled, better trained, productive and resilient labor force (Choi et al., 2024; Kheng et al., 2017). This, in turn, enhances the attractiveness of the country to foreign investors. An educated workforce is important for investors interested in expanding into environments where local labor can efficiently utilize specific technologies with which investors expand. Although HDI does not explicitly include governance factors, higher HDI values are often correlated with stronger institutions, better governance and lower levels of corruption. These institutional features contribute to a stable and predictable economic environment and attract foreign investors interested in well-governed countries with reduced investment risk (Tabash et al., 2024; Osuma et al., 2024; Magbondé and Konté, 2022). States with robust institutional framework and democratic governance usually have infrastructure that attract FDI (Sethi et al., 2022; Jaiblai and Shenai, 2019). Unlike more developed regions, LDC countries are often characterized by high levels of political and social instability. However, higher HDI scores due to improvements in education can mitigate this risk by encouraging civic approach, reducing conflict and enhancing political stability. Such improvements decrease socio-political risk and increase the country's desirability for investors, while instability and terrorist tactics significantly deter FDI (Ajide, 2025; Abdoulaye, 2023). Furthermore, larger HDI based on the increased GNI *per capita* contributes to consumers purchasing power and could be associated with an expanding domestic market and in aggregate demand for goods and services (Alalmai, 2024; Jaiblai and Shenai, 2019). This enhances the attractiveness of foreign investors interested in finding new markets.

TABLE 5 PVAR's model selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−3574.958		12191553	36.1814	36.2976	36.2285
1	201.1774	7247.128	$5.44*10^{-10}$	−1.4664	−0.5364	−1.0899
2	2027.948	3476.758	$8.67*10^{-18}$	−19.4237	−17.6799	−18.7179
3	2305/805	493.9675	$8.63*10^{-19}$	−21.7354	−19.1779	−20.7002

TABLE 6 VAR.

Variable	HDI	HAI	FDI	Urbanization	Water access	Sanitation access	Fertility rate
HDI (−1)	1.0538 (0.0576) [18.3112]	8.8826 (17.0070) [0.5223]	77.7522 (56.2111) [1.3832]	0.2431 (0.4247) [0.5723]	−0.3778 (0.7872) [−0.4799]	−0.0608 (1.5445) [−0.0394]	−0.0278 (0.0278) [−0.9996]
HDI (−2)	−0.0158 (0.0766) [−0.2063]	0.4795 (22.6430) [0.0212]	−32.9693 (74.8392) [−0.4405]	−0.3189 (0.5655) [−0.5639]	0.9460 (1.0481) [0.9026]	−0.2173 (2.0565) [−0.1057]	0.0158 (0.0371) [0.4265]
HDI (−3)	−0.0398 (0.049) [−0.8161]	−5.3440 (14.4087) [0.3709]	−63.8434 (47.6233) [−1.3406]	0.0667 (0.3598) [0.1855]	−0.2975 (0.6669) [−0.4461]	0.2549 (1.3086) [0.1948]	0.0147 (0.0236) [0.6252]
HAI (−1)	0.0002 (0.0002) [1.0097]	0.9210 (0.0582) [15.8264]	−0.2480 (0.1925) [−1.2895]	−0.0005 (0.0015) [−0.3301]	−0.0001 (0.0027) [−0.1681]	0.0049 (0.0053) [0.9187]	$2{,}86*10^{-5}$ ($9.5*10^{-5}$) [0.3001]
HAI (−2)	−0.0003 (0.0003) [−1.0148]	0.2299 (0.0793) [2.8992]	0.0562 (0.2621) [0.2134]	−0.0008 (0.0019) [−0.4205]	0.0005 (0.0037) [−0.1274]	−0.0021 (0.0072) [−0.2934]	$-3.96*10^{-5}$ (0.0001) [−0.3047]
HAI (−3)	−0.0001 (0.0002) [−0.5402]	−0.1979 (0.0587) [−3.3738]	0.2339 (0.1939) [1.2060]	0.0013 (0.0015) [0.9205]	0.0003 (0.0027) [0.0947]	−0.0027 (0.0053) [0.5075]	$5.47*10^{-6}$ ($9.6*10^{-5}$) [0.0569]
FDI (−1)	−0.0001 ($6.1*10^{-5}$) [−2.0727]	0.0030 (0.0179) [0.1701]	0.6073 (0.0591) [10.2768]	0.00005 (0.0005) [1.1122]	0.0003 (0.0008) [0.3655]	0.0015 (0.0016) [0.9153]	$1.96*10^{-5}$ ($2.9*10^{-5}$) [0.6696]
FDI (−2)	0.0002 ($7.2*10^{-5}$) [2.1572]	0.0142 (0.0214) [0.6620]	−0.0102 (0.0708) [−0.1442]	−0.0002 (0.0005) [−0.3872]	0.0002 (0.0009) [−0.2484]	−0.0023 (0.0019) [−1.2073]	$1.59*10^{-5}$ ($3.5*10^{-5}$) [0.4550]
FDI (−3)	$2.64*10^{-5}$ ($5.9*10^{-5}$) [−0.4469]	−0.0040 (0.0175) [−0.2319]	0.6635 (0.0577) [−0.1507]	−0.0013 (0.0004) [−3.0255]	0.0004 (0.0008) [0.5334]	0.0020 (0.0016) [1.2894]	$-3.63*10^{-7}$ ($2.9*10^{-5}$) [−0.0127]
Urbani-zation (−1)	−0.0046 (0.0066) [−0.6919]	−2.1540 (1.9576) [−1.1003]	2.9872 (6.4701) [0.4617]	1.9378 (0.0489) [39.6384]	0.0685 (0.0906) [0.7560]	0.1131 (0.1778) [0.6360]	−0.0008 (0.0032) [−0.2456]
Urbani-zation (−2)	0.0087 (0.0129) [0.6745]	3.7245 (3.8169) [0.9758]	−8.8221 (12.6154) [−0.6993]	−0.9295 (0.0953) [−9.7516]	−0.1444 (0.1767) [−0.8226]	−0.1936 (0.3467) [−0.5585]	0.0019 (0.0063) [0.3003]
Urbani-zation (−3)	−0.0041 (0.0064) [−0.6493]	−1.5809 (1.8814) [−0.8403]	5.8681 (6.2183) [0.9434]	−0.0082 (0.0470) [−0.1749]	0.0760 (0.0871) [0.8731]	0.0808 (0.1709) [0.4729]	−0.0011 (0.0031) [0.3505]
Water access (−1)	−0.0026 (0.0048) [−0.5408]	−0.5605 (1.4290) [−0.3922]	6.1089 (4.7231) [1.3125]	0.0667 (0.0357) [1.8703]	2.0991 (0.0661) [31.735]	−0.6605 (0.1298) [−5.0890]	−0.0006 (0.0023) [0.2371]
Water access (−2)	0.0036 (0.0097) [0.3715]	1.4478 (2.8694) [0.5046]	−10.7106 (9.4839) [−1.1294]	−0.1173 (0.0717) [−1.6374]	−1.1954 (0.1328) [−9.0003]	1.3411 (0.2606) [5.1463]	−0.0011 (0.0047) [−0.2431]
Water access (−3)	−0.0011 (0.0049) [−0.2209]	−0.8821 (−1.4461) [−0.6099]	4.5126 (4.7797) [0.9441]	0.0507 (0.0361) [1.4037]	0.0961 (0.0669) [1.4357]	−0.6801 (0.1314) [−5.1783]	0.0006 (0.0024) [−0.2509]
Sanita-tion access (−1)	−0.0001 (0.0023) [−0.3890]	0.0939 (0.6891) [−0.2006]	−2.0550 (2.2776) [−0.9023]	−0.0119 (0.0172) [−0.6902]	0.0083 (0.0319) [0.2615]	1.9023 (0.0626) [30.3961]	−0.0007 (0.0011) [0.6712]
Sanita-tion access (−2)	0.0029 (0.0047) [0.6117]	0.0939 (1.3875) [0.0677]	3.6829 (4.5858) [0.8031]	0.0157 (0.0347) [0.4541]	−0.0275 (0.0642) [−0.4276]	−0.8222 (0.1260) [−6.5245]	0.0015 (0.0023) [0.6712]
Sanita-tion access (−3)	−0.0019 (0.0024) [−0.7870]	0.0600 (0.7044) [0.0852]	−1.6582 (2.3283) [−0.7122]	−0.0042 (0.0176) [−0.2369]	0.0193 (0.0326) [0.5922]	−0.0801 (0.0640) [−1.2522]	0.0007 (0.0012) [−0.6696]
Fertility rate (−1)	−0.2237 (0.0568) [−3.9402]	−1.5949 (16.7797) [−0.0951]	20.5563 (55.4600) [0.3707]	−0.8932 (0.4190) [−2.1314]	1.3173 (0.7767) [−0.6921]	−0.0932 (1.5239) [−0.0612]	2.8156 (0.0275) [102.514]
Fertility rate (−2)	0.4469 (0.1127) [3.9669]	4.6679 (33.2916) [0.1402]	−34.8648 (110.035) [−0.3169]	1.8239 (0.8314) [2.1939]	1.3173 (1.5409) [0.8549]	0.2377 (3.0236) [0.0786]	−2.6665 (0.0545) [−48.934]
Fertility rate (−3)	−0.2249 (0.0564) [−3.9841]	−3.3407 (16.6797) [−0.2003]	13.4745 (55.1295) [0.2444]	−0.9418 (0.4166) [−2.2609]	−0.7841 (0.7720) [−1.0156]	−0.1498 (1.5149) [−0.0989]	0.8509 (0.0273) [31.1665]
C	0.0268 (0.0049) [5.4769]	2.7450 (1.4469) [1.8972]	12.6123 (4.7821) [2.6374]	0.0905 (0.0361) [2.5055]	−0.0088 (0.0670) [−0.1315]	−0.0245 (0.1314) [−0.1868]	−0.0044 (0.0024) [−1.8346]

