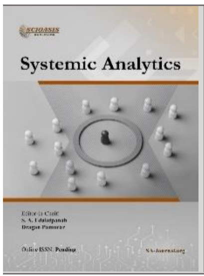

Systemic Analytics

www.sa-journal.org

Syst. Anal. Vol. 1, No. 1 (2023) 11–26.

Paper Type: Original Article

Assessment of the Challenges to Urban Sustainable Development Using an Interval-Valued Fermatean Fuzzy Approach

Clement Kiprotich Kiptum[1], Mouhamed Bayane Bouraima[2,*], Ibrahim Badi[3], Babatounde Ifred Paterne Zonon[4], Kevin Maraka Ndiema[1], Yanjun Qiu[2]

[1] Department of Civil and Structural Engineering, School of Engineering, University of Eldoret, 1125-30100 Eldoret, Kenya; chelalclement@yahoo.com; marakakevin@yahoo.com.

[2] Department of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China; mouba121286@yahoo.fr; publicqiu@vip.163.com.

[3] Department of Mechanical Engineering, Libyan Academy, 2429 Misurata, Libya; i.badi@lam.edu.ly.

[4] Department of Economics and Management, Southwest Jiaotong University, Chengdu 610031, China; zifrpat@yahoo.fr.

Citation:

Received: 21 March 2023 *Revised: 15 Apr 2023* *Accepted: 04 May 2023*	Kiptum, C. K., Bouraima, M. B., Badi, I., Zonon, B.I.P., Ndiema, K.M., Qiu, Y. (Date). Assessment of the challenges to urban sustainable development using an interval-valued fermatean fuzzy approach. *Systemic Analytics*, *1*(1), 11-26.

Abstract

Amidst the battle against sustainability challenges, global attention is increasingly directed towards urban development. A comprehensive review of current literature pertaining to urban sustainability indicates a swift upsurge in research concerning the development of cities, encompassing both developed and developing nations, all underscored by a strong commitment to sustainable progress. However, only a small fraction of this research presents a structured framework for systematically recognizing and investigating the diverse facets of urban sustainability, as well as for appropriately gauging and assessing them. The objective of this study is to evaluate the challenges associated with the attainment of sustainable urban development. An exhaustive examination of the available literature was undertaken to formulate a two-level criteria framework. The allocation of weights to these criteria was ascertained through the application of the interval-valued Fermatean fuzzy analytical hierarchy process methodology. The findings of the analysis unveiled that primary challenges to the development of urban sustainability encompass lack of water and improved sanitation, lack of solid waste management system, and threats to the attainment of the millennium development goals.

Keywords: Interval-valued fermatean fuzzy sets, Urban sustainable development, Challenge, AHP.

Corresponding Author: mouba121286@yahoo.fr

1 | Introduction

The rapid urbanization is expected to create an opportunity for humanity's evolution and transformation. Cities are intricate and interconnected systems that extend beyond the mere sum of their individual sectors. The well-being of millions of people and a significant portion of the economy are reliant on the dynamics of these cities [1]. Korff and Rothfußlig [2] assert that cities function as essential nodes connecting diverse networks of human movement, capital, and knowledge at the local, regional, and global levels [3]. As such, they play a transformative role in shaping developmental processes [4]. While rapid urbanization can bring about urban challenges, conflicts, and tensions, it should also be recognized as a process that offers opportunities for growth [5]. This growth, in turn, affords city residents the chance to adapt to the dynamic principles of urban sustainability [6].

Understanding the complex interactions within urban areas and their environments is crucial for informing decision-makers about the social, economic, and environmental consequences of addressing urban needs [7]. According to the Report of the World Commission on Environment and Development (WCED) titled "Our Common Future" (1987), sustainability involves aligning resource exploitation, investment directions, technological development, and governance with both present and future needs. To achieve sustainable urban development, governance must be integrated with environmental, economic, and social considerations [8]. This requires a multi-faceted strategy that brings these interests into harmony through appropriate governance organizations and institutions.

An increasing body of literature has been dedicated to addressing the challenge of urban sustainability, focusing on the socio-economic, and environmental development of cities from a global perspective [9]. However, the literature has generally overlooked the role of governance institutions at the local level. Recent efforts have led to the development and proposal of various urban development frameworks tailored to different cities [10], emphasizing socio-economic and environmental progress within regional contexts. For the Asia-Pacific region, a specific framework has been identified, which explores the transnational flow of environmental, economic, and social conditions in rapidly developing cities. This framework is essential because urban areas in the developing world often struggle to maintain continuity and survival due to short-term interests, while poverty plays a more constraining role, leading to rapid growth of slum populations in countries like Kenya [8].

Over the years, Kenya has experienced one of the highest urban population growth rates in Sub-Saharan Africa. In 2010, 32.4% of the population lives in cities, which is six times more than in 1950. Kenya's urban annual population growth rate stands at 4%, significantly surpassing the world's average of around 1.66%, Asia's average of 1.87%, and Africa's average of 3.09%. It is projected that by the year 2030, more than 50% of Kenya's population will be living in urban areas.

The economic activities in Kenya primarily revolve around and within its cities, reflecting the concentration of the population in urban areas [11]. Despite the significant economic contributions of cities, a large majority of urban dwellers in Kenya, particularly in cities like Mombasa, and Kisumu, live in extreme poverty. In fact, between 50% and 60% of urban residents are affected by this poverty concentration, residing in slums and informal settlements [11]. Given these challenges and the increasing impact of disasters, there is a pressing need to contemplate the concepts and frameworks of urban sustainability in Kenya's context.

The rapid urbanization in Kenya is influenced by changing environmental, economic, and social dynamics. Many cities in the country demonstrate the challenging conditions faced by the urban poor, who live in perilous environments marked by poverty, crime, disease, and a lack of access to municipal services [11]. The inadequate infrastructure, both socio-economically and environmentally, leads to a lack of essential services [11]. Informal settlements, which are common in urban areas of Kenya, have been overlooked by city planners, resulting in poorly structured housing due to insecure land tenure. These settlements suffer from a lack of infrastructure, with inaccessible road networks and no drainage systems, leading to poor solid waste disposal methods and threatening the lives of their residents [11]. These environmental, economic, and social imbalances in cities create significant barriers to achieving urban sustainability.

1.1 | Literature Review

Numerous studies have focused on assessing urban sustainability [12–19]. Various methodologies have been employed for this purpose, including the trapezoidal interval type-2 fuzzy SWARA-COPRAS approach [18], fuzzy DEMATEL [12, 19], Group fuzzy BWM, AHP, and TOPSIS–GIS [17], grey LBWA-EDAS approach [13], fuzzy Delphi method-AHP approach [15], AHP [14], [16]. In the African context, numerous studies have investigated sustainable urban development in several countries, including Kenya [11], Ethiopia [20], Zambia [21], South Africa [22], Nigeria [23], Guinea Bissau [24], and a more comprehensive literature review spanning various regions [25–27]. Nevertheless, there remains a limited number of researchers who have assessed the specific challenges to urban sustainability in Africa [28], [29].

Given the constraints of earlier studies, it becomes apparent that achieving urban sustainability requires assessing a wide range of contradictory factors. Traditional decision-making methods that focus on a single criterion are inadequate to tackle the inherent intricacies of these issues [30–36]. As a result, Multi-Criteria Decision-Making (MCDM) approaches have gained traction, offering flexible tools for policymakers and managers [37–41]. These approaches use predetermined parameters to classify and select elements from alternatives [29], [31], [36], [38], [41-51], and the chosen parameters are then assessed based on their effectiveness in fulfilling their functions and determining alternative suitability [29], [53–59], [61].

This study presents an interval-valued Fermatean fuzzy analytical hierarchy process approach. Its main purpose is to address the shortcomings of previous research and provide a means to identify the specific challenges obstructing the advancement of urban sustainability in Kenya.

2 | Methodology

The research design of this study, consisted of several sequential steps. Initially, a thorough examination of existing literature was undertaken to establish a two-level criteria hierarchy encompassing potential challenges related to urban sustainable development. Subsequently, experts' insights were sought to classify and refine these factors. To determine the relative weights of the two-level criteria, the IVFF-AHP method was employed, involving the creation of a pairwise comparison matrix.

