Received 27 April 2018
Revised 9 December 2018
Accepted 6 March 2019

Influencing sustainability by controlling future brownfields in Africa: a case study of Ethiopia

Mikiale Gebreslase Gebremariam, Yuming Zhu and Naveed Ahmad
Department of Management,
Northwestern Polytechnical University, Xi'an, China, and
Dawit Nega Bekele
Global Center for Environmental Remediation,
University of Newcastle, Callaghan, Australia

Abstract

Purpose – The increasing African population and economic growth leading to urbanisation continues to increase the need to redevelop brownfields as a strategy of encouraging sustainable development of cities, in particular in Ethiopia. However, the adoption of brownfield redevelopment in Ethiopia is at initial stage. Thus, the purpose of this paper is to highlight the framework based on grey-incidence decision-making approach to manage brownfields in African countries by taking Ethiopia as case example. The grey-incidence decision-making model integrates multiple factors such as economic, social, environmental, technical and associated risks and provides an effective decision-making and management tool for environmental practitioners and government agencies.

Design/methodology/approach – Questionnaires were used to collect data on terms and definitions of brownfield. The questions were prepared on the basis of currently used definitions developed by a number of developed countries. Moreover, this study utilises a grey-incidence decision-making approach to help in management and decision-making for the implementation of brownfield redevelopment projects (BRPs) in the remediated sites.

Findings – Standard definition of brownfield and essential guidelines for brownfield redevelopment is proposed for Ethiopian context. The research findings were tested and verified using literature data and survey from major stakeholders. In addition, the grey-incidence decision-making approach is applied for the evaluation of BRPs in the remediated sites. A framework is proposed to control future brownfields for African countries by taking Ethiopia as a case example.

Originality/value – This research stresses the significance of an urban structure to address sustainable development, and the need to consider redevelopment of brownfields and identify the potential for a specific government policy framework. This research provides the best opportunity for Ethiopia by devising an urban land policy and create a strategy to contribute social, economic, financial and environmental benefits. It also provides a foundation to solve environmental issues by involving all major stakeholders, including community citizens, environmentalists and government agencies, and it also serves as guidelines to transform brownfields into Greenfields; and finally, it contributes to achieve the 2030 UN global goals.

Keywords Environment, Guidelines, Contamination, Brownfield, Grey-incidence decisions-making, Sustainable development goals (SDG's)

Paper type Case study

Introduction

Albert Einstein said that "intellectuals solve problems; geniuses prevent them" (Ushakov, 2007). Unlike in the industrialised world, the concept of brownfield is not widely recognised on the African continent as a whole and particularly in Ethiopia. However, the increasing population growth and economic development in Ethiopia, and the significant role of brownfield redevelopment will be investigated as a strategy of encouraging sustainable

The authors would like to dedicate this contemporary work to the Blessed Mother Mary and to Archangel St Michael. Last but not least, this project was supported by the Provincial Natural Science Foundation in Shaanxi, China through the Project "Research on Risk Allocation and Income Distribution Mechanism of Public Private Partnership for Brownfield Regeneration Project" (2017JM7002).

World Journal of Science, Technology and Sustainable Development
Vol. 16 No. 3, 2019
pp. 102-120

2042-5945
DOI 10.1108/WJSTSD-04-2018-0031

development in Ethiopian cities. From the developing countries point of view, brownfield sites are the result of waste materials from air pollution control facilities, wastewater treatment plants, community activities, agricultural operations, mining, commercial, industrial and other interrelated problems, such as urban sprawl and residential segregation (Van Rooyen, 2001). These environmental issues are creating hurdles to achieve environmental excellence in Ethiopia. Brownfield redevelopment projects (BRPs) are the practical solution to achieve environmental excellence and sustainable cities in Ethiopia (Figure 1).

Brownfield problems are capturing a deepening concentration of government policy makers, real estate developers, investors, and researchers. There are a suspected 500,000–600,000 contaminated brownfield sites in the USA (Simons, 1998), with around 362,000 in Germany (National Round Table on the Environment the Economy, 2003). There is still an ambiguity about the common understanding of brownfield and its basic concept. However, an initial effort has been made by the US Environmental Protection Agency (USEPA) who defined brownfields as underutilised land where redevelopment or expansion is not an easy task due to real or perceived environmental contamination (Van Vliet, 2003).

There is a different perspective about the definition of brownfield in the UK planning context. In the UK, a brownfield site can be any kind of property that has been previously developed for non-rural purposes (Alker *et al.*, 2000).

It is clear from the above definitions that brownfield land is that having real or perceived contamination problems, affected by previous use, ruined and underused properties in urban areas that require redevelopment for sustainable development. Worldwide, brownfield redevelopment land strategy is taken as sustainable land use strategy due to the focus on the environmental and health protection; they have a major role in the contribution towards economic development and community revitalisation (Brebbia, 2006; De Sousa, 2003, 2005; Dixon, 2007).

In order to achieve the sustainable development goals, the Ethiopian government is collaborating with different international private and governmental agencies in order to create a green economy and save the country from the negative effects of environment and conventional development. Considering all the points, such as a greater growth in population, urban growth, development through green economy, the Ethiopian Government is trying to encourage the city municipalities to adopt brownfield redevelopment as a strategy for sustainable development.