Note: standard errors in () and t−statistics in [].

10.3389/fenvs.2025.1561945

TABLE 7 Panel VAR–Granger causality Wald test.

Dependent variable	Excluded	Chi–sq	df	Prob
HDI	HAI	2.9894	3	0.3933
	FDI	1.1048	3	0.7759
	Urbanization	8.1937	3	0.0422**
	Water access	3.3220	3	0.3446
	Sanitation access	6.8619	3	0.0764*
	Fertility rate	4.6201	3	0.2018
	All	27.4087	18	0.0716*
HAI	HDI	2.9894	3	0.3933
	FDI	1.1048	3	0.7759
	Urbanization	8.1937	3	0.0422**
	Water access	3.3220	3	0.3446
	Sanitation access	6.8619	3	0.0764**
	Fertility rate	4.6201	3	0.2018
	All	27.4087	18	0.0716*
FDI	HDI	8.1197	3	0.0436**
	HAI	3.9730	3	0.2644
	Urbanization	5.7145	3	0.1264
	Water access	12.4866	3	0.0059***
	Sanitation access	3.9082	3	0.2716
	Fertility rate	5.3771	3	0.1462
	All	34.7494	18	0.0102***
Urbanization	HDI	0.3847	3	0.9434
	HAI	0.9324	3	0.8176
	FDI	16.0438	3	0.0011***
	Water access	18.6339	3	0.0003***
	Sanitation access	10.8208	3	0.0127**
	Fertility rate	10.3191	3	0.0160**
	All	50.4687	18	0.0001***
Water access	HDI	5.8719	3	0.1180
	HAI	1.0652	3	0.7855
	FDI	0.5717	3	0.9029
	Urbanization	10.5520	3	0.0144**
	Sanitation access	3.4935	3	0.3216
	Fertility rate	5.3934	3	0.1452
	All	17.1058	18	0.5156
Sanitation access	HDI	0.056	3	0.9965
	HAI	1.0612	3	0.7865
	FDI	2.4651	3	0.4816

(Continued on following page)

TABLE 7 (*Continued*) Panel VAR–Granger causality Wald test.

Dependent variable	Excluded	Chi–sq	df	Prob
	Urbanization	1.8383	3	0.6066
	Water access	27.3663	3	0.0000***
	Fertility rate	0.2191	3	0.9744
	All	46.1392	18	0.0000***
Fertility rate	HDI	1.7745	3	0.6205
	HAI	0.18823	3	0.9804
	FDI	2.1729	3	0.5373
	Urbanization	1.8782	3	0.5846
	Water access	0.5314	3	0.5981
	Sanitation access	1.9416	3	0.5205
	All	12.7004	18	0.9119

Note: ***, ** and * denote significance at 1, 5, and 10 percent levels, respectively.