2.1 | Criteria Determination

Examining the complexities surrounding challenges in urban sustainable development involves a multifaceted decision-making process that encompasses various aspects. The inclusion of numerous variables that require consideration makes the identification of these challenges difficult. To address this issue, an extensive literature review was conducted to select the most appropriate criteria, with a particular focus on urban sustainable development. The potential factors identified as criteria were further refined through consultations with a panel of experts. To analyze the challenges related to urban sustainable development, the inner level (Level-2) is presented in *Table 1*.

Table 1. Inner level criteria for the challenges to urban sustainable development.

Criteria	Sub-Criteria	References
Environmental	Lack of water and improved sanitation (EN1)	[61]
	Poor urban transport (EN2)	[29]
	Lack of solid waste management systems (EN3)	[62]
Economic	Lack of jobs (EC1)	[63]
	Low incomes (EC2)	[11]
	Low rate of industrialization (EC3)	[64]
Social	Deepening of urban poverty (SO1)	[65]
	Jeopardize in the achievement of the Millennium Development Goals (SO2)	[66]
	Increased growth of slum populations (SO3)	[67]

2.2 | Preliminary

This section provides introductory explanations for Intuitionistic Fuzzy Sets (IFSs), Pythagorean Fuzzy Sets (PFSs), Fermatean Fuzzy Sets (FFSs), and IVFFSs [68–70].

Definition 1. Let $X = \emptyset$ be a given set. An IFS $\tilde{I}$ in X is shown as:

$$\tilde{I} = \{(x, \mu_{\tilde{I}}(x), v_{\tilde{I}}(x)) \mid x \in X\}, \tag{1}$$

where $\mu_{\tilde{I}}: X \to [0,1]$ and $v_{\tilde{I}}: X \to [0,1]$ represents the degree of membership and the degree of non-membership of the component $x \in X$ to $\tilde{I}$ and it holds that,

$$0 \le \mu_{\tilde{I}}(x) + v_{\tilde{I}}(x) \le 1, \quad \texttt{for} \ \ \forall x \in X. \tag{2}$$

The degree of hesitancy is given as follows:

$$\pi_{\tilde{I}}(x) = 1 - \mu_{\tilde{I}}(x) - v_{\tilde{I}}(x). \tag{3}$$

Definition 2. Let X be a non-empty set. A PFS $\tilde{P}$ in X is an expression given by:

$$\tilde{P} = \{\langle x, \mu_{\tilde{P}}(x), v_{\tilde{P}}(x)\rangle \mid x \in X\}, \tag{4}$$

where $\mu_{\tilde{P}}: X \to [0,1]$ and $v_{\tilde{P}}: X \to [0,1]$ define the two degrees of the component $x \in X$ to $\tilde{P}$ and given that,

$$0 \le \left(\mu_{\tilde{P}}(x)\right)^2 + \left(v_{\tilde{P}}(x)\right)^2 \le 1, \quad \text{for all } x \in X. \tag{5}$$

The degree of uncertainty is computed by:

$$\pi_{\tilde{P}}(X) = \sqrt{1 - \mu_{\tilde{P}}(x)^2 - v_{\tilde{P}}(x)^2}. \tag{6}$$

Definition 3. Let X be a universe of discourse. An FFS $\tilde{F}$ in X is defined as:

$$\tilde{F} = \{\langle x, \mu_{\tilde{F}}(x), v_{\tilde{F}}(x)\rangle \mid x \in X\}. \tag{7}$$

where $\mu_{\tilde{F}}: X \to [0,1]$ and $v_{\tilde{F}}: X \to [0,1]$ refers to the two degrees of the component $x \in X$ to $\tilde{F}$, where;

$$0 \le \left(\mu_{\tilde{F}}(x)\right)^3 + \left(v_{\tilde{F}}(x)\right)^3 \le 1, \quad \text{for all } x \in X. \tag{8}$$

Definition 4. Let $\tilde{F} = (\mu_{\tilde{F}}, v_{\tilde{F}})$, $\tilde{F}_1 = \left(\mu_{\tilde{F}_1}, v_{\tilde{F}_1}\right)$ and $\tilde{F}_2 = \left(\mu_{\tilde{F}_2}, v_{\tilde{F}_2}\right)$ be three FFSs. Then, some operations of FFSs are described as follows:

$$\tilde{F}_1 \oplus \tilde{F}_2 = \left(\sqrt[3]{\mu_{\tilde{F}_1}^3 + \mu_{\tilde{F}_2}^3 - \mu_{\tilde{F}_1}^3\mu_{\tilde{F}_2}^3}, v_{\tilde{F}_1}v_{\tilde{F}_2}\right). \tag{9}$$

$$\tilde{F}_1 \otimes \tilde{F}_2 = \left(\mu_{\tilde{F}_1}\mu_{\tilde{F}_2}, \sqrt[3]{v_{\tilde{F}_1}^3 + v_{\tilde{F}_2}^3 - v_{\tilde{F}_1}^3 v_{\tilde{F}_2}^3}\right). \tag{10}$$

$$\lambda\tilde{F}=\left(\sqrt[3]{1-\left(1-\mu_{\tilde{F}}^{3}\right)^{\lambda}},v_{\tilde{F}}^{\lambda}\right)\quad,\lambda>0. \tag{11}$$

$$\tilde{F}^{\lambda}=\left(\mu_{\tilde{F}}^{\lambda},\sqrt[3]{1-\left(1-v_{\tilde{F}}^{3}\right)^{\lambda}}\right)\quad,\lambda>0. \tag{12}$$

Definition 5. Let $X=\emptyset$ be a given set. An IVFFS $\tilde{F}$ in X is an expression provided by:

$$\tilde{F}\ =\{\langle x,\mu_{\tilde{F}}\,(x),v_{\tilde{F}}\,(x)\rangle\mid x\in X\}, \tag{13}$$

where $\mu_{\tilde{F}}\,(x)\subseteq[0,1]$ and $v_{\tilde{F}}\,(x)\subseteq[0,1]$ constitute the two degrees of the component $x\in X$ to $\tilde{F}$, respectively. Also, for each $x\in X$, $\mu_{\tilde{F}}\,(X)$ and $v_{\tilde{F}}\,(X)$ are immediate intervals and their inferior and superior bounds are designated by $\mu_{\tilde{F}}^{L}\,(x),\mu_{\tilde{F}}^{U}\,(x),v_{\tilde{F}}^{L}\,(x)$ and $v_{\tilde{F}}^{U}\,(x)$, respectively. Therefore, $\tilde{F}$ is described bellows:

$$\mu_{\tilde{F}}\,(x)=\left[\mu_{\tilde{F}}^{L}\,(x),\mu_{\tilde{F}}^{U}\,(x)\right]\subseteq[0,1]. \tag{14}$$

$$v_{\tilde{F}}\,(x)=\left[v_{\tilde{F}}^{L}\,(x),v_{\tilde{F}}^{U}\,(x)\right]\subseteq[0,1], \tag{15}$$

where

$$0\le\left(\mu_{\tilde{F}}^{U}(x)\right)^{3}+\left(v_{\tilde{F}}^{U}(x)\right)^{3}\le 1.$$

For every $x\in X$, the degree of hesitancy $\pi_{\tilde{F}}\,(x)$ to $\tilde{F}$ as:

$$\pi_{\tilde{F}}\,(x)=\left[\pi_{\tilde{F}}^{L}\,(x),\pi_{\tilde{F}}^{U}\,(x)\right]=\left[\sqrt[3]{1-\left(\mu_{\tilde{F}}^{U}\,(x)\right)^{3}-\left(v_{\tilde{F}}^{U}\,(x)\right)^{3}},\sqrt[3]{1-\left(\mu_{\tilde{F}}^{L}\,(x)\right)^{3}-\left(v_{\tilde{F}}^{L}\,(x)\right)^{3}}\right]. \tag{16}$$