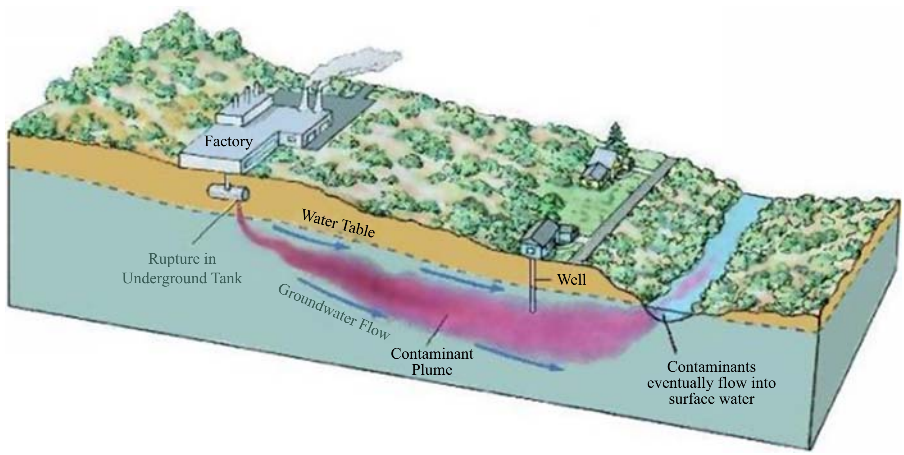


Figure 1.
Sources of brownfield sites

The countless benefits of brownfield redevelopment for sustainable development make brownfields significant in the eyes of developing countries. The major benefits of brownfield redevelopment includes social, environmental, economics, improved quality of life around the community, minimisation of health threats by removing the hazardous waste materials, transformation of brownfields into green fields in congested urban areas, housing facilities, employment opportunities in the surroundings and neighbourhood, payment of taxes and duties to government (De Sousa, 2006; Greenberg *et al.*, 2001). Currently, BRPs are capturing more attention from policy makers due to the intense focus on environmental issues. They are also are gaining deepening interest of different government agencies, financial institutions, environmental scientists, scientific research scholars, environment legal advisors and community citizens for the betterment of society (Eckerd and Heidelberg, 2015).

Different approaches from the social sciences and management fields have been used to deal with the environmental problems. An approach named a rough set approach was employed by Chen *et al.* (2009) to solve problems related to brownfield redevelopment in urban areas. Another approach was used by Guo *et al.* (2010) to evaluate BRPs with multi-hierarchical grey evaluation modelling.

For the evaluation of compound and financial benefits provided by BRPs, BenDor *et al.* (2011) utilised the system dynamic model. Chrysochoou *et al.* (2012) developed an index for evaluating the different alternatives for brownfield sites, and focussed on the strategic view of brownfield sites for the allocation of resources.

In a case study, the results of Schädler *et al.* (2013) show that spatially explicit algorithm assessment of different indicators of sustainable development can successfully improve its application, comprehensiveness and reliability. Grey cluster methods can also be an effective way of dealing with the environmental issues related to renewable energy resources and climate change (Wang *et al.*, 2014). Zhu *et al.* (2015) developed a framework for optimising and establishing an evaluation index for BRPs. Structural equation modelling was used in order to verify the effectiveness of the index with the help of a real world example. Furthermore, the further application of this index was recommended for the evaluation of brownfield projects, and constructs a guideline for other researchers in the area of brownfield redevelopment. Although all these approaches were mainly utilised by developed countries, there is less attention in developing countries. Specifically, BRPs are at the development stage in Africa, and there is no focus by Ethiopian Government specifically.

Methodology

Plentiful international literature was reviewed to create a foundation for defining brownfield in the Ethiopian context. However, there is no consensus-based universal definition of brownfield, and every country has its own definition and parameters of brownfield. For example, the US definition focusses on the presence of contaminants, while the UK definition focusses on sites previously developed in urban areas. Due to the unfamiliarity of the term brownfield in the Ethiopian context, this research is dependent on international literature to devise primary guidelines. Moreover, it was also difficult to take the appropriate population and sample due to a lack of awareness about the brownfield problem. Therefore, multiple non-probability sampling techniques were used to solve the population and sampling issues.

Three sampling techniques, including judgement, convenient and snowball, were utilised to simplify the data collection by following the guidelines of Nachmias and Nachmias (2008), as their research proves the significance of using multiple sampling techniques in research.

The judgement sampling technique is useful to propose a sample based on researcher experience; the convenient sampling technique also increases the flexibility in data collection due to the involvement of multiple stakeholders. Data were collected from government employees working in environmental agencies and municipalities, private investors, community citizens, real estate agents and academicians.

A pilot test was conducted before the data collection; this was done by asking some basic questions related to brownfields and the transformation of brownfields into greenfields for environmental excellence. If the average score obtained by a respondent was up to mark, that respondent was considered an appropriate participant in the research.

A survey-based questionnaire consisting of two parts was developed to gather information. The first part was about different elements of brownfields that can be a part of the pioneer definition of brownfield in the Ethiopian context. Definitions developed by different countries were considered as a base, and different elements of brownfield (e.g. vacant, derelict, contaminated, underused, etc.) were included in the final questionnaire. A sample question related to the definition of brownfield redevelopment, for example, is brownfield a location or land vacant for development. The second part included questions related to the evaluation of brownfields. This study received support from the research of Hou *et al.* (2014), including social economic and ecological benefits of brownfield redevelopment, and Zhu *et al.* (2015), including health benefits, brownfield development policy, financial, public welfare policy. Although the reliability and validity of both questionnaires are appropriate, the analysis technique is different. As far as their studies are concerned, the Likert scale was utilised under the rigorous analysis technique of structural equation modelling. However, this study utilised the grey incidence approach to evaluate BRPs.

Data were collected during the period July–December 2015. It took three months to collect data with the help of ten key members helping with the data collection. Masters' level students from three key universities of Ethiopia, Addis Ababa University, Mekelle University and Hawassa University, were hired for the collection of data. A nominal remuneration was given to them for keeping the ethical consideration of the research. Questionnaires were sent out to relevant stakeholders as mentioned above. From the 300 questionnaires that were sent out, only 221 completed questionnaires were received back; 79 respondents declined to complete the questionnaire as they were not aware of the term "brownfields" and were not in a position to complete the questionnaire.

This led to the conclusion that the above survey assisted us to extract the elements of brownfield definitions based on judgements of different stakeholders as follows (Figure 2).