Second *Hypothesis* H_2: Urbanization contributes to human development, which in turn influences the degree of urbanization in LDC nations. Similar to Tripathi (2021), this has only been partially validated by showing that urbanization causes HDI and HAI in a one-way causal relationship. This relationship is also highlighted by Tostensen et al. (2001), Bhattarai and Budd (2019), and Bundhoo (2018), those studies indicating a significant relationship between human development and the degree of urbanization. The literature presents mixed empirical evidence regarding the relationship between urbanization and human development. On the one hand, numerous studies disclose the positive impact of urbanization on human development, primarily due to enhanced access to healthcare services, education and economic opportunities. In rural regions of LDC, there is often a severe deficiency in health infrastructure, which tends to be more concentrated and advanced in urban areas. Urban healthcare facilities typically benefit from superior infrastructure and a more highly trained medical workforce, facilitating improved access to essential health services. This directly contributes for a long and healthy life, which is a key component of HDI (Chatterjee and Sarkar, 2022; Prasad et al., 2018). Urban areas also serve as centers for educational institutions, offering both basic and specialized education opportunities that are less accessible in rural regions. This urban educational advantage enables citizens to obtain the skills required for participation in a dynamic competitive labor market, which often attracts foreign direct investment due to the availability of a skilled and adaptable workforce (Ouedraogo and Mano, 2025). Moreover, urban environment contributes to knowledge spillovers, enhancing collective learning and human capital accumulation, which indirectly boost human development (Bugge and Thune, 2016). Additionally, the concentration of economic activities and the more developed infrastructure in urban settings creates opportunities for higher wage employment, thereby positively contributing to the decent standard of living dimension of the HDI (Khan et al., 2019). On the other hand, urbanization may exert adverse effects on human development. Rapid urban expansion is frequently associated with environmental degradation, air and water pollution and associated health risks, all of which can damage human wellbeing (Wang et al., 2023). Furthermore, urbanization can aggravate socio-economic inequalities and lead to social exclusion, especially for vulnerable populations with incomplete educational backgrounds (Nguea, 2023). In the absence of adequate employment opportunities and proper infrastructure, urban overcrowding can hinder access to healthcare, education and other essential services, thereby impeding human development progress (Okoth and Omar, 2025).

Hypothesis H_3: Access to water and sanitation in LDC countries has a mutual influence on the degree of human development has been partially validated because sanitation access causes HDI and HAI. These results are in line with Goswami and Ghosal (2022), Dondeynaz et al. (2012), Mehta (2014), Sapkota (2014), and Ladi et al. (2021). Although access to sanitation is recognized as a universal right, and the Sustainable Development Goal 6 explicitly aims to ensure universal access to clean water and adequate sanitation by 2030 (Ando et al., 2025; Ibrahim, 2021), significant disparities persist globally. In particular, many low- and lower-middle-income countries, especially in rural and resource-constrained areas, continue to exhibit alarming low sewerage connection rates (Lohman et al., 2025; Werku and Woldeamanuel, 2025). The improper management of human waste, which can transmit severe and potentially fatal diseases, underscores the urgent need for coherent national strategies, effective sanitation governance and investment in robust infrastructure in promoting human development (Alzua et al., 2025). In the absence of adequate sanitation infrastructure, population face a greater risk of exposure to various pathologies and infectious diseases, which negatively impact both health status and life expectancy–two critical determinants of HDI (Ginja et al., 2021). Furthermore, poor sanitation conditions are associated with diminishing educational outcomes, particularly through increased absenteeism and illness among school-aged children, thereby

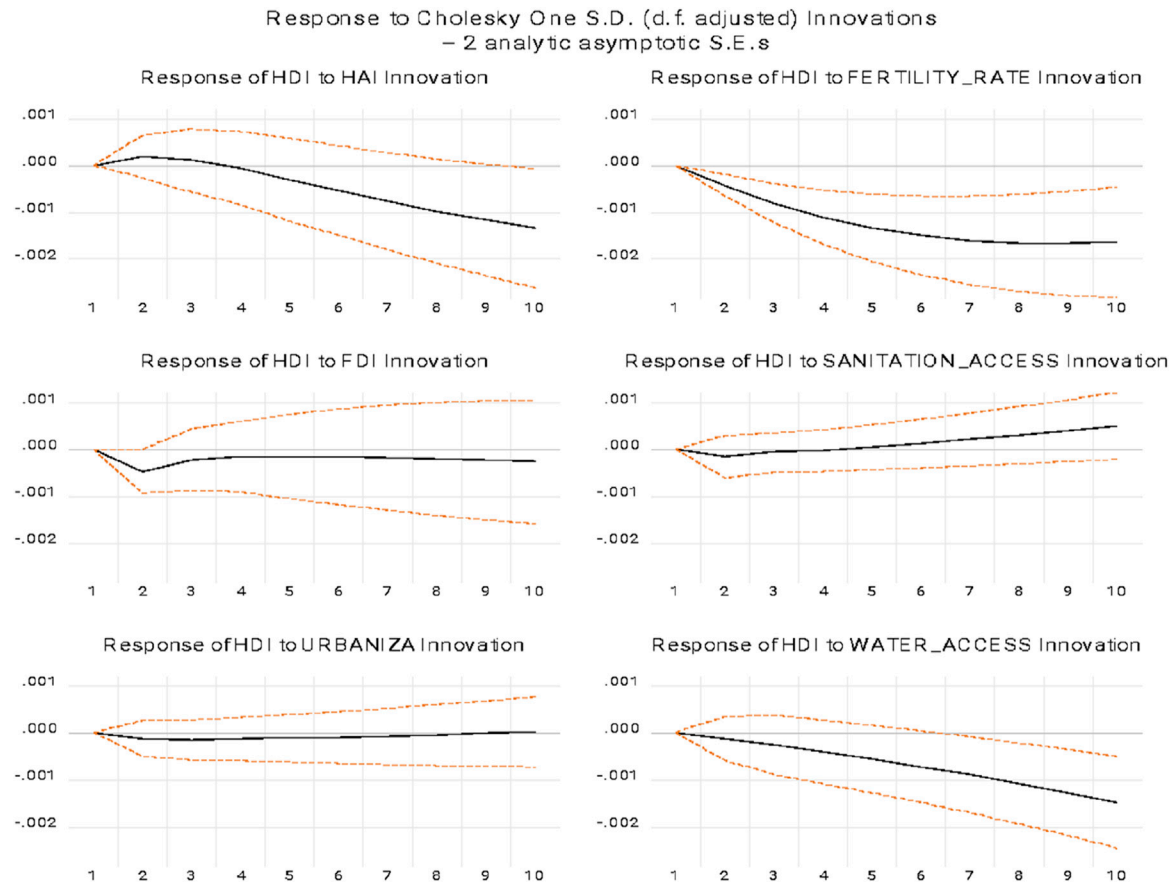

FIGURE 1
The impulse function of HDI (authors projections).

constraining human capital accumulation–a key driver of long-term economic growth and development (Francois et al., 2023; Pakhtigian et al., 2022). Additionally, poor sanitation may lead to health problem and restrict economic activities (Wang and Shen, 2022), whereas improve sanitation coverage yields substantial returns in terms of human capital formation and labor productivity (Orgill-Meyer and Pattanayak, 2020). As better sanitation improves population health, it contributes to higher income levels, increased economic participation and reduced healthcare expenses, all of which have positive indirect effects on human development. Coversely, higher household income is positively associated with improved sanitation access. Income levels significantly influence a household's likelihood of adopting and maintaining improved sanitation facilities (Gurung et al., 2023). Therefore, to mitigate disparities and promote equitable development, it is imperative that low-income countries implement comprehensive and context-sensitive policies that directly address the sanitation gap. Such interventions are essential not only for reducing inequalities but also fostering sustainable human development (Werku and Woldeamanuel, 2025).