Definition 6. Let $\tilde{F}=\left(\left[\mu_{\tilde{F}}^{L},\mu_{\tilde{F}}^{U}\right],\left[v_{\tilde{F}}^{L},v_{\tilde{F}}^{U}\right]\right)$, $\tilde{F}_1=\left(\left[\mu_{\tilde{F}_1}^{L},\mu_{\tilde{F}_1}^{U}\right],\left[v_{\tilde{F}_1}^{L},v_{\tilde{F}_1}^{U}\right]\right)$ and $\tilde{F}_2=\left(\left[\mu_{\tilde{F}_2}^{L},\mu_{\tilde{F}_2}^{U}\right],\left[v_{\tilde{F}_2}^{L},v_{\tilde{F}_2}^{U}\right]\right)$ be three IVFFSs and $\lambda>0$. Then some arithmetic operations of IVFFSs are denoted by *Eqs. (21)-(25)*:

$$\tilde{F}_1\oplus\tilde{F}_2=\left(\begin{bmatrix}\sqrt[3]{\left(\mu_{\tilde{F}_1}^{L}\right)^{3}+\left(\mu_{\tilde{F}_2}^{L}\right)^{3}-\left(\mu_{\tilde{F}_1}^{L}\right)^{3}\left(\mu_{\tilde{F}_2}^{L}\right)^{3}},\\ \sqrt[3]{\left(\mu_{\tilde{F}_1}^{U}\right)^{3}+\left(\mu_{\tilde{F}_2}^{U}\right)^{3}-\left(\mu_{\tilde{F}_1}^{U}\right)^{3}\left(\mu_{\tilde{F}_2}^{U}\right)^{3}}\end{bmatrix},\left[v_{\tilde{F}_1}^{L}v_{\tilde{F}_2}^{L},v_{\tilde{F}_1}^{U}v_{\tilde{F}_2}^{U}\right]\right). \tag{17}$$

$$\tilde{F}_1\otimes\tilde{F}_2=\left(\left[\mu_{\tilde{F}_1}^{L}\mu_{\tilde{F}_2}^{L},\mu_{\tilde{F}_1}^{U}\mu_{\tilde{F}_2}^{U}\right],\begin{bmatrix}\sqrt[3]{\left(v_{\tilde{F}_1}^{L}\right)^{3}+\left(v_{\tilde{F}_2}^{L}\right)^{3}-\left(v_{\tilde{F}_1}^{L}\right)^{3}\left(v_{\tilde{F}_2}^{L}\right)^{3}}\\ \sqrt[3]{\left(v_{\tilde{F}_1}^{U}\right)^{3}+\left(v_{\tilde{F}_2}^{U}\right)^{3}-\left(v_{\tilde{F}_1}^{U}\right)^{3}\left(v_{\tilde{F}_2}^{U}\right)^{3}}\end{bmatrix}\right). \tag{18}$$

$$\lambda\tilde{F}=\left(\left[\sqrt[3]{1-\left(1-\left(\mu_{\tilde{F}}^{L}\right)^{3}\right)^{\lambda}},\sqrt[3]{1-\left(1-\left(\mu_{\tilde{F}}^{U}\right)^{3}\right)^{\lambda}}\right],\left[\left(v_{\tilde{F}}^{L}\right)^{\lambda},\left(v_{\tilde{F}}^{U}\right)^{\lambda}\right]\right). \tag{19}$$

$$\tilde{F}^{\lambda}=\left(\left[\left(\mu_{\tilde{F}}^{L}\right)^{\lambda},\left(\mu_{\tilde{F}}^{U}\right)^{\lambda}\right],\left[\sqrt[3]{1-\left(1-\left(v_{\tilde{F}}^{L}\right)^{3}\right)^{\lambda}},\sqrt[3]{1-\left(1-\left(v_{\tilde{F}}^{U}\right)^{3}\right)^{\lambda}}\right]\right). \tag{20}$$

Definition 7. Let $\tilde{F}=\left(\left[\mu_{\tilde{F}}^{L},\mu_{\tilde{F}}^{U}\right],\left[v_{\tilde{F}}^{L},v_{\tilde{F}}^{U}\right]\right)$ be an IVFFS. The score function $S(\tilde{F})$ of $\tilde{F}$ is described.

$$\mathrm{S}(\tilde{F})=\frac{\left(\mu_{\tilde{F}}^{L}\right)^{3}+\left(\mu_{\tilde{F}}^{U}\right)^{3}-\left(v_{\tilde{F}}^{L}\right)^{3}-\left(v_{\tilde{F}}^{U}\right)^{3}}{2}. \tag{21}$$

Definition 8. Let $\tilde{F}_i = \left(\left[\mu^L_{\tilde{F}_i}, \mu^U_{\tilde{F}_i}\right], \left[v^L_{\tilde{F}_i}, v^U_{\tilde{F}_i}\right]\right) (i = 1,2,\dots,n)$ be a category of IVFFSs and $w = (w_1, w_2, \dots, w_n)^T$ be a vector weight of $\tilde{F}_i$ with $\sum_{i=1}^{n} w_i = 1$, then an IVFF weighted average operator is a framing IVVWA: $\tilde{F}^n \to \tilde{F}$, where,

$$\text{IVFFWA}\left(\tilde{F}_1, \tilde{F}_2, \dots, \tilde{F}_n\right) = \left(\left[\sqrt[3]{\left(1 - \prod_{i=1}^{n}\left(1 - \left(\mu^L_{\tilde{F}_i}\right)^3\right)^{w_i}\right)}, \sqrt[3]{\left(1 - \prod_{i=1}^{n}\left(1 - \left(\mu^U_{\tilde{F}_i}\right)^3\right)^{w_i}\right)}\right], \left[\prod_{i=1}^{n}\left(v^L_{\tilde{F}_i}\right)^{w_i}, \prod_{i=1}^{n}\left(v^U_{\tilde{F}_i}\right)^{w_i}\right]\right). \quad (22)$$

Definition 9. Let $\tilde{F}_i = \left(\left[\mu^L_{\tilde{F}_i}, \mu^U_{\tilde{F}_i}\right], \left[v^L_{\tilde{F}_i}, v^U_{\tilde{F}_i}\right]\right) (i = 1,2,\dots,n)$ be a set of IVFFSs and $w = (w_1, w_2, \dots, w_n)^T$ be a weight vector of $\tilde{F}_i$ with $\sum_{i=1}^{n} w_i = 1$, thus an IVFF Weighted Geometric (IVFFWG) operator is a mapping IVVWG: $\tilde{F}^n \to \tilde{F}$, where

$$\text{IVFFWG}\left(\tilde{F}_1, \tilde{F}_2, \dots, \tilde{F}_n\right) = \left(\left[\prod_{i=1}^{n}\left(\mu^L_i\right)^{w_i}, \prod_{i=1}^{n}\left(\mu^U_i\right)^{w_i}\right], \left[\sqrt[3]{\left(1 - \prod_{i=1}^{n}\left(1 - \left(v^L_{\tilde{F}_i}\right)^3\right)^{w_i}\right)}, \sqrt[3]{\left(1 - \prod_{i=1}^{n}\left(1 - \left(v^U_{\tilde{F}_i}\right)^3\right)^{w_i}\right)}\right]\right). \quad (23)$$

Definition 10. Let $F_1 = ([\mu_{F_{1L}}, \mu_{F_{1U}}], [v_{F_{1L}}, v_{F_{1U}}]), F_2 = ([\mu_{F_{2L}}, \mu_{F_{2U}}], [v_{F_{2L}}, v_{F_{2U}}]) \in$ IVFFN. Let $J_M(F_i), J_H(F_i), J_P(F_i)$ and $J_C(F_i)$ be the membership, hesitancy, precise and complete score functions for $F_i, (i = 1,2)$. Then the ordering principle (O) for comparing arbitrary IVFFNs is defined below:

I. If $J_M(F_1) < J_M(F_2)$ then $F_1 < F_2$.

II. If $J_M(F_1) > J_M(F_2)$ then $F_1 > F_2$.

III. If $J_M(F_1) = J_M(F_2)$.

then

I. If $J_H(F_1) < J_H(F_2)$ then $F_1 < F_2$.

II. If $J_H(F_1) > J_H(F_2)$ then $F_1 > F_2$.

III. If $J_H(F_1) = J_H(F_2)$.

then

I. If $J_P(F_1) < J_P(F_2)$ then $F_1 < F_2$.

II. If $J_P(F_1) > J_P(F_2)$ then $F_1 > F_2$.

III. If $J_P(F_1) = J_P(F_2)$.

then

I. If $J_H(F_1) < J_H(F_2)$ then $F_1 < F_2$.

II. If $J_H(F_1) > J_H(F_2)$ then $F_1 > F_2$.

III. If $J_H(F_1) = J_H(F_2)$.

then

2.3 | Interval-Valued Fermatean Fuzzy AHP Method

The IVFF-AHP method introduced by Alkan and Kahraman [68] is an extension of the Analytic Hierarchy Process (AHP) designed to address Multiple Criteria Decision Making (MCDM) problems. The key steps of the IVFF-AHP method are outlined below [68].