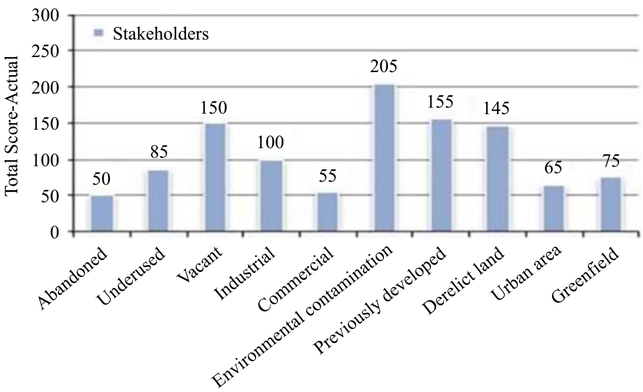


Figure 2.
Elements of brownfield definitions

Brownfield definition: an overview

Generally, brownfield refers to underused, abandoned, derelict and often contaminated lands and premises, which can vary in terms of size and location. The first official definition of brownfields was proposed by the USEPA as follows:

> Abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination (USEPA, 2002).

Similarly, in Europe, Ferber *et al.* (2006) defined brownfields as:

> Currently derelict or underused sites which have been affected by former uses of the site or surrounding land; they are mainly located in fully or partly developed urban areas and may have real or perceived contamination problems thus require intervention to bring them back to beneficial use (Ferber *et al.*, 2006).

However, this concept of brownfield does not work in the UK. According to the views of UK brownfield professionals, it is not necessary to have hazardous contaminants on the site. Michael Gwilliam, Director of the Civic Trust, has stated that in the UK:

> Brownfield sites are buildings and land either now vacant or that could become vacant or suitable for development, during a relevant [development] plan period (Gwilliam, 1997).

In France, it is taken as different concept. Darmendrail (1999) reports that the French Ministry of Environment interprets brownfield as:

> A space that has been temporarily abandoned following the cessation of activity (agricultural, protoindustrial, service, processing, military defense, storage or transport) and that needs to be reclaimed for a future use (Darmendrail, 1999).

Karin Freier of the German Environment Agency (Freier, 1998) defined brownfield land as:

> Abandoned pieces of land, mainly in inner cities, which are often blocked for economic development due to their ecological and economic risks (Freier, 1998).

An Australian expert website (Plater-Zyberk, 1998) suggests that:

> A brownfield site is one which has been urbanised or used industrially, subsequently vacated and available for re-urbanisation (Plater-Zyberk, 1998).

This definition implies that the site is urban and vacant, but it does not consider the condition of any buildings that might be on the site, nor does it incorporate any mention of land contamination.

Potts and Cloete (2012) devise a definition for South Africa described as:

> A brownfield site is infill land or premises where remedial action is required prior to redevelopment. It may also be vacant, derelict or contaminated. No specific land use is attributed (Potts and Cloete, 2012).

A comprehensive literature review on the definitions of brownfields is used to propose the definition for the Ethiopian context, as well as draft the direction for preparation of the guidelines.

Results

Proposed definition of brownfields for the Ethiopian context

Potts and Cloete's (2012) definition in the South African context was the base to get a basic concept of brownfields in Africa. When considering the extensive international literature review and the research that was undertaken, one can conclude that it is essential to set out a common definition of the term brownfields. In proposing a definition, it is important that the Ethiopian context is taken into consideration in order to ensure that the proposed definition is broad enough to cover all relevant aspects. Special consideration has also been given to the questions that the respondents were asked in relation to the understanding and development of its definition in the Ethiopian context. It is obvious that there already exist various accepted categories of land use, for instance, vacant, derelict and statutory contaminated land, which impinge on the definition of brownfield, and that this has the potential to cause confusion.

Taking into account the factors related to brownfield in the Ethiopian context, and the internationally accepted definitions of brownfields, the following definition for Ethiopian usage is proposed:

> A brownfield site is land located in urban areas where remedial action is required for development or redevelopment. It could be vacant, derelict or contaminated; regardless of the quality of the land use.

Proposed guidelines for brownfield redevelopment in Ethiopia

Brownfield redevelopment is at the rising stage in the Ethiopian. Thus, it is important to depend merely on the international literature. The following guidelines are proposed:

(1) In order to achieve sustainability by controlling future brownfields in Africa as a whole and particularly in Ethiopia, it is necessary to propose a common definition for the so called "brownfield". The proposed brownfield definition based on the Ethiopian context should be accepted and assimilated into Ethiopian National Environmental Policy for standard use.

(2) The Environmental Policy of Ethiopia should devise an update policy and legislation on brownfield redevelopment. Adaption of definition, developing brownfield database and redeveloping city centres should be given strategic priority to foster urban sustainable.

(3) The government of the federal democratic republic of Ethiopia should place a high premium on environmental excellence by controlling future brownfields. To achieve this, risk assessments should be carried out for brownfield redevelopment; identifying the possible risks that might be associated with brownfield sites could assist in setting out a strategy about how to control future brownfield problems. Risks associated with brownfield sits could be:
   - environmental risks;
   - public welfare risks; and
   - health risks, and so forth.

(4) Certainly, BRP contribute a lot to sustainable development goals. In order to setup excellent brownfield redevelopment planning, it is critical to include the following elements in the brownfield redevelopment planning database:
   - Identifying the site circumstances. For example, site size, location and boundaries.
   - Identifying the circumstance of land from different angles. For instance, previous land use, proposed future redevelopment planning options and its ownership.
   - Identifying types of contaminations. For example, groundwater contamination, soil contamination, air contamination.
   - Evaluating the potential cost of remediation and its geotechnical circumstances.

(5) Stakeholder identification is also crucial in brownfield redevelopment process, a list of potential stakeholders should be developed with the collaboration of local authorities and stakeholders.

(6) A financial mechanism including financing and incentives for private investors is necessary. Public private partnership should be encouraged. Therefore, developing an appropriate financial mechanism can be a key factor for successful brownfield redevelopment in Ethiopia and Africa at large.

(7) In the present circumstances, governments are facing financial deficits, and identifying potential stakeholders and supporting public, private and partnership for brownfield restoration projects are the icing on the cake. Above and beyond that, allowing public participation and preparing conferences will add value in the achievement of environmental excellence by controlling brownfields in Ethiopia. Their advantages are infinitely greater than grateful. Such as:

- satisfy community health concerns;
- making sites with poor ground conditions economically viable;
- minimise overall environmental damage;
- restore the land as a contributing element of the local ecosystem; and
- prevent future contamination.