The last assumption, *Hypothesis* H_4, that fertility rate and human development have a reciprocal influence in LDC countries, has been invalidated. Previous literature in the files is mixed, the bidirectional relationship between fertility rate and HDI appears to be dependent upon country-specific institutional, cultural and policy contexts. Generally, improvements in HDI are associated with declining fertility rates; however, a moderate fertility rebound may occur beyond a certain threshold of development (Cheng et al., 2022). Conversely, in less developed countries, persistently high fertility is negatively correlated with human development, primarily due to increased pressure on land and water resources and chronic underinvestment in education, health and nutrition (Cheng et al., 2022). Moreover, elevated fertility rates have detrimental effects on human development, particularly through heightened health risks for women and children in developing countries with limited health infrastructure (Osakede et al., 2023).

In addition to the results presented for testing configured hypotheses, Granger's study of causality between variables also confirmed that FDIs are caused by water access, which in turn is caused by urbanization and causes sanitation access. Urbanization is caused by FDI, water access, sanitation access and fertility rate. The match of the results between our panel VAR analysis and Granger causality tests further convinces the robustness of the results. There are also studies highlighting an inverse relationship between fertility rates and HDI in least developed countries, for instance, Haq et al. (2023) and Myrskylä et al. (2011).

Figure 1 exhibits the impulse function of HDI changes over 10 periods when all the other indicators are hit with a one-unit shock.

The impulse function shows how much the HDI variable changes over 10 periods when all the other indicators are hit with a one-unit shock. Granger's study of causality between variables shows that HAI, water access, and fertility rate influence HDI. The red dots show the standard error confidence interval, which is +/−2. es. In addition to the results from testing the hypotheses, it was also shown that access to water, which leads to urbanization and sanitation, is a result of FDIs. In fact, FDI, urbanization, and sanitation have negative effects.

5 Conclusion

This study examines the dynamic relationship between the two indices of human development (Human Development Index and Human Assets Index) and the capacity of 22 LDCs, between 2003 and 2019, to attract FDI, the degree of urbanization, water and sanitation access, as well as fertility rate. Our contribution consists of examining these interrelationships and their causality for human development and FDI. To the best of our knowledge, no previous study presented such a selection of indicators studied for the chosen countries and the analyzed period.

In this paper, we use the Panel Vector Autoregressive, which is a powerful tool to address this topic. The findings of Granger causality indicated that in the context under study, urbanization and sanitation access cause human development (HAI and HDI), HDI causes FDI, and urbanization causes water access. FDI, water access, sanitation access, and fertility rate cause urbanization. Sanitation access is caused by Water access.

The results are in line with the previous literature, which emphasized the importance of equal and non-discriminatory access to water and sanitation services, an objective otherwise configured in SDG 6 "Clean water and sanitation". Countries Higher levels of human development are linked to more people living in cities because they lead to more social and economic progress. Research examining how investments, access to water and sanitation, and birth rates affect human development supports this. The mechanisms of such interaction reside in higher income levels in urban areas, employment opportunities, and increased access to educational and health services.

So, policies are needed to encourage the good effects of these factors on human development and investment. For example, LDC governments and authorities should use their own money and get help from international financing mechanisms to build modern water and sanitation infrastructure. This seems to improve people's health, education, and ability to attract foreign investment. Urbanization is a consequence of FDI and access to clean water and sanitation facilities. Our findings from the study indicate that the degree of human development in LDCs is positively correlated with urbanization. These results have real-world implications for governments and international organizations. Configuring those policies and implementing those tools that lead to sustainable urbanization is likely to lead to an increase in the level of human development.

Sustainable economy focuses on long-term economic growth while minimizing negative impacts on the environment and society. Thus, in order to achieve a developed society high human development is needed, thus FDI and variables related to urbanization, access to water and sanitation are targeted.

The study has implications, both for public and private institutions, academics, also for organizations in the domain. These consider the size and destination of funds to finance the development of countries.

The study presents some limitations, such as only looking at 22 out of 44 LDCs because that is all the data that was available and only looking at a few indicators over a short period of time and without considering the COVID-19 pandemic period, when states changed their policies and regulations, which would lead to different results.

Further research implies an expanded research, including all LDC states, data should be collected as close to the present time as possible, and new indicators should be added that might be useful in the analysis. These could be things like economic growth, state institutions, corruption, economic freedom, and political instability.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AT-T: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft. SA: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft. AS: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft. OI: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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References

Abdiyev, K., Azat, S., Kuldeyev, E., Ybyraiymkul, D., Kabdrakhmanova, S., Berndtsson, R., et al. (2023). Review of slow sand filtration for raw water treatment with potential application in less-developed countries. *Water* 15, 2007. doi:10.3390/w15112007

Abdoulaye, D. (2023). Effects of democracy and natural resources on foreign direct investment in African natural resource-rich countries. *Int. J. Sustain. Dev.* 26 (1), 51–70. doi:10.1504/IJSD.2023.129144

Acheampong, A. O. (2018). Economic growth, CO2 emissions, and energy consumption: what causes what and where? *Energy Econ.* 74, 677–692. doi:10.1016/j.eneco.2018.07.022

Acheampong, A. O., and Opoku, E. E. O. (2025). Democracy, human capital, and foreign direct investment: evidence from developing economies. *Econ. and Polit. Early View*, ecpo.70004. doi:10.1111/ecpo.70004

Ahmad, F., Draz, M. U., Su, L., Ozturk, I., Rauf, A., and Ali, S. (2019). Impact of FDI inflows on poverty reduction in the ASEAN and SAARC economies. *Sustainability* 11, 2565. doi:10.3390/su11092565

Ajide, K. B. (2025). Do terrorist attacks deter foreign investors from entering African markets? *Int. Econ. J.* 39, 531–567. doi:10.1080/10168737.2025.2484759