Step 1. Construction of a hierarchical framework through the finding of main and sub-criteria. Suppose that $C_j(j = 1,2,\ldots,m)$ be a set of m criteria with $w_j = (w_1, w_2, \ldots, w_m)$, where $w_j > 0$ and $\sum_{j=1}^{m} w_j = 1$ as the vector of the criteria weights. Let ψ^t the reputation (weight) of experts t and k is the number of experts where $\sum_{t=1}^{k} \psi^t = 1$.

Step 2. The IVFF pairwise comparison matrix $Z = (z_{ij})_{m\times m}$ is constructed according to experts' judgments using variables provided in *Table 2*.

$$Z = \begin{bmatrix} 1 & z_{12} & \cdots & z_{1m} \\ z_{21} & 1 & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ z_{m1} & z_{m2} & \cdots & 1 \end{bmatrix} \text{ where } z_{ij} = \langle [\mu_{ij}^L, \mu_{ij}^U], [v_{ij}^L, v_{ij}^U] \rangle. \quad (24)$$

Table 2. Linguistic variables and IVFFNs.

Linguistic variables	IVFFNs			
	μ_L	μ_U	v_L	v_U
Categorically High Influence (CHI)	0.95	1.00	0.00	0.00
Very High Influence (VHI)	0.80	0.90	0.10	0.20
High Influence (HI)	0.70	0.80	0.20	0.30
Slightly More Influence (SMI)	0.60	0.65	0.35	0.40
Equally Influence (EI)	0.50	0.50	0.50	0.50
Slightly Less Influence (SLI)	0.35	0.40	0.60	0.65
Low Influence (LI)	0.20	0.30	0.70	0.80
Very Low Influence (VLI)	0.10	0.20	0.80	0.90
Categorically Low Influence (CLI)	0.00	0.00	0.95	1.00

Step 3. Each Pairwise Comparison (PC) matrix (*Z*) has found a Consistency Ratio (CR). A CR of a matrix is determined based on the procedure of Saaty's classical consistency.

Step 4. Expert opinions are aggregated by using the IVFFWG operator given in the Definition. 9. Let $A_{ij}^t = ([\mu_{ij}^{Lt}, \mu_{ij}^{Ut}], [v_{ij}^{Lt}, v_{ij}^{Ut}])$ be the PC of criteria i and j by expert t.

$$\text{IVFFWG}(A_{ij}^1, A_{ij}^2, \ldots, A_{ij}^k)$$
$$= \left(\left[\prod_{t=1}^{k} (\mu_{ij}^{Lt})^{\psi^t}, \prod_{t=1}^{k} (\mu_{ij}^{Ut})^{\psi^t} \right], \left[\sqrt[3]{\left(1 - \prod_{t=1}^{k} \left(1 - (v_{ij}^{Lt})^3\right)^{\psi^t}\right)}, \sqrt[3]{\left(1 - \prod_{t=1}^{k} \left(1 - (v_{ij}^{Ut})^3\right)^{\psi^t}\right)} \right] \right). \quad (25)$$

Step 5. The distinction in the computation matrix $\mathrm{D} = (\mathrm{d_{ij}})_{\mathrm{m\times m}}$ between the inferior and superior points the two degrees of functions through *Eqs. (26)* and *(27)*:

$$d_{ij}^L = (\mu_{ij}^L)^3 - (v_{ij}^U)^3. \quad (26)$$

$$d_{ij}^U = (\mu_{ij}^U)^3 - (v_{ij}^L)^3. \quad (27)$$

Step 6. The interval generative matrix $S = (s_{ij})_{m\times m}$ is calculated by *Eqs. (28)* and *(29)*:

$$s_{ij}^L = \sqrt[3]{1000^{d_{ij}^L}}. \quad (28)$$

$$s_{ij}^U = \sqrt[3]{1000^{d_{ij}^U}}. \quad (29)$$

Step 7. The uncertainty value $T = (t_{ij})_{m\times m}$ of the z_{ij} is obtained.

$$t_{ij} = 1 - (\mu_{ij_U}^3 - \mu_{ij_L}^3) - (v_{ij_U}^3 - v_{ij_L}^3). \quad (30)$$

Step 8. The uncertainty levels are multiplied with $S = (s_{ij})_{m\times m}$ matrix to find the matrix of unnoted weights $R = (r_{ij})_{m\times m}$ by Eq. (31):

$$r_{ij} = \left(\frac{s_{ij}^L + s_{ij}^U}{2}\right) t_{ij}. \quad \textbf{(31)}$$

Step 9. The computation of the normalized priority weights w_i is as bellows.

$$w_i = \frac{\sum_{j=1}^{m} r_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} r_{ij}}. \quad \textbf{(32)}$$

3 | Application

In this research, the study identified nine challenges related to urban sustainable development in Kenya, which were then categorized into three distinct groups. To ensure the successful evaluation of the proposed framework, the careful selection of qualified experts (referred to as Es) as the primary sources of data was deemed essential. Among these experts, top-tier individuals from academia who possessed at least 10 years of experience and held a master's degree or higher were chosen to participate in the survey. Three such experts were selected to provide valuable data for this study.

3.1 | Criteria Determination

Step 1. Firstly, weights of level-1 criteria were determined. For this purpose, experts analyzed the environmental, economic and social criteria.

Step 2. To establish a Pairwise Comparison (PC) of the level-1 criteria, the experts were tasked with utilizing linguistic variables in Table 2. The pairwise comparisons produced by the experts for the criteria are presented in *Table 3*.

Table 3. PC for main criteria.

Criteria	E-1	CR=0		E-2	CR=0.039		E-3	CR=0.01	
	EN	EC	SO	EN	EC	SO	EN	EC	SO
EN	EI	CHI	LI	EI	SLI	CHI	EI	SLI	LI
EC	CLI	EI	LI	SMI	EI	SLI	SMI	EI	CHI
SO	HI	HI	EI	CLI	SMI	EI	HI	CLI	EI

Step 3. Each matrix's consistency was verified, and all were found to be consistent based on the Consistency Ratio (CR) values calculated and presented in *Table 2*.

Step 4. The experts' opinions were then aggregated, taking into account their reputations, to determine the criteria weights using the IVFF-AHP method. *Table 4* shows the aggregated evaluation matrix for level-1 criteria.

Table 4. Aggregated PC matrix for level-1 criteria.

	Environmental				Economic				Social			
	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U
EN	0.500	0.500	0.500	0.500	0.500	0.550	0.450	0.550	0.350	0.450	1.000	0.720
EC	0.000	0.000	0.820	1.000	0.500	0.500	0.500	0.500	0.390	0.470	0.540	0.660
SO	0.000	0.000	0.170	0.790	0.000	0.000	0.770	1.000	0.500	0.500	0.500	0.500

Step 5. Difference matrix between lower and upper values was generated based on *Eqs. (26)* and *(27)* and presented in *Table 5*.

Table 5. Difference matrix for level-1 criteria.

	Environmental		Economic		Social	
EN	0.000	0.000	-0.040	0.070	-0.330	-0.900
EC	-1.000	-0.550	0.000	0.000	-0.220	-0.050
SO	-0.500	-0.010	-1.000	-0.460	0.000	0.000

Step 6. The interval generative matrix was generated based on *Eqs. (28)* and *(29)* as given in *Table 6*.

Table 6. Interval generative matrix for level-1 criteria.

	Environmental		Economic		Social	
EN	1.000	1.000	0.900	1.190	0.470	0.120
EC	0.100	0.270	1.000	1.000	0.590	0.890
SO	0.310	0.980	0.100	0.340	1.000	1.000

Step 7. The uncertainty value for each criterion was calculated as given in *Table 7*.

Table 7. Uncertainty levels for level-1 criteria.

	Environmental	Economic	Social
EN	1.000	0.880	1.570
EC	0.550	1.000	0.820
SO	0.500	0.470	1.000

Step 8. Unnormalized weights were calculated based on *Table 6* and *Table 7* via *Eq. (32)*. *Table 8* presents the weights before normalization.