Management framework for brownfields in Ethiopia

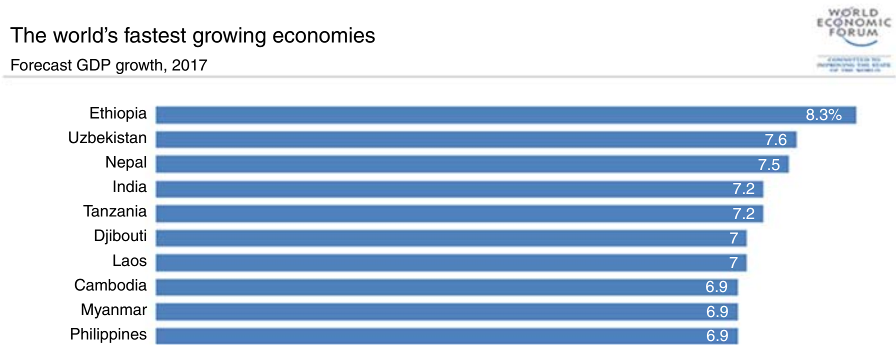
Progress and need to control brownfield issues

Ethiopia is growing significantly in Africa; the urban growth rate in Ethiopia is 4 per cent. Although this is not the highest growth rate in the continent, it is greater than the least developing nations in the African continent. It is also greater than the average of this whole continent, which is 3.2 per cent. All these indicators show the great future of this African nation on the world platform.

The growth of Ethiopia is indicated by the report of the International Monetary Fund, who ranked Ethiopia in the list of the top five fastest growing economies in the world. The growth can be seen over the last decade, and it is continuously growing by 8.3 per cent (Gray, 2017) (Figure 3).

Every sector in the country is part of the country's growth. Ethiopia is also showing responsibility for the betterment of society and climate change.

It has a very important role to fight for the different environmental changes for a sustainable world. The major aim of Ethiopia at this moment is to gain the status of a middle-income country by adopting green economic strategies; this is also necessary for



Source: World Bank

Figure 3. Ethiopian progress and its future brownfield challenges

Ethiopia to progress. Following the conventional methods of development, this progress impacted adversely and caused a sharp rise in GHG emissions (Federal Democratic Republic of Ethiopia, 2011). It also created a hazardous environment by utilising natural resources in an unsustainable way.

Therefore, as Ethiopia's economy and population growth continues to increase, the possible role of brownfield redevelopment will be investigated as a strategy for encouraging sustainable development in Ethiopia. Proposing a research framework to control future brownfields could help to achieve the sustainable development goals in Ethiopia.

Proposed research framework to control future brownfields

In the twenty-first century most African countries have adopted an industry-led economy to support an ever increasing population growth and urbanisation; this involves using a large volume and types of hazardous chemicals. Accidental spills and damping of these chemicals leads to environmental contamination and, subsequently, to brownfields. Thus, the research framework has been prepared for African governments in a precise and simple way so they can understand the core source of brownfield sites and their health, environmental and public welfare risks. It also outlines an opportunity for African countries to encourage and facilitate forming of legislation for brownfield redevelopment. A project that is evaluated using a research framework, as shown in Figure 4, illustrates the stages for controlling future brownfields in African countries by taking Ethiopia as an example. These stages are described hereinafter:

Stage 1: summarises the core sources of brownfield sites. In this phase, it is mentioned that the possible source of brownfield sites is abandoned factories, industrial workshops and solid wastes due to improper land administration. According to the international context, solid waste means any garbage, refuse, sludge from a wastewater treatment plant,

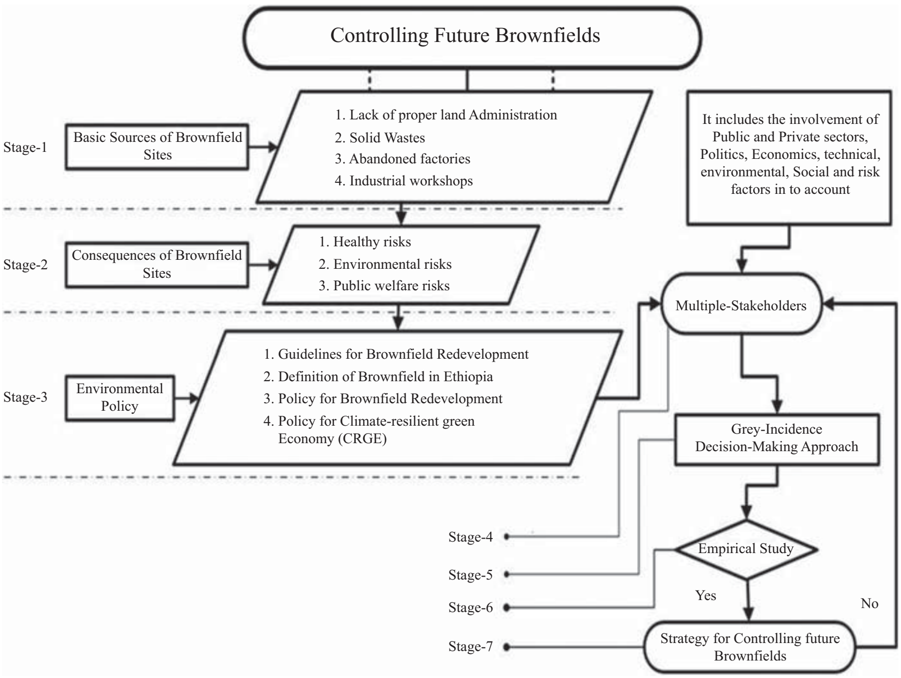


Figure 4.
Research framework for controlling future brownfields

water supply treatment plant, or air pollution control facility, and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations and from community activities (Department of Environmental Conservation, 2017). From this work, African countries can learn and be aware of the possible sources of brownfields sites.

Stage 2: summarises and analyses the risks and consequences of brownfield sites. Through this work, African countries can learn and be aware of the possible risks and consequences of brownfield sites.