Akbaş, Y. E., and Lebe, F. (2016). Current account deficit, budget deficit, and savings gap: is the twin or triplet deficit hypothesis valid in G7 countries? *Prague Econ. Pap.* 25 (3), 271–286. doi:10.18267/j.pep.565

Alalmai, S. (2024). Impact of determinants on foreign direct investment in Saudi Arabia: a multiple linear regression analysis. *Int. J. Adv. Appl. Sci.* 11 (2), 50–56. doi:10.21833/ijaas.2024.02.007

Alzua, M. L., Cardenas, J. C., and Djebbari, H. (2025). Effective community mobilization: evidence from Mali. *World Dev.* 190, 106956. doi:10.1016/j.worlddev.2025.106956

Amorocho-Daza, H., van der Zaag, P., and Susnik, J. (2023). Access to water-related services strongly modulates human development. *Earth's Future* 11 (4), e2022EF003364. doi:10.1029/2022EF003364

Ando, H., Kitajima, M., Oki, T., and Murakami, M. (2025). Advancements in global water and sanitation access (2000–2020). *Sci. Rep.* 15, 6399. doi:10.1038/s41598-025-90980-7

Apostu, S. A., Tiron-Tudor, A., Socol, A., Ivan, O. R., Mihaescu, C., and Gogu, E. (2022). Determinants of foreign direct investment in the least developed countries: static and dynamic panel data evidence. *J. Econ. Comput. Econ. Cybern. Stud. Res.* 56 (3), 21–36. doi:10.24818/18423264/56.3.22.02

Ashraf, Q. H., Weil, D. N., and Wilde, J. (2013). The effect of fertility reduction on economic growth. *Popul. Dev. Rev.* 39 (1), 97–130. doi:10.1111/j.1728-4457.2013.00575.x

Bado, A. R., Badolo, H., and Zoma, L. R. (2020). Use of modern contraceptive methods in Burkina Faso: what are the obstacles to Male involvement in improving indicators in the centre-east and centre-north regions? *Open Access J. Contracept.* 28 (11), 147–156. doi:10.2147/OAJC.S274570

Bartkute, R., Griesiene, I., Grikietyte-Cebataviciene, J., and Delibasic, M. (2023). The impact of social and economic factors on income inequalities in EU countries. *Transformations Bus. and Econ.* 22 (60), 464–485. Available online at: http://www.transformations.knf.vu.lt/60/article/theipac.

Bhattarai, K., and Budd, D. (2019). "Effects of rapid urbanization on the quality of life. *Multidimensional approach to quality of life issues: a spatial analysis*, 327-341," in *Multidimensional approach to quality of life issues*. Editor B. Sinha (Singapore: Springer). doi:10.1007/978-981-13-6958-2_21

Budiono, S., and Purba, J. T. (2023). Factors affecting foreign direct investment flows to Indonesia in the era of the COVID-19 pandemic. *Heliyon* 9 (4), e25429. doi:10.1016/j.heliyon.2023.e15429

Bugge, M. M., and Thune, T. (2016). Situated knowledge spillovers: a case study of industry specificity in urban knowledge sourcing. *Geogr. Ann. Ser. B, Hum. Geogr.* 98 (3), 255–270. doi:10.1111/geob.12097

Bundhoo, Z. M. (2018). Solid waste management in least developed countries: current status and challenges faced. *J. Material Cycles Waste Manag.* 20, 1867–1877. doi:10.1007/s10163-018-0728-3

Chatterjee, S., and Sarkar, K. (2022). Appraisal of urban–rural disparities in access to health care facilities and exposure to health risk factors: a case study of durgapur industrial region, India. *GeoJournal* 87, 4007–4024. doi:10.1007/s10708-021-10480-9

Chen, C. W. (2024). Who wins and who loses in global SDGs rankings? Clarifying the influence of the north-south divide and foreign direct investment on spillover effects. *Sustain. Dev.* 32 (3), 2653–2665. doi:10.1002/sd.2806

Cheng, H., Luo, W., Si, S., Xin, X., Peng, Z., Zhou, H., et al. (2022). Global trends in total fertility rate and its relation to national wealth, life expectancy and female education. *BMC Public Health* 22, 1346. doi:10.1186/s12889-022-13656-1

Chipalkatti, N., Le, Q. V., and Rishi, M. (2021). Sustainability and society: do environmental, social, and governance factors matter for foreign direct investment? *Energies* 14, 6039. doi:10.3390/en14196039

Choi, C.-H., Zhou, X., and Ko, J.-O. (2024). Can human capital drive sustainable international trade? Evidence from BRICS countries. *Sustainability* 16, 135. doi:10.3390/su16010135

Colen, L., Maertens, M., and Swinnen, J. (2012). "Foreign direct investment as an engine for economic growth and human development: a review of the arguments and empirical evidence. 70-115," in *Foreign direct investment and human development: the law and economics of international investment agreements*. Editors O. De Schutter, J. Swinnen, and J. Wouters (London: Routledge). Available online at: https://publications.goettingen-research-online.de/ID-69213.

Cudjoe, D. A., Yumei, H., and Hu, H. (2023). The impact of China's trade, aid and FDI on African economies. *Int. J. Emerg. Mark.* 18 (10), 3528–3549. doi:10.1108/IJOEM-10-2020-1180

De Hoyos, R. E., and Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. *Stata J.* 6 (4), 482–496. doi:10.1177/1536867X0600600403

Dondeynaz, C., Carmona Moreno, C., and Céspedes Lorente, J. J. (2012). Analysing inter-relationships among water, governance, human development variables in developing countries. *Hydrology Earth Syst. Sci.* 16 (10), 3791–3816. doi:10.5194/hess-16-3791-2012

Dos Santos, S., Adams, E. A., Neville, G., Wada, Y., de Sherbinin, A., Mullin Bernhardt, E., et al. (2017). Urban growth and water access in Sub-Saharan Africa: progress, challenges, and emerging research directions. *Sci. Total Environ.* 607-608, 497–508. doi:10.1016/j.scitotenv.2017.06.157

Du, G., Liu, S., Lei, N., and Huang, Y. (2018). A test of environmental kuznets curve for haze pollution in China: evidence from the penal data of 27 capital cities. *J. Clean. Prod.* 205, 821–827. doi:10.1016/j.jclepro.2018.08.330

Ejigu, A. K., and Yeshitela, K. (2024). Envisioning sustainable sanitation planning: a unified approach of diffusion of innovation and theory of planned behavior in predicting ecosan toilet adoption in arba minch City, Ethiopia. *Front. Environ. Sci.* 12, 1371659. doi:10.3389/fenvs.2024.1371659

Feindouno, S., and Goujon, M. (2019). Human assets index: insights from a retrospective series analysis. *Soc. Indic. Res.* 141 (3), 959–984. doi:10.1007/s11205-018-1870-y