Table 8. Unnormalized weights of level-1 criteria.

	Environmental	Economic	Social
EN	1.000	0.920	0.460
EC	0.110	1.000	0.610
SO	0.330	0.100	1.000

Step 9. Finally, weights are normalized and criteria weights are determined. The results of level-1 criteria are presented in *Fig. 1,* which highlights that the Environmental (EN) criterion is the most critical, with a weight of 0.431. Following in critical importance is the Economic (EC) criterion, which weighs 0.310, while the Social (SO) criterion is lastly ranked, with a weight of 0.285.

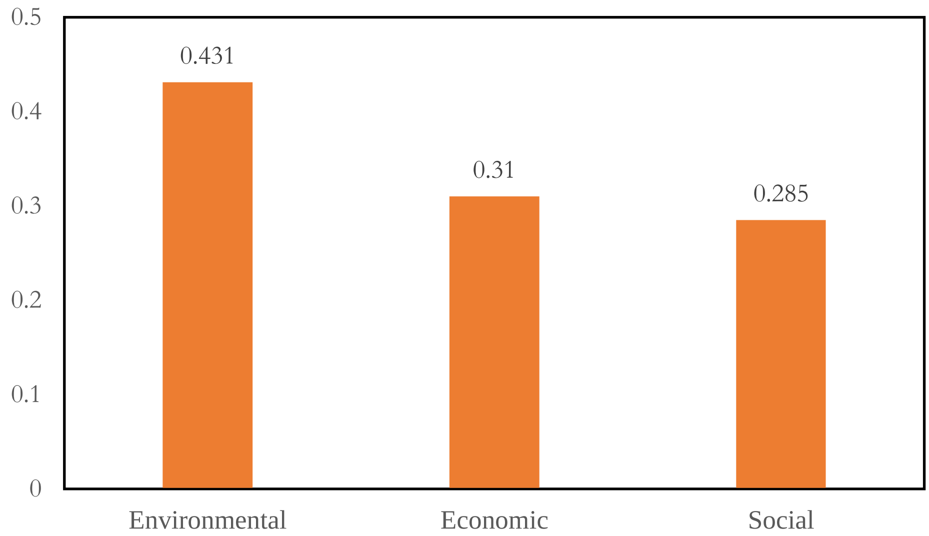

Fig. 1. Ranking of level-1 criteria.

The same experts were then consulted to evaluate the inner levels of criteria. To this end, they established PC matrices for level-2 criteria based on their professional judgment. *Table 9* presents the matrices for the PC of level-2 criteria for each main criterion.

Table 9. PC matrices for level-2 criteria

					ENV.				
Level-2	E-1	CR		E-2	CR		E-3	CR	
	EN-1	EN-2	EN-3	EN-1	EN-2	EN-3	EN-1	EN-2	EN-3
EN-1	EI	SLI	CHI	EI	CHI	SLI	EI	CHI	LI
EN-2	SMI	EI	LI	CLI	EI	LI	CLI	EI	SLI
EN-3	CLI	HI	EI	SMI	HI	EI	HI	SMI	EI
					EC.				
	E-1	CR		E-2	CR		E-3	CR	
	EC-1	EC-2	EC-3	EC-1	EC-2	EC-3	EC-1	EC-2	EC-3
EC-1	EI	SLI	CHI	EI	CHI	SLI	EI	CHI	LI
EC-2	SMI	EI	LI	CLI	EI	LI	CLI	EI	SLI
EC-3	CLI	HI	EI	SMI	HI	EI	HI	SMI	EI
					SO.				
	E-1	CR		E-2	CR		E-3	CR	
	SO-1	SO-2	SO-3	SO-1	SO-2	SO-3	SO-1	SO-2	SO-3
SO-1	EI	SLI	CHI	EI	CHI	SLI	EI	CHI	LI
SO-2	SMI	EI	LI	CLI	EI	LI	CLI	EI	SLI
SO-3	CLI	HI	EI	SMI	HI	EI	HI	SMI	EI

*Note: Env-Environmental, EC-Economic, SO-Social.

After testing the level-2 comparison matrices for consistency, it was determined that all of them are consistent. The weights of criteria for the inner level is then calculated by applying the IVFF-AHP steps again. The weights attributed to criteria by individual experts at level-2 within each level-1 category are presented in *Figs. 2, 3*, and *4*. The analysis of *Fig. 2* underscores that for urban sustainable development's environmental aspect, the most pivotal challenge pertains to lack of water and improved sanitation. Turning to the economic dimension depicted in *Fig. 3*, the challenge of low income sub-criteria emerges as foremost, whereas in the social aspect in *Fig. 4*, the most critical challenge revolves around jeopardizing the achievement of the Millennium development goals.

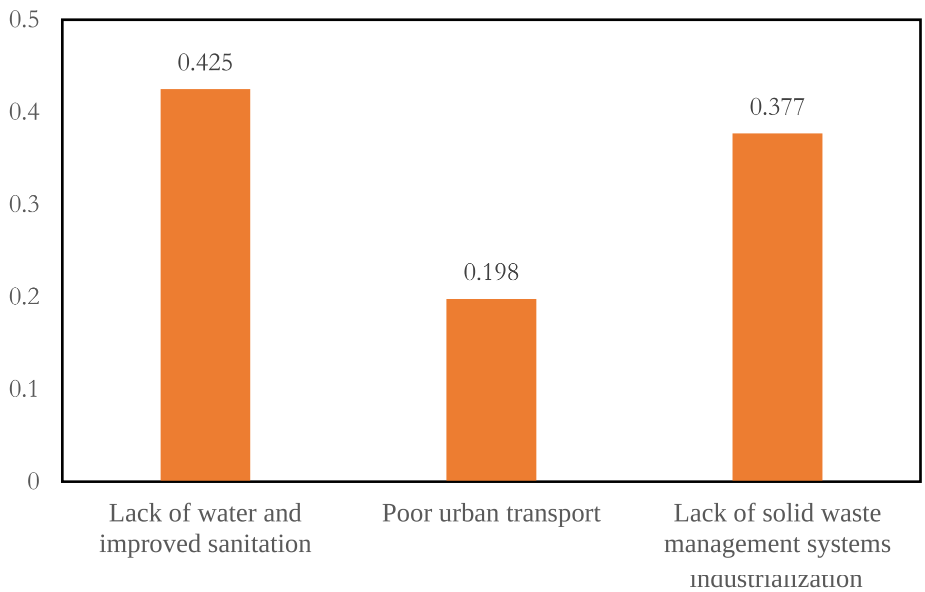

Fig. 2. Ranking of level-2 sub-criteria under environmental dimension.

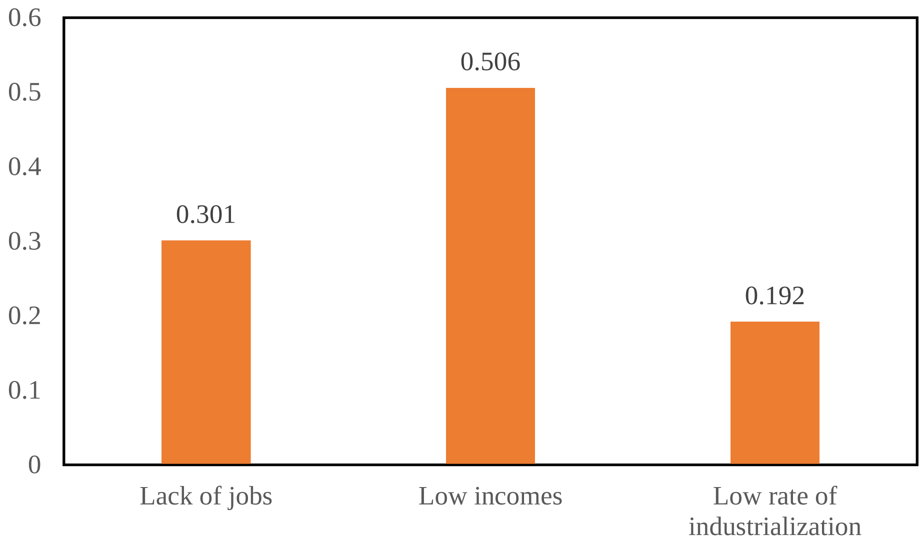

Fig.3. Ranking of level-2 sub-criteria under economic dimension.