Stage 3: establishes policy for brownfield redevelopment and includes a standard definition for brownfield within the context of Ethiopia and a relevant policy and guidelines for brownfield redevelopment in Ethiopian National Environmental Policy. Most African countries temperature or a change in rainfall patterns, climate change also presents the necessity and opportunity of switching to a new sustainable development model adopt an industry-led economy to support an ever increasing population growth and urbanisation which will involve using large volumes and types of hazardous chemicals. As a result, the rise of catastrophic climate change is very real. Thus, Ethiopia is experiencing the effects of climate change. In addition to the direct effects, such as an increase in average.

The Government of the Federal Democratic Republic of Ethiopia has therefore initiated the Climate-Resilient Green Economy (CRGE) initiative to protect the country from the adverse effects of climate change, and to build a green economy that will help realise its ambition of reaching middle-income status before 2025 (Federal Democratic Republic of Ethiopia, 2011). Therefore, establishing a policy for brownfield development will accelerate Ethiopia's vision to achieve middle-income status by 2025 in a CRGE.

Stage 4: indicates the multiple stakeholder's involvement in the evaluation system. The evaluation system will include criteria from the public and private sectors, political, legislative, economic, technical, environmental, and societal and risk factors, and take the different characteristics of stakeholders into consideration within the context of a project's full life span. While establishing an evaluation criteria system, one has to take every factor into consideration, and must be aware that the factors will change together with the different phases of the full life span of the projects (Zhu and Hipel, 2007).

Stage 5: establishes a grey incidence decision-making model for brownfield redevelopment. An illustrative example is prepared in the next section to show how the proposed grey incidence decision-making model works. The decision-making process starts from an overview of the situation, from which three alternatives: industrial park planning; commercial centre planning; and real estate planning, are identified for further evaluation. Above and beyond that, the grey incidence decision-making approach is selected because it is a convenient approach to utilise regardless of the sample size. In addition, the amount of computation assimilated is small and can be succeeded classically, without the difficulty between quantitative and qualitative conclusions (Gebreslase and Zhu, 2016). The process of a grey incidence decision-making model will be explained in detail below in the next section.

Stage 6: verifies the established grey-incidence decision-making model through empirical studies.

Stage 7: recommends strategic options for controlling future brownfields in Ethiopia, lesson to Africa based on the obtained analytical results.

Basic concepts of grey incidence decision-making approach

The grey system theory and application is well studied and applied around the globe in different disciplines. Over the past 30 years, it has been a well-known theory in the area of artificial intelligence; as a result it has attracted a wide range of researchers from the four corners of the world. The grey relation analysis approach is employed by Delcea *et al.* (2012), in shaping the relationship between a firm's situation, its symptoms, the bankruptcy syndrome and the causes that led to a certain situation.

A new structure grey forecasting model, NSGM (1, 1), is proposed by Zeng and Luo (2017) to forecast the trend of China's total energy consumption.

Grey incidence analysis is used by Zhanand Liu (2015) to optimise agricultural industrial structure and distribute the ratio of various inputs in agriculture, farming, forestry, animal husbandry and fishery, so as to improve the GPA of Huangshan City.

Above all, grey system theory mainly deals with uncertain systems, mini samples and poor information. Thus, its application assimilates industry, environment, ecology, agriculture, economy, biological protection, medicine and management. In addition, remarkable projects have been completed successfully with grey system theory, including, regional economic planning for several provinces in China, analysing the agricultural economy in China, forecasting yields of grain for some provinces in China, and building a diagnosis model available for medicine, to estimate the economic effect (Liu *et al.*, 2012).

This led to the conclusion that the grey-incidence decision-making approach is selected because it is a convenient approach to utilise regardless of the sample size. In addition, the amount of computation assimilated is small and can be succeeded classically without the difficulty between quantitative and qualitative conclusions (Gebreslase and Zhu, 2016).

Let $X = \{X_{ij} = (a_i, b_j) | a_i \in A, b_j \in B\}$ be a set of situations, and $H_{i_0j_0} = \{H^{(1)}_{i_0j_0}, H^{(2)}_{i_0j_0}, \cdots, H^{(x)}_{i_0j_0}\}$ is the optimum effect vector. If the situations corresponding to, $H_{i_0j_0}$ fulfils $H_{i_0j_0} \notin x$, then $H_{i_0j_0}$ is called the imagined optimum effect vector, and $X_{i_0j_0}$ is called imagined optimum situations (Liu and Forrest, 2010):

Definition 1. Let M_i and M_j be two sequences having the same length (Zhang *et al.*, 2012) represented as:

$$x_i = \int_1^n M_i^0 dt \quad x_j = \int_1^n M_j^0 dt \quad x_i - x_j \int_1^n \left(M_i^0 - M_j^0\right) dt.$$

Then: $\varepsilon_{ij} = \left(1 + |x_i| + |x_j| / 1 + |x_i| + |x_j| + |x_i - x_j|\right)$ is absolute degree of grey-incidence between M_i^0 and M_j^0:

P1. Let X be a set of situations and the effect vector of situation X_{ij} is:

$$Z_{ij} = \left\{Z_{ij}^{(1)}, Z_{ij}^{(2)}, \ldots, Z_{ij}^{(k)}\right\}, \text{for } i = 1, 2, \ldots, m.$$

(1) When K is a purpose such that the larger its effect vector is the best, let:

$$Z_{i_0j_0}^{(k)} = \max_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(k)}\right\};$$

(2) When K is a purpose such that the closer to a fixed moderate value Z_0 its effect value is the best, let $Z_{i_0j_0}^{(k)} = Z_0$ and;

(3) When K is a purpose such that the mini its effect value is the best, let:

$$Z_{i_0j_0}^{(k)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(k)}\right\}.$$

Then $Z_{i_0j_0} = \{Z^{(1)}_{i_0j_0}, Z^{(2)}_{i_0j_0}, \ldots, Z^{(K)}_{i_0j_0}\}$ is the imagined optimum effect vector:

P2. Let $Z_{i_0j_0} = \{Z^{(1)}_{i_0j_0}, Z^{(2)}_{i_0j_0}, \ldots, Z^{(k)}_{i_0j_0}\}$ be the imagined optimum effect vector, ε_{ij} the absolute degree of grey incidence between Z_{ij} and $Z_{i_0j_0}$, for $i = 1, 2, \ldots, n, j = 1, 2, \ldots, m$. If for any $i \in \{1, 2, \ldots, m\}$ satisfying $i \neq i$, and $j \neq j$, $\varepsilon_{i_1j_1} \geqslant \varepsilon_{ij}$ always holds true, then $Z_{i_1j_1}$ is a quasi-optimum effect vector and $X_{i_1j_1}$ a quasi-optimum situation.