Ferdous, S., Chowdhury, F. N., Ali, M. L., Bodrud-Doza, M., and Rahman, M. M. (2022). Assessment of urban sanitation status and management gaps in a metropolitan city, Bangladesh: potential challenges to achieve SDG 6. *Front. Water* 4, 950887. doi:10.3389/frwa.2022.950887

Fojtíková, L., Vavrek, R., and Doleželová, P. (2023). Road of the least developed countries to sustainable development: assessing trade participation in the context of the sustainable development goals. *Sustain. Dev.* 31 (4), 2492–2506. doi:10.1002/sd.2524

Foley, E. E. (2022). In pursuit of the demographic dividend: the return of economic justifications for family planning in Africa. *Sex. Reprod. Health Matters* 30 (1), 2133352. doi:10.1080/26410397.2022.2133352

Francois, J. N., Gyimah-Brempong, K., Kakeu, J., and Kouame, C. (2023). *The people's voice and access to sanitation* in *Policy research working paper series* (Washington DC, United States: The World Bank), 10430. Available online at: https://documents1.worldbank.org/curated/en/099443205022319591/pdf/IDU0f30a6e340b50e04ab00a334070641ae4a9ab.pdf.

Frees, E. W. (1995). Assessing cross-sectional correlation in panel data. *J. Econ.* 69 (2), 393–414. doi:10.1016/0304-4076(94)01658-M

Frees, E. W. (2004). *Longitudinal and panel data: analysis and applications in the social sciences*. Cambridge University Press. Available online at: https://library.wbi.ac.id/repository/90.pdf.

Friedman, M. (1937). The use of ranks to avoid the assumption of normality implicit in the analysis of variance. *J. Am. Stat. Assoc.* 32, 675–701. doi:10.1080/01621459.1937.10503522

Friedman, B. M. (1988). Lessons on monetary Policy from the 1980s. *J. Econ. Perspect.* 2 (3), 51–72. doi:10.1257/jep.2.3.51

García-Lopez, M., Cuadrado-Quesada, G., and Montano, B. (2024). Untangling the vicious cycle around water and poverty. *Sustain. Dev.* 32 (3), 1845–1860. doi:10.1002/sd.2753

Ginja, S., Gallagher, S., and Keenan, M. (2021). Water, sanitation and hygiene (WASH) behaviour change research: why an analysis of contingencies of reinforcement is needed. *Int. J. Environ. Health Res.* 31 (6), 715–728. doi:10.1080/09603123.2019.1682127

Gökmenoğlu, K. K., Apinran, M. O., and Taşpınar, N. (2018). Impact of foreign direct investment on human development index in Nigeria. *Bus. Econ. Res. J.* 9 (1), 1–13. doi:10.20409/berj.2018.90

Goswami, T., and Ghosal, S. (2022). Domestic water poverty in a semi-arid district of eastern India: multiple dimensions, regional pattern, and association with human development. *Environ. Dev.* 44, 100742. doi:10.1016/j.envdev.2022.100742

Guerrero-Ruiz, A., Sachin, K., and Schnatz, J. (2021). "Aligning development co-operation to the SDGs in least developed countries: a case study of Uganda," in *OECD development Co-operation working papers* (Paris, France: OECD Publishing), 102. doi:10.1787/5551470f-en

Gurung, R., Tirkey, C., Takri, K. K., Diyali, N., Choubey, M., and Rai, R. (2023). Determinants of access to improved drinking water and sanitation in India: evidence from india human Development Survey-II (IHDS). *Water Policy* 25 (10), 980–995. doi:10.2166/wp.2023.083

Haq, S. M. A., Chowdhury, M. A. F., Ahmed, K. J., and Chowdhury, M. T. A. (2023). Environmental quality and its impact on total fertility rate: an econometric analysis from a new perspective. *BMC Public Health* 23 (1), 2397. doi:10.1186/s12889-023-17305-z

Harttgen, K., and Vollmer, S. (2014). A reversal in the relationship of human development with fertility? *Demography* 51, 173–184. doi:10.1007/s13524-013-0252-y

Ho, H. L., Benesova, I., and Rumankova, L. (2023). Examining income inequality in Vietnam: the role of ODA, economic growth and unemployment. *Transformations Bus. and Econ.* 22 (60A), 732–750. Available online at: http://www.transformations.knf.vu.lt/60a/article/exam.

Hong, S., Reed, W. R., Tian, B., Wu, T., and Chen, G. (2021). Does FDI promote entrepreneurial activities? A meta-analysis. *Word Dev.* 142, 105436. doi:10.1016/j.worlddev.2021.105436

Hurley, G., and Voituriez, T. (2016). Financing the SDGs in the least developed countries (LDCs): diversifying the financing tool-box and managing vulnerability. *Work. Pap. Hal-02567989. Hal.* Available online at: https://hal.science/hal-02567989/document.

Iamsiraroj, S. (2016). The foreign direct investment-economic growth nexus. *Int. Rev. Econ. Finance* 42, 116–133. doi:10.1016/j.iref.2015.10.044

Ibrahim, I. A. (2021). Water as a human right, water as a commodity: can SDG6 be a compromise? *Int. J. Hum. Rights* 26 (3), 469–493. doi:10.1080/13642987.2021.1945582

Im, K. S., Pesaran, M. H., and Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *J. Econ.* 115 (1), 53–74. doi:10.1016/S0304-4076(03)00092-7

Jaiblai, P., and Shenai, V. (2019). The determinants of FDI in sub-saharan economies: a study of data from 1990-2017. *Int. J. Financial Stud.* 7, 43. doi:10.3390/ijfs7030043

Jeuland, M. A., Fuente, D. E., Ozdemir, S., Allaire, M. C., and Whittington, D. (2013). The long-term dynamics of mortality benefits from improved water and sanitation in less developed countries. *PLoS ONE* 8 (10), e74804. doi:10.1371/journal.pone.0074804

JinRu, L., Qamruzzaman, M., Hangyu, W., and Kler, R. (2022). Do environmental quality, financial inclusion, and good governance ensure the FDI sustainably in belt and road countries? Evidence from an application of CS-ARDL and NARDL. *Front. Environ. Sci.* 10, 936216. doi:10.3389/fenvs.2022.936216

Jouida, S. (2018). Diversification, capital structure and profitability: a panel VAR approach. *Res. Int. Bus. Finance* 45, 243–256. doi:10.1016/j.ribaf.2017.07.155

Juodis, A. (2018). First difference transformation in panel VAR models: robustness, estimation, and inference. *Econ. Rev.* 37 (6), 650–693. doi:10.1080/07474938.2016.1139559