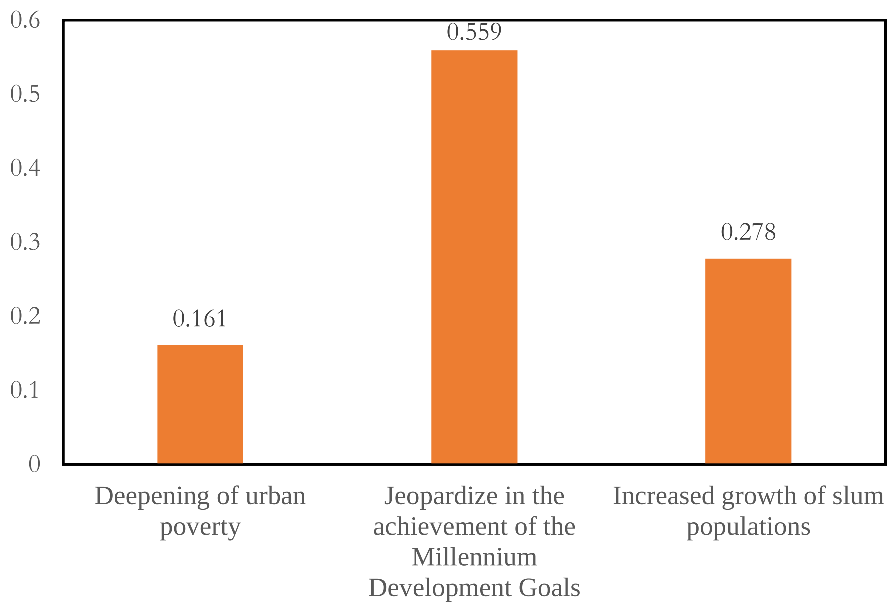

Fig.4. Ranking of Level-2 sub-criteria under social dimension.

The sub-criteria's weights in level-2 *Fig. 5* are determined by multiplying their weights with those of the level-1 criteria. Among all level-2 criteria, lack of water and improved sanitation is the most significant sub-criterion, which is not surprising since it falls under the environmental aspect which is the most important criterion under level-1 criteria. Lack of solid waste management system and jeopardizing in the achievement of the millennium development goals follow in second and third place, with final weights of 0.162 and 0.159, respectively. This ranking highlights the critical role of the environmental aspect and the parameters listed below in impeding the development of urban sustainability, emphasizing the need for authorities to consider these factors when making decisions. The low incomes sub-criterion under economic aspect rank fourth, indicating also their importance in identifying challenges to urban sustainability development. Conversely, the criterion deepening the urban poverty is the least critical challenge and falls under the social aspect. This suggests that it is more appropriate to focus on criteria that are more essential in developing urban sustainability.

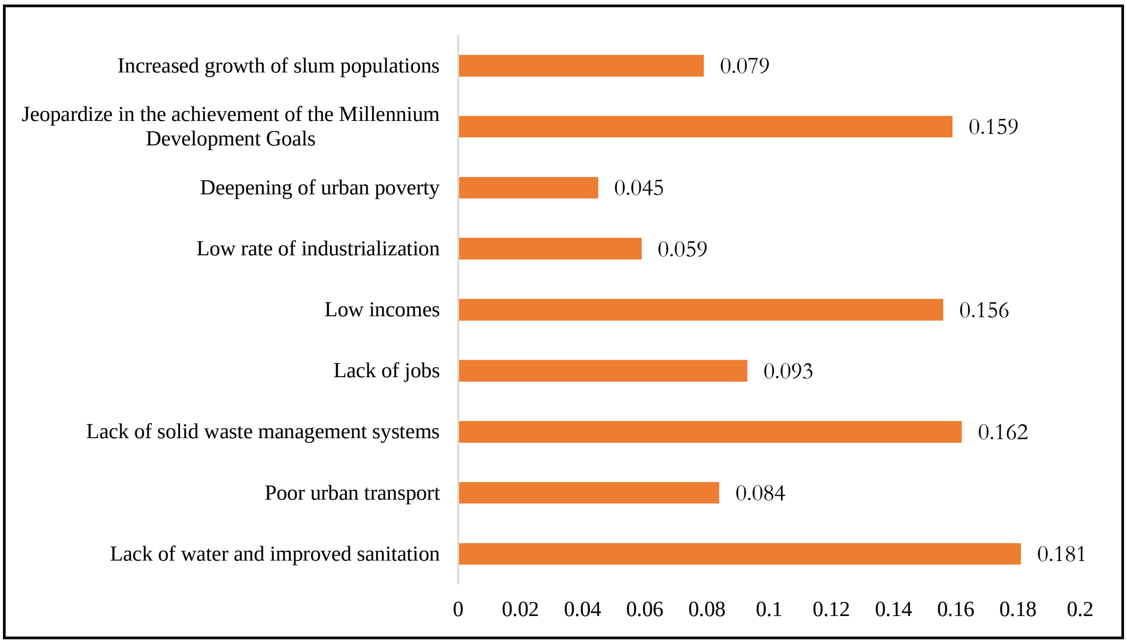

Fig. 5. Ranking of all sub-criteria under level-2.

4 | Conclusion

The primary objective of this study is to discern the challenges hindering the progression of sustainable development within urban areas. It is imperative for stakeholders invested in urban sustainability to comprehend the fundamental challenges and their repercussions. The study conducts an extensive analysis to identify these challenges and assess their significance accurately. To delineate the challenges affecting urban sustainable development, the study undertook a thorough examination of existing literature and sought the input of three experts. The IVFF-AHP methodology was applied to assign relative weights to these challenges within the context of urban sustainability. The findings of the study unveiled that the principal hindrances to urban sustainable development encompass the lack of water and improved sanitation, lack of solid waste management system, and threats to the attainment of the millennium development goals. The insights derived from this study hold the potential to guide well-informed decision-making in Kenya, facilitating the efficient allocation of resources to reinforce urban sustainability endeavors. By systematically addressing the identified challenges, Kenya can propel itself toward accomplishing its urban sustainable development objectives. Furthermore, the knowledge extracted from this study can be extrapolated to benefit other nations grappling with analogous challenges in the domain of urban sustainability

Acknowledgment

This research was not found by any grant.

Conflicts of interest

The authors declare no conflicts of interests.

References

[1] Africa, U. N. E. C. (2008). *The state of African cities 2008: a framework for addressing urban challenges in Africa*. UN-HABITAT.

[2] Korff, R., & Rothfußlig, Tat. (2009). Ambivalence of megacities: catastrophe or solution? *TATuP-zeitschrift für technikfolgenabschätzung in theorie und praxis*, *18*(1), 8–16.

[3] Castells, M. (2009). The Rise of the network society Volume 1 With a new preface. *Book the rise of the network society, volume 1, with a new preface*, *1*, 91.

[4] Dwyer, D. J. (1972). *The city as a centre of change in Asia* (Vol. 4). Hong Kong University Press.

[5] Hall, P. (2000). Creative cities and economic development. *Urban studies*, *37*(4), 639–649.

[6] Holston, J. (2001). Urban Citizenship and Globalization. *Global city-regions : trends, theory, policy: trends, theory, policy*, 325–48. https://books.google.com/books?id=mHE0b45cEEUC&pgis=1

[7] Zellner, M. L., Theis, T. L., Karunanithi, A. T., Garmestani, A. S., & Cabezas, H. (2008). A new framework for urban sustainability assessments: Linking complexity, information and policy. *Computers, environment and urban systems*, *32*(6), 474–488.

[8] Camagni, R., Capello, R., & Nijkamp, P. (1998). Towards sustainable city policy: An economy-environment technology nexus. *Ecological economics*, *24*(1), 103–118. DOI:10.1016/S0921-8009(97)00032-3

[9] Burgess, R., Carmona, M., & Kolstee, T. (1997). The challenge of sustainable cities: neoliberalism and urban strategies in developing countries. *(No title)*.

[10] Frenken, K., & Boschma, R. A. (2007). A theoretical framework for evolutionary economic geography: industrial dynamics and urban growth as a branching process. *Journal of economic geography*, *7*(5), 635–649.

[11] Mutisya, E., & Yarime, M. (2014). Moving towards urban sustainability in Kenya: a framework for integration of environmental, economic, social and governance dimensions. *Sustainability science*, *9*, 205–215.