Grey-incidence decision-making steps:

Step 1: assign the set of events and set of countermeasures, respectively, as: $A = \{a_1, a_2, \ldots, a_n\}$, $B = \{b_1, b_2, \ldots, b_m\}$. Following this, build the set of situations as: $X = \{X_{ij} = (a_i, b_j)|a_i \in A, b_j \in B\}$.

Step 2: select Purposes as 1, 2, …, x, for decision making.

Step 3: calculate the effect values $H_{ij}^{(k)}$, for each Situations X_{ij}, for $i = 1, 2, \ldots, n$, and $j = 1, 2, \ldots, m$. with respect to Purpose k:

$$H_{ij} = \left(H_{11}^{(k)}, H_{12}^{(k)}, \ldots H_{1m}^{(k)}; H_{21}^{(k)}, H_{22}^{(k)}, \ldots H_{2m}^{(k)}; \ldots; H_{n1}^{(k)}, H_{n2}^{(k)}, \ldots H_{nm}^{(k)}\right); k = 1, 2, \ldots, x.$$

Step 4: calculate the average image of the situation effect sequence $H^{(k)}$, with respect to purpose k which is:

$$H_{ij} = \left(H_{11}^{(k)}, H_{12}^{(k)}, \ldots H_{1m}^{(k)}; H_{21}^{(k)}, H_{22}^{(k)}, \ldots H_{2m}^{(k)}; \ldots; H_{n1}^{(k)}, H_{n2}^{(k)}, \ldots H_{nm}^{(k)}\right); k = 1, 2, \ldots x.$$

Step 5: according to the output of step 4, the effect vector is expressed as: $H_{ij} = \{H_{ij}^{(1)}, H_{ij}^{(2)}, \ldots, H_{ij}^{(x)}\}$, of the situation X_{ij}, for $i = 1, 2, \ldots, n, j = 1, 2, \ldots, m$.

Step 6: calculate the imagined Optimum effect vector as: $H_{i_0 j_0} = \{H_{i_0 j_0}^{(1)}, H_{i_0 j_0}^{(2)}, \ldots, H_{i_0 j_0}^{(x)}\}$.

Step 7: calculate the absolute degree incidence ε_{ij}, between H_{ij} and $H_{i_0 j_0}$, for, $i = 1, 2, \ldots, n, j = 1, 2, \ldots, m$.

Step 8: finally, from $\max_{1 \leq i \leq n, 1 \leq j \leq m}\{\varepsilon_{ij}\} = \varepsilon_{i_1 j_1}$,the quasi-Optimum effect vector $H_{i_1 j_1}$ and the quasi-optimum Situation $X_{i_1 j_1}$ are obtained.

Application of grey incidence decision-making to control brownfields in Ethiopia

Numerical example

A hypothetical scenario was developed in order to apply a grey-incidence decision-making approach to control the brownfield issue in Ethiopia. The scenario assumes that the government intends to clean up a brownfield site, and after the remediation of the contaminated site the government has to select the best development proposal from three planning options. Such as: (b1) industrial park planning, (b2) commercial centre planning and (b3) real estate planning.

The decision-making process starts from an overview of the situation, from which three alternatives, b1, b2 and b3 are identified for further evaluation. Next, the government employs the evaluation index system derived completely from a literature review as shown in Table I (Zhu *et al.*, 2015). Relevant stakeholders evaluate each alternative based on their own skills by completing questionnaires. The values from the questionnaires are then used as the input to a grey incidence analysis, which computes the absolute degrees of grey-incidence; this example is used to demonstrate the proposed approach.

Let us denote the event of evaluating the proposed option models by a_1.

Then the events set is $A = \{a_1\}$.

There are three plans of the development planning options under consideration:

- Plan 1: building an industrial park, which is treated as countermeasure b1;
- Plan 2: building a commercial centre, which is treated as countermeasure b2;
- Plan 3: building a real estate, which is treated as countermeasure b3.

So, the set of countermeasure is:

$B = \{b1, b2, b3\}$, and

Factor	Purposes	Development planning options b1	b2	b3
Environmental and health benefits	Improvement of the quality of groundwater	75	85	77
	Improvement of soil quality	70	82	60
	Improvement of air quality	78	84	65
	Lowering the health risk of local residents	80	89	68
	Increase of green cover percentage	77	87	85
	Improvement of remediation technologies	75	80	90
Financial	Payback period (PP)	5	7	4
	Return on investment (ROI)	21	30	17
	Total cost of brownfield remediation and construction	1,500	2,700	2,100
	Ratio of brownfield remediation cost to total cost	15	27	18
	Net present value (NPV)	2,580	3,500	2,600
Brownfield	Location of brownfield	75	85	80
	Status of infrastructure facilities of brownfield area	85	82	90
	Transportation convenience of brownfield area	80	88	90
	Size of brownfield	55	80	85
Societal stability	Increase local employment rate	90	92	75
	Increase local tax base	85	90	72
	Improvement of local security status	80	75	88
Policy and technical	Protecting and recycling the land/soil resource	75	90	75
	Influence from other contamination hazards nearby	60	65	60
	Easing the pressure on green land development	60	90	85
Performance	Matchup with city planning	70	85	80
	Improvement of image of local community and government	70	80	85
	Increase land value of neighbourhood	75	70	85

Table I. Comprehensive evaluation index for brownfield redevelopment projects

The set of circumstances is:

$$X = \{X_{ij} = (a_I, b_j) a_i \in A, b_j \in B\} = \{X_{11}, X_{12}, X_{13}\},$$