Khan, N. H., Ju, Y., and Hassan, S. T. (2019). Investigating the determinants of human development index in Pakistan: an empirical analysis. *Environ. Sci. Pollut. Res.* 26, 19294–19304. doi:10.1007/s11356-019-05271-2

Kheng, V., Sun, S., and Anwar, S. (2017). Foreign direct investment and human capital in developing countries: a panel data approach. *Econ. Change Restruct.* 50, 341–365. doi:10.1007/s10644-016-9191-0

Kireyev, A. (2000). Comparative macroeconomic dynamics in the Arab world: a panel VAR approach. *IMF Work. Pap.* 00, 1. doi:10.5089/9781451847505.001

Kirschke, S., Avellan, T., Barlund, I., Bogardi, J. J., Carvalho, L., Chapman, D., et al. (2020). Capacity challenges in water quality monitoring: understanding the role of human development. *Environ. Monit. Assess.* 192 (5), 298. doi:10.1007/s10661-020-8224-3

Ladi, T., Mahmoudpour, A., and Sharifi, A. (2021). Assessing impacts of the water poverty index components on the human development index in Iran. *Habitat Int.* 113, 102375. doi:10.1016/j.habitatint.2021.102375

Levin, A., Lin, C. F., and Chu, C. S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *J. Econ.* 108 (1), 1–24. doi:10.1016/S0304-4076(01)00098-7

Lewis, J. (2000). Factors influencing foreign direct investment in lesser developed countries. *Park Place Econ.* 8, 99–107. Available online at: http://digitalcommons.iwu.edu/parkplace/vol8/iss1/19.

Lin, B., and Wang, Y. (2019). Inconsistency of economic growth and electricity consumption in China: a panel VAR approach. *J. Clean. Prod.* 229, 144–156. doi:10.1016/j.jclepro.2019.04.396

Lohman, H. A. C., Li, Y., Zhang, X., Morgan, V. L., Watabe, S., Rowles, L. S., et al. (2025). Defining economic and environmental typologies across 77 countries to prioritize opportunities for nonsewered sanitation. *Environ. Sci. and Technol. Early View* 59, 15101–15114. doi:10.1021/acs.est.5c02064

Lopez, L., and Weber, S. (2017). Testing for granger causality in panel data. *Stata J.* 17 (4), 972–984. doi:10.1177/1536867X1801700412

Magbondé, G. K., and Konté, M. A. (2022). Developing countries' economic fundamentals and FDI inflows: the moderating role of institutions. *Cogent Econ. and Finance* 10 (1), 2028976. doi:10.1080/23322039.2022.2028976

Majeed, M. T., and Ahmad, E. (2008). *Human capital development and FDI in developing countries*. Munich, Germany: MPRA. Available online at: https://ideas.repec.org/p/pra/mprapa/57514.html.

Mason, L. R. (2014). Examining relationships between household resources and water security in an urban Philippine community. *J. Soc. Soc. Work Res.* 5 (4), 489–512. doi:10.1086/678923

Mehta, L. (2014). Water and human development. *World Dev.* 59, 59–69. doi:10.1016/j.worlddev.2013.12.018

Moreira, J. S. S., Azzoni, C. R., and Menezes-Filho, N. (2024). Sanitation conditions and education outcomes in Brazilian municipalities. *Sustain. Dev.* 32 (3), 1987–2000. doi:10.1002/sd.2754

Mpuure, D.M.-N., and Mengba, J. D. (2024). Natural resource dependence, policy and institutions for environmental sustainability and African welfare. *Sustain. Dev.* 32 (3), 2176–2193. doi:10.1002/sd.2752

Myrskylä, M., Kohler, H. P., and Billari, F. (2009). Advances in development reverse fertility declines. *Nature* 460, 741–743. doi:10.1038/nature08230

Myrskylä, M., Billari, F. C., and Kohler, H. P. (2011). High development and fertility: fertility at older reproductive ages and gender equality explain the positive link. *MPIDR Work. Pap. WP-2011-017*. Available online at: https://www.demogr.mpg.de/papers/working/wp-2011-017.pdf.

Neumayer, E. (2010). *Human development and sustainability, human development report: research paper 2010/05*. London: United Nations Development Programme. Available online at: https://citeseerx.ist.psu.edu/document?repid=rep1andtype=pdfanddoi=c638460e88be39d8f20a417b474dfeac30625539.

Nguea, S. M. (2023). Improving human development through urbanization, demographic dividend and biomass energy consumption. *Sustain. Dev.* 31 (4), 2517–2535. doi:10.1002/sd.2528

Ofori, I. K., Figari, F., and Ojong, N. (2023a). Towards sustainability: the relationship between foreign direct investment, economic freedom and inclusive green growth. *J. Clean. Prod.* 406, 137020. doi:10.1016/j.jclepro.2023.137020

Ofori, I., Kgbolonyo, E. Y., and Ojong, N. (2023b). Foreign direct investment and inclusive green growth in Africa: energy efficiency contingencies and thresholds. *Energy Econ.* 117, 106414. doi:10.1016/j.eneco.2022.106414

Okoth, E., and Omar, A. E. (2025). "Urban expansion, governance, and environmental quality: decoding the drivers of human of human development," in *SADC countries (2000-2020)* (SAGE Open), 1–22. doi:10.1177/21582440251335192

Olaoye, O., Ibukun, C. O., Razzak, M., and Mose, N. (2023). Poverty prevalence and negative spillovers in Sub-Saharan Africa: a focus on extreme and multidimensional poverty in the region. *Int. J. Emerg. Mark.* 18 (9), 2993–3021. doi:10.1108/IJOEM-01-2021-0028

Onuoha, F. C., Okonkwo, I. C., Okoro, P., and Okere, K. (2018). The causal relationship between foreign direct investment (FDI) and the macro-economy of selected West African countries: panel ARDL/granger causality analysis. *Afr. Res. Rev.* 12 (1), 140–163. doi:10.4314/afrrev.v12i1.15

Orgill-Meyer, J., and Pattanayak, S. K. (2020). Improved sanitation increases long-term cognitive test scores. *World Dev.* 132, 104975. doi:10.1016/j.worlddev.2020.104975

Osakede, U. A., Aramide, V. O., Adesipo, A. E., and Akunna, L. C. (2023). Correlates of human development in Africa: evidence across gender and income group. *Res. Glob.* 6, 100135. doi:10.1016/j.resglo.2023.100135

Osuma, G., Ayinde, A., Ntokozo, N., and Ehikioya, B. (2024). Evaluating the impact of systemic corruption and political risk on foreign direct investment inflows in Nigeria: an analysis of key determinants. *Discov. Sustain.* 5, 432. doi:10.1007/s43621-024-00676-7