[12] Abdullah, L., & Rahim, N. (2020). *The use of fuzzy dematel for urban sustainable development* [presentation]. Intelligent and fuzzy techniques in big data analytics and decision making: proceedings of the infus 2019 conference, istanbul, turkey, july 23-25, 2019 (pp. 722–729).

[13] Aytaç Adali, E., Öztaş, G. Z., Öztaş, T., & Tuş, A. (2022). Assessment of European cities from a smartness perspective: An integrated grey MCDM approach. *Sustainable cities and society*, *84*, 104021. DOI:10.1016/j.scs.2022.104021

[14] Ameen, R. F. M., & Mourshed, M. (2019). Urban sustainability assessment framework development: The ranking and weighting of sustainability indicators using analytic hierarchy process. *Sustainable cities and society*, *44*, 356–366. DOI:10.1016/j.scs.2018.10.020

[15] Amoushahi, S., Salmanmahiny, A., Moradi, H., Tabrizi, A. R. M., & Galán, C. (2022). Localizing sustainable urban development (SUD): Application of an FDM-AHP approach for prioritizing urban sustainability indicators in Iran provinces. *Sustainable cities and society*, *77*, 103592. DOI:10.1016/j.scs.2021.103592

[16] Awad, J., & Jung, C. (2022). Extracting the Planning Elements for Sustainable Urban Regeneration in Dubai with AHP (Analytic Hierarchy Process). *Sustainable cities and society*, *76*, 103496. DOI:10.1016/j.scs.2021.103496

[17] Foroozesh, F., Monavari, S. M., Salmanmahiny, A., Robati, M., & Rahimi, R. (2022). Assessment of sustainable urban development based on a hybrid decision-making approach: Group fuzzy BWM, AHP, and TOPSIS–GIS. *Sustainable cities and society*, *76*, 103402. DOI:10.1016/j.scs.2021.103402

[18] Toptancı, Ş., Gündoğdu, H. G., Korucuk, S., Aytekin, A., & Stević, Ž. (2023). Corporate sustainability strategy selection for a metropolitan municipality using a trapezoidal interval type-2 fuzzy SWARA–COPRAS framework. *Soft computing*, 1–35. DOI:10.1007/s00500-023-08800-x

[19] Vardopoulos, I. (2019). Critical sustainable development factors in the adaptive reuse of urban industrial buildings. A fuzzy DEMATEL approach. *Sustainable cities and society*, *50*, 101684. DOI:10.1016/j.scs.2019.101684

[20] Koroso, N. H., Zevenbergen, J. A., & Lengoiboni, M. (2020). Urban land use efficiency in Ethiopia: An assessment of urban land use sustainability in Addis Ababa. *Land use policy*, *99*, 105081. DOI:10.1016/j.landusepol.2020.105081

[21] Simwanda, M., & Murayama, Y. (2018). Spatiotemporal patterns of urban land use change in the rapidly growing city of Lusaka, Zambia: Implications for sustainable urban development. *Sustainable cities and society*, *39*, 262–274.

[22] Musakwa, W., & Van Niekerk, A. (2013). Implications of land use change for the sustainability of urban areas: A case study of Stellenbosch, South Africa. *Cities*, *32*, 143–156.

[23] Barredo, J. I., & Demicheli, L. (2003). Urban sustainability in developing countries' megacities: modelling and predicting future urban growth in Lagos. *Cities*, *20*(5), 297–310.

[24] Ferrari, K., Cerise, S., Gamberini, R., Rimini, B., & Lolli, F. (2016). An international partnership for the sustainable development of municipal solid waste management in Guinea-Bissau, West Africa. *Proceedings of the summer school francesco turco*, 113–117.

[25] Charrouf, Z., & Guillaume, D. (2009). Sustainable development in Northern Africa: The argan forest case. *Sustainability*, *1*(4), 1012–1022. DOI:10.3390/su1041012

[26] Gill, J. C., Mankelow, J., & Mills, K. (2019). The role of Earth and environmental science in addressing sustainable development priorities in Eastern Africa. *Environmental development*, *30*, 3–20.

[27] Lwasa, S., & Kinuthia-Njeng, C. (2012). Reappraising Urban Planning and Urban Sustainability in East Africa. *Urban development*, *3*. DOI:10.5772/35133

[28] Lubida, A., Veysipanah, M., Pilesjo, P., & Mansourian, A. (2019). Land-use planning for sustainable urban development in Africa: A spatial and multi-objective optimization approach. *Geodesy and cartography*, *45*(1), 1–15.

[29] Badi, I., Bouraima, M. B., & Muhammad, L. J. (2022). The role of intelligent transportation systems in solving traffic problems and reducing environmental negative impact of urban transport. *Decis mak anal*, *1*(1), 1–9.

[30] Akram, M., Bibi, R., & Deveci, M. (2023). An outranking approach with 2-tuple linguistic Fermatean fuzzy sets for multi-attribute group decision-making. *Engineering applications of artificial intelligence*, *121*, 105992. DOI:10.1016/j.engappai.2023.105992

[31] Badi, I., & Kridish, M. (2020). Landfill site selection using a novel FUCOM-CODAS model: A case study in Libya. *Scientific african*, *9*, e00537.

[32] Bouraima, M. B., Kiptum, C. K., Ndiema, K. M., Qiu, Y., & Tanackov, I. (2022). Prioritization road safety strategies towards zero road traffic injury using ordinal priority approach. *Operational research in engineering sciences: theory and applications*, *5*(2), 206–221.

[33] Deveci, M., Gokasar, I., Pamucar, D., Chen, Y., & Coffman, D. M. (2023). Sustainable E-scooter parking operation in urban areas using fuzzy Dombi based RAFSI model. *Sustainable cities and society*, *91*, 104426. DOI:10.1016/j.scs.2023.104426

[34] Ecer, F., Küçükönder, H., Kayapınar Kaya, S., & Faruk Görçün, Ö. (2023). Sustainability performance analysis of micro-mobility solutions in urban transportation with a novel IVFNN-Delphi-LOPCOW-CoCoSo framework. *Transportation research part a: policy and practice*, *172*, 103667. DOI:10.1016/j.tra.2023.103667

[35] Pamucar, D., Deveci, M., Gokasar, I., Delen, D., Köppen, M., & Pedrycz, W. (2023). Evaluation of metaverse integration alternatives of sharing economy in transportation using fuzzy Schweizer-Sklar based ordinal priority approach. *Decision support systems*, *171*, 113944. DOI:10.1016/j.dss.2023.113944

[36] Tirkolaee, E. B., & Aydin, N. S. (2022). Integrated design of sustainable supply chain and transportation network using a fuzzy bi-level decision support system for perishable products. *Expert systems with applications*, *195*, 116628. DOI:10.1016/j.eswa.2022.116628

[37] Bouraima, M. B., Qiu, Y., Kiptum, C. K., & Ndiema, K. M. (2023). Evaluation of factors affecting road maintenance in Kenyan counties using the ordinal priority approach. *Journal of computational and cognitive engineering*, *2*(3), 260–265.

[38] Celik, E., Bilisik, O. N., Erdogan, M., Gumus, A. T., & Baracli, H. (2013). An integrated novel interval type-2 fuzzy MCDM method to improve customer satisfaction in public transportation for Istanbul. *Transportation research part e: logistics and transportation review*, *58*, 28–51. DOI:10.1016/j.tre.2013.06.006

[39] Kiptum, C. K., Bouraima, M. B., Stević, Ž., Okemwa, S., Birech, S., & Qiu, Y. J. (2022). Sustainable strategies for the successful operation of the bike-sharing system using an ordinal priority approach. *Journal of engineering management and systems engineering*, *1*(2), 43–50.

[40] Qahtan, S., Alsattar, H. A., Zaidan, A. A., Deveci, M., Pamucar, D., & Delen, D. (2023). Performance assessment of sustainable transportation in the shipping industry using a q-rung orthopair fuzzy rough sets-based decision making methodology. *Expert systems with applications*, *223*, 119958. DOI:10.1016/j.eswa.2023.119958

[41] Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers and industrial engineering*, *140*, 106231. DOI:10.1016/j.cie.2019.106231

[42] Bouraima, M. B., Tengecha, N. A., Stević, Ž., Simić, V., & Qiu, Y. (2023). An integrated fuzzy MCDM model for prioritizing strategies for successful implementation and operation of the bus rapid transit system. *Annals of operations research*, 1–32.