ꞩ[21]: "Grey System Theory Modeling Software 6.0 (GTMS 6.0)", used to evaluate and to get the following results:

In total, 24 purposes were chosen. Following this, we computed situational effect sequences Z^K ($k = 1, 2, \ldots, 24$) with respect to the purposes:

- For purpose 1, we have extracted $Z^1 = (Z_{11}^{(1)}, Z_{12}^{(1)}, Z_{13}^{(1)}) = (75, 85, 77)$.
- For purpose 2, we have extracted $Z^2 = (Z_{11}^{(2)}, Z_{12}^{(2)}, Z_{13}^{(2)}) = (70, 82, 60)$.
- For purpose 3, we have extracted $Z^3 = (Z_{11}^{(3)}, Z_{12}^{(3)}, Z_{13}^{(3)}) = (78, 84, 65)$.
- For purpose 4, we have extracted $Z^4 = (Z_{11}^{(4)}, Z_{12}^{(4)}, Z_{13}^{(5)}) = (80, 89, 68)$.
- For purpose 5, we have extracted $Z^5 = (Z_{11}^{(5)}, Z_{12}^{(5)}, Z_{13}^{(5)}) = (77, 87, 85)$.
- For purpose 6, we have extracted $Z^6 = (Z_{11}^{(6)}, Z_{12}^{(6)}, Z_{13}^{(6)}) = (75, 80, 90)$.
- For purpose 7, we have extracted $Z^7 = (Z_{11}^{(7)}, Z_{12}^{(7)}, Z_{13}^{(7)}) = (5, 7, 4)$.
- For purpose 8, we have extracted $Z^8 = (Z_{11}^{(8)}, Z_{12}^{(8)}, Z_{13}^{(8)}) = (21, 30, 17)$.
- For purpose 9, we have extracted $Z^9 = (Z_{11}^{(9)}, Z_{12}^{(9)}, Z_{13}^{(9)}) = (1{,}500, 2{,}700, 2{,}100)$.
- For purpose 10, we have extracted $Z^{10} = (Z_{11}^{(10)}, Z_{12}^{(10)}, Z_{13}^{(10)}) = (15, 27, 18)$.
- For purpose 11, we have extracted $Z^{11} = (Z_{11}^{(11)}, Z_{12}^{(11)}, Z_{13}^{(11)}) = (2{,}580, 3{,}500, 2{,}600)$.

- For purpose 12, we have extracted $Z^{12} = (Z_{11}^{(12)}, Z_{12}^{(12)}, Z_{13}^{(12)}) = (75, 85, 80)$.
- For purpose 13, we have extracted $Z^{13} = (Z_{11}^{(13)}, Z_{12}^{(13)}, Z_{13}^{(13)}) = (85, 82, 90)$.
- For purpose 14, we have extracted $Z^{14} = (Z_{11}^{(14)}, Z_{12}^{(14)}, Z_{13}^{(14)}) = (80, 85, 85)$.
- For purpose 15, we have extracted $Z^{15} = (Z_{11}^{(15)}, Z_{12}^{(15)}, Z_{13}^{(15)}) = (55, 80, 85)$.
- For purpose 16, we have extracted $Z^{16} = (Z_{11}^{(16)}, Z_{12}^{(16)}, Z_{13}^{(16)}) = (90, 92, 75)$.
- For purpose 17, we have extracted $Z^{17} = (Z_{11}^{(17)}, Z_{12}^{(17)}, Z_{13}^{(17)}) = (85, 90, 72)$.
- For purpose 18, we have extracted $Z^{18} = (Z_{11}^{(18)}, Z_{12}^{(18)}, Z_{13}^{(18)}) = (80, 90, 88)$.
- For purpose 19, we have extracted $Z^{19} = (Z_{11}^{(19)}, Z_{12}^{(19)}, Z_{13}^{(19)}) = (75, 90, 75)$.
- For purpose 20, we have extracted $Z^{20} = (Z_{11}^{(20)}, Z_{12}^{(20)}, Z_{13}^{(20)}) = (60, 65, 60)$.
- For purpose 21, we have extracted $Z^{21} = (Z_{11}^{(21)}, Z_{12}^{(21)}, Z_{13}^{(21)}) = (60, 90, 85)$.
- For purpose 22, we have extracted $Z^{22} = (Z_{11}^{(22)}, Z_{12}^{(22)}, Z_{13}^{(22)}) = (70, 85, 80)$.
- For purpose 23, we have extracted $Z^{23} = (Z_{11}^{(23)}, Z_{12}^{(23)}, Z_{13}^{(23)}) = (70, 80, 85)$.
- For purpose 24, we have extracted $Z^{24} = (Z_{11}^{(24)}, Z_{12}^{(24)}, Z_{13}^{(24)}) = (75, 70, 85)$.

Hereafter we computed the average images of the situational effect sequences for each of the purposes:

$$
\begin{array}{llll}
Z^1 = (1, 1.13, 1.03) & Z^4 = (1, 1.11, 0.85) & Z^7 = (1, 1.40, 0.80) & Z^{10} = (1, 1.80, 1.20) \\
Z^2 = (1, 1.17, 0.86) & Z^5 = (1, 1.13, 1.10) & Z^8 = (1, 1.43, 0.81) & Z^{11} = (1, 1.36, 1.01) \\
Z^3 = (1, 1.08, 0.83) & Z^6 = (1, 1.07, 1.20) & Z^9 = (1, 1.80, 1.40) & Z^{12} = (1, 1.13, 1.07) \\
Z^{13} = (1, 0.96, 1.06) & Z^{16} = (1, 1.02, 0.83) & Z^{19} = (1, 1.20, 1) & Z^{22} = (1, 1.21, 1.14) \\
Z^{14} = (1, 1.06, 1.06) & Z^{17} = (1, 1.06, 0.85) & Z^{20} = (1, 1.08, 1) & Z^{23} = (1, 1.14, 1.21) \\
Z^{15} = (1, 1.45, 1.55) & Z^{18} = (1, 1.13, 1.10) & Z^{21} = (1, 1.50, 1.42) & Z^{24} = (1, 0.93, 1.13)
\end{array}
$$

And then effect vectors Z_{ij} of the situations X_{ij}, $i = 1$, $j = 1, 2, 3$:

$$Z_{11} = \left(Z_{11}^{(1)}, Z_{11}^{(2)}, \ldots, Z_{11}^{(24)}\right) = (1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1),$$

$$
\begin{aligned}
Z_{12} = \left(Z_{12}^{(1)}, Z_{12}^{(2)}, \ldots, Z_{12}^{(24)}\right) \\
&= (1.13, 1.17, 1.08, 1.11, 1.13, 1.07, 1.40, 1.43, 1.80, 1.80, 1.36, 1.13, 0.96, \\
&\quad 1.06, 1.45, 1.02, 1.06, 1.13, 1.20, 1.50, 1.21, 1.14, 0.93),
\end{aligned}
$$

$$
\begin{aligned}
U_{13} = \left(Z_{13}^{(1)}, Z_{13}^{(2)}, \ldots, Z_{13}^{(24)}\right) \\
&= (1.03, 0.86, 0.83, 0.85, 1.10, 1.20, 0.85, 1.10, 1.20, 0.80, 0.81, 1.40, 1.20, \\
&\quad 1.01, 1.07, 1.06, 1.06, 1.55, 0.83, 1.10, 1, 1, 1.42, 1.14, 1.21, 1.13).
\end{aligned}
$$

Finally we calculated the optimum reference sequences, from the average images of the situational effect sequences of the purposes as follows:

- For purpose 1, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(1)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(1)}\right\} = \left\{Z_{12}^{(1)}\right\} = 1.13;$$

- For purpose 2, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(2)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(2)}\right\} = \left\{Z_{12}^{(2)}\right\} = 1.17;$$

- For Purpose 3, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(3)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(3)}\right\} = \left\{Z_{12}^{(3)}\right\} = 1.08;$$

- For Purpose 4, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(4)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(4)}\right\} = \left\{Z_{12}^{(4)}\right\} = 1.11;$$

- For Purpose 5, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(5)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(5)}\right\} = \left\{Z_{12}^{(5)}\right\} = 1.13;$$

- For Purpose 6, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(6)} = \max_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(6)}\right\} = \left\{Z_{12}^{(6)}\right\} = 1.20;$$

- For Purpose 7, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(7)} = \min_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(7)}\right\} = \left\{Z_{13}^{(7)}\right\} = 0.80;$$

- For Purpose 8, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(8)} = \min_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(8)}\right\} = \left\{Z_{13}^{(8)}\right\} = 0.81;$$

- For Purpose 9, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(9)} = \min_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(9)}\right\} = \left\{Z_{11}^{(9)}\right\} = 1;$$

- For Purpose 10, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(10)} = \min_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(10)}\right\} = \left\{Z_{11}^{(10)}\right\} = 1;$$

- For Purpose 11, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(11)} = \min_{1\leqslant i\leqslant n, 1\leqslant j\leqslant m}\left\{Z_{ij}^{(11)}\right\} = \left\{Z_{11}^{(11)}\right\} = 1;$$

- For Purpose 12, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(12)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(12)}\right\} = \left\{Z_{13}^{(12)}\right\} = 1;$$

- For Purpose 13, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(13)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(13)}\right\} = \left\{Z_{12}^{(13)}\right\} = 0.96;$$

- For Purpose 14, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(14)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(14)}\right\} = \left\{Z_{11}^{(14)}\right\} = 1;$$

- For Purpose 15, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(15)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(15)}\right\} = \left\{Z_{11}^{(15)}\right\} = 1;$$

- For Purpose 16, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(16)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(16)}\right\} = \left\{Z_{12}^{(16)}\right\} = 1.02;$$

- For Purpose 17, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(17)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(17)}\right\} = \left\{Z_{12}^{(17)}\right\} = 1.06;$$

- For Purpose 18, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(18)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(18)}\right\} = \left\{Z_{12}^{(18)}\right\} = 1.06;$$

- For Purpose 19, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(19)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(19)}\right\} = \left\{Z_{12}^{(19)}\right\} = 1.20;$$

- For Purpose 20, the mini effect value is the best, so:

$$Z_{i_0j_0}^{(20)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(20)}\right\} = \left\{Z_{13}^{(20)}\right\} = 1;$$

- For Purpose 21, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(21)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(21)}\right\} = \left\{Z_{12}^{(21)}\right\} = 1.50;$$

- For Purpose 22, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(22)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(22)}\right\} = \left\{Z_{12}^{(22)}\right\} = 1.21;$$

- For Purpose 23, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(23)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(23)}\right\} = \left\{Z_{12}^{(23)}\right\} = 1.14;$$

- For Purpose 24, the larger effect value is the best, so:

$$Z_{i_0j_0}^{(24)} = \min_{1 \leqslant i \leqslant n, 1 \leqslant j \leqslant m}\left\{Z_{ij}^{(24)}\right\} = \left\{Z_{12}^{(24)}\right\} = 1.13.$$

We obtained the following optimum reference sequence:

$$Z_{i_0j_0}^{(11)} = \left(Z_{i_0j_0}^{(1)}, Z_{i_0j_0}^{(2)}, Z_{i_0j_0}^{(24)}\right)$$

$$= (1.13, 1.17, 1.08, 1.11, 1.13, 1.20, 0.80, 0.81, 1, 1, 1, 0.96, 1, 1, 1.02, 1.06, 1.13, 1.20, 1, 1.50, 1.21, 1.14, 1.13).$$

From Z_{ij} and $Z_{i_0j_0}$, we computed the absolute degrees of grey incidence:

$$\varepsilon_{11} = 0.6359, \varepsilon_{12} = 0.8251, \varepsilon_{13} = 0.8370.$$

This led to the conclusion that since Max $\{\varepsilon_{ij}\} = \varepsilon_{13} = 0.8370$, Z_{13} is the quasi-optimum vector and X_{13} the quasi-optimum situation. In terms of