Ouedraogo, H., and Mano, H. (2025). Response of human development to urbanization in the West African economic and monetary union (WAEMU). *Sustain. Dev. Early View*, sd.3475. doi:10.1002/sd.3475

Pakhtigian, E. L., Dickinson, K. L., Orgill-Meyer, J., and Pattanayak, S. K. (2022). Sustaining latrine use: peers, policies, and sanitation behaviors. *J. Econ. Behav. and Organ.* 200, 223–242. doi:10.1016/j.jebo.2022.05.024

Peña, K. A. L., and Hernández, R. G. F. (2018). Aid for trade and its relationship to least-developed countries international competitiveness. *Rev. Econ. Y Soc.* 23 (54), 1–23. doi:10.15359/eys.23-54.1

Pesaran, M. H. (2004). *General diagnostic tests for cross section dependence in panels* in *Cambridge working papers in economics no. 0435* (Cambridge, United Kingdom: University of Cambridge). Available online at: https://docs.iza.org/dp1240.pdf.

Petrakis, P. P., and Stamatakis, D. (2002). Growth and educational levels: a comparative analysis. *Econ. Educ. Rev.* 21, 513–521. doi:10.1016/S0272-7757(01)00050-4

Polemis, M. L. (2017). Capturing the impact of shocks on the electricity sector performance in the OECD. *Energy Econ.* 66, 99–107. doi:10.1016/j.eneco.2017.06.014

Prasad, A., Borrell, C., Mehdipanah, R., and Chatterji, S. (2018). Tackling health inequalities using urban HEART in the sustainable development goals era. *J. Urban Health* 95, 610–612. doi:10.1007/s11524-017-0165-y

Sahai, A., and Kumar, R. (2021). A cross country study of financial inclusion and economic development with special emphasis on India. *Indian J. Econ. Dev.* 17 (1), 11–24. doi:10.35716/IJED/20245

Sapkota, J. B. (2014). *Access to infrastructure and human development: cross-country evidence* in *Working papers 70* (Tokyo, Japan: JICA Research Institute). Available online at: https://ideas.repec.org/p/jic/wpaper/70.html.

Sethi, M., Baby, S., and Sharma, A. M. (2022). A cross-country analysis of the relationship between human capital and foreign direct investment. *J. Econ. Stud.* 49 (7), 1197–1211. doi:10.1108/JES-07-2021-0348

Shank, C. A., and Vianna, A. C. (2016). Are US-Dollar-Hedged-ETF investors aggressive on exchange rates? A panel VAR approach. *Res. Int. Bus. Finance* 38, 430–438. doi:10.1016/j.ribaf.2016.05.002

Sharma, B., and Gani, A. (2004). The effects of foreign direct investment on human development. *Glob. Econ. J.* 4 (2), 1850025. doi:10.2202/1524-5861.1049

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica* 48 (1), 1–48. doi:10.2307/1912017

Tabash, M. I., Farooq, U., Matar, A., and Al-Absy, M. S. M. (2024). Role of governance in attracting foreign direct investment inflow: empirical evidence from south Asia region. *Cogent Econ. and Finance* 12 (1), 2358930. doi:10.1080/23322039.2024.2358930

Tostensen, A., Tvedten, I., and Kamete, A. Y. (2001). From global village to urban globe. Urbanisation and poverty in Africa: implications for Norwegian aid policy. *Bergen chr. Michelsen Inst. (CMI Rep. R. 2001:2)*. Available online at: https://www.cmi.no/publications/951-from-global-village-to-urban-globe.

Tripathi, S. (2021). How does urbanization affect the human development index? A cross-country analysis. *Asia-Pacific J. Regional Sci.* 5, 1053–1080. doi:10.1007/s41685-021-00211-w

United Nations (2015). Transforming our world: the 2030 agenda for sustainable development. Available online at: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1andLang=E.

United Nations (2018). Achieving the sustainable development goals in the least developed countries. Available online at: https://unctad.org/system/files/official-document/aldc2018d4_en.pdf.

United Nations (2024). The sustainable development goals report. Available online at: https://unstats.un.org/sdgs/report/2024/The-Sustainable-Development-Goals-Report-2024.pdf.

United Nations (2025a). Least developed countries. Available online at: https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html.

United Nations (2025b). LDC data. Available online at: https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-data-retrieval.html.

United Nations Conference on Trade and Development (2013). The least developed countries report. Available online at: https://unctad.org/system/files/official-document/ldc2013_en.pdf.

United Nations Conference on Trade and Development (2021). UN recognition of the least developed countries. UNCTAD. Available online at: https://unctad.org/topic/least-developed-countries/recognition.

United Nations Development Programme (2025). The human development index. *Hum. Dev. Rep. U. N. Dev. Programme*. Available online at: https://hdr.undp.org.

Venkatesh, B., and Velkennedy, R. (2023). Formulation of citizen science approach for monitoring sustainable development goal 6: clean water and sanitation for an Indian city. *Sustain. Dev.* 31 (1), 56–66. doi:10.1002/sd.2373

Wang, D., and Shen, Y. (2022). Sanitation and work time: evidence from the toilet revolution in rural China. *World Dev.* 158, 105992. doi:10.1016/j.worlddev.2022.105992

Wang, F., Liu, S., Chen, T., Zhang, H., Zhang, Y., and Bai, X. (2023). How urbanization affects residents' health risks: evidence from China. *Environ. Sci. Pollut. Res.* 30, 35554–35571. doi:10.1007/s11356-022-24767-y

Werku, B. C., and Woldeamanuel, A. A. (2025). Assesing rural communities in central and East Africa: how to provide clean water and sanitation by 2030. *Environ. Health Insights* 19, 1–20. doi:10.1177/11786302251335130

World Bank (2010). World development report. Available online at: https://documents1.worldbank.org/curated/en/201001468159913657/pdf/530770WDR02010101Official0Use0Only1.pdf.

World Bank (2025). The world bank's world development indicators (WDIs). Available online at: https://data.worldbank.org/indicator?tab=all.

Yamin, M., and Sinkovics, R. R. (2014). A retrospective on: infrastructure or foreign direct investment? International business and sustainable development. *Prog. Int. Bus. Res.* 8, 231–247. doi:10.1108/S1745-8862(2013)0000008015

Yeyouomo, A. K., and Asongu, S. A. (2024). Sustainable urbanization and vulnerability to climate change in Africa: accounting for digitalization and institutional quality. *Sustain. Dev.* 32 (1), 1188–1216. doi:10.1002/sd.2721