[43] Deveci, M., Gokasar, I., Mishra, A. R., Rani, P., & Ye, Z. (2023). Evaluation of climate change-resilient transportation alternatives using fuzzy Hamacher aggregation operators based group decision-making model. *Engineering applications of artificial intelligence*, *119*, 105824.

[44] Kovač, M., Tadić, S., Krstić, M., & Bouraima, M. B. (2021). Novel spherical fuzzy MARCOS method for assessment of drone-based city logistics concepts. *Complexity*, *2021*, 1–17.

[45] Stević, Ž., Bouraima, M. B., Subotić, M., Qiu, Y., Buah, P. A., Ndiema, K. M., & Ndjegwes, C. M. (2022). Assessment of causes of delays in the road construction projects in the Benin Republic using fuzzy PIPRECIA method. *Mathematical problems in engineering*, *2022*, 1–18.

[46] Qiu, Y., Bouraima, M. B., Kiptum, C. K., Ayyildiz, E., Stević, Ž., Badi, I., & Ndiema, K. M. (2023). Strategies for Enhancing Industry 4.0 Adoption in East Africa: An Integrated Spherical Fuzzy SWARA-WASPAS Approach. *Journal of industrial intelligence*, *1*(2), 87–100. DOI:10.56578/jii010202

[47] Ala, A., Simic, V., Pamucar, D., & Tirkolaee, E. B. (2022). Appointment Scheduling Problem under Fairness Policy in Healthcare Services: Fuzzy Ant Lion Optimizer. *Expert systems with applications*, *207*, 117949. DOI:10.1016/j.eswa.2022.117949

[48] Badi, I., Bouraima, M. B., & Jibril, M. L. (2022). Risk assessment in construction projects using the grey theory. *Journal of engineering management and systems engineering*, *1*(2), 58–66.

[49] Bouraima, M. B., Qiu, Y., Ayyildiz, E., & Yildiz, A. (2023). Prioritization of strategies for a sustainable regional transportation infrastructure by hybrid spherical fuzzy group decision-making approach. *Neural computing and applications*, 1–20.

[50] Bouraima, M. B., Qiu, Y., Stević, Ž., Marinković, D., & Deveci, M. (2023). Integrated intelligent decision support model for ranking regional transport infrastructure programmes based on performance assessment. *Expert systems with applications*, *222*, 119852. DOI:10.1016/j.eswa.2023.119852

[51] Bouraima, M. B., Qiu, Y., Stević, Ž., & Simić, V. (2023). Assessment of alternative railway systems for sustainable transportation using an integrated IRN SWARA and IRN CoCoSo model. *Socio-economic planning sciences*, *86*, 101475. DOI:10.1016/j.seps.2022.101475

[52] Bouraima, M. B., Stević, Ž., Tanackov, I., & Qiu, Y. (2021). Assessing the performance of Sub-Saharan African (SSA) railways based on an integrated Entropy-MARCOS approach. *Operational research in engineering sciences: theory and applications*, *4*(2), 13–35.

[53] Badi, I., Pamucar, D., Gigović, L., & Tatomirović, S. (2021). Optimal site selection for sitting a solar park using a novel GIS-SWA’TEL model: A case study in Libya. *International journal of green energy*, *18*(4), 336–350.

[54] Badi, I., Stević, Ž., & Bouraima, M. B. (2023). Evaluating free zone industrial plant proposals using a combined full consistency method-grey-cocoso model. *J Ind Intell* *1*(2), 101–109.

[55] Bouraima, M. B., Qiu, Y., Yusupov, B., & Ndjegwes, C. M. (2020). A study on the development strategy of the railway transportation system in the West African Economic and Monetary Union (WAEMU) based on the SWOT/AHP technique. *Scientific african*, *8*, e00388. DOI:10.1016/j.sciaf.2020.e00388

[56] Deveci, M., Gokasar, I., Pamucar, D., Zaidan, A. A., Wen, X., & Gupta, B. B. (2023). Evaluation of Cooperative Intelligent Transportation System scenarios for resilience in transportation using type-2 neutrosophic fuzzy VIKOR. *Transportation research part a: policy and practice*, *172*, 103666.

[57] Görçün, Ö. F., Pamucar, D., Krishankumar, R., & Küçükönder, H. (2023). The selection of appropriate Ro-Ro Vessel in the second-hand market using the WASPAS’ Bonferroni approach in type 2 neutrosophic fuzzy environment. *Engineering applications of artificial intelligence*, *117*, 105531. DOI:10.1016/j.engappai.2022.105531

[58] Moslem, S., Stević, Ž., Tanackov, I., & Pilla, F. (2023). Sustainable development solutions of public transportation:An integrated IMF SWARA and Fuzzy Bonferroni operator. *Sustainable cities and society*, *93*, 104530. DOI:10.1016/j.scs.2023.104530

[59] Pamučar, D., Puška, A., Simić, V., Stojanović, I., & Deveci, M. (2023). Selection of healthcare waste management treatment using fuzzy rough numbers and Aczel–Alsina Function. *Engineering applications of artificial intelligence*, *121*, 106025. DOI:10.1016/j.engappai.2023.106025

[60] Badi, I., & Bouraima, M. B. (2023). Development of MCDM-based Frameworks for Proactively Managing the Most Critical Risk Factors for Transport Accidents: A Case Study in Libya. *Spectrum of engineering and management sciences*, *1*(1), 38–47.

[61] Bouraima, M. B., Gore, A., Ayyildiz, E., Yalcin, S., Badi, I., Kiptum, C. K., & Qiu, Y. (2023). Assessing of causes of accidents based on a novel integrated interval-valued Fermatean fuzzy methodology: towards a sustainable construction site. *Neural computing and applications*, 1–26.

[62] Pichdara, L., Monin, N., Marong, C., Sivmuy, D., & Saren, K. (2022). Challenges of Targeting Poor and Vulnerable Groups to Reduce Climate Change Vulnerability: The Case of a Water and Sanitation Project in Kampong Svay District, Cambodia. *Financial crises, poverty and environmental sustainability: challenges in the context of the sdgs and covid-19 recovery*, 155–169. DOI:10.1007/978-3-030-87417-9_11

[63] Hemidat, S., Achouri, O., Fels, L. El, Elagroudy, S., Hafidi, M., Chaouki, B., … Guo, J. (2022). Solid Waste Management in the Context of a Circular Economy in the MENA Region. *Sustainability (switzerland)*, *14*(1), 480. DOI:10.3390/su14010480

[64] Holzer, H. J. (2017). The role of skills and jobs in transforming communities. *Cityscape*, *19*(1), 171–190.

[65] Samouel, B., & Aram, B. (2016). The determinants of industrialization: Empirical evidence for Africa. *European scientific journal*, *12*(10), 219–239.

[66] Odhiambo, W., & Manda, D. K. (2003). Urban poverty and labour force participation in Kenya. *Nairobi, kenya: kenya institute for public policy research and analysis (kippra)*, *12*, 89–103.

[67] Rahman, M. M. (2021). Achieving Sustainable Development Goals of Agenda 2030 in Bangladesh: the crossroad of the governance and performance. *Public administration and policy*, *24*(2), 195–211. DOI:10.1108/PAP-12-2020-0056

[68] Saghir, J., & Santoro, J. (2018). *Urbanization in sub-saharan africa* [presentation]. Meeting challenges by bridging stakeholders. washington, dc, usa: center for strategic \& international studies.

[69] Alkan, N., & Kahraman, C. (2023). Prioritization of Supply Chain Digital Transformation Strategies Using Multi-Expert Fermatean Fuzzy Analytic Hierarchy Process. *Informatica (slovenia)*, *34*(1), 1–33. DOI:10.15388/22-INFOR493

[70] S, J. (2021). Ordering of interval-valued Fermatean fuzzy sets and its applications. *Expert systems with applications*, *185*, 115613. DOI:10.1016/j.eswa.2021.115613

[71] Senapati, T., & Yager, R. R. (2020). Fermatean fuzzy sets. *Journal of ambient intelligence and humanized computing*, *11*(2), 663–674. DOI:10.1007/s12652-019-01377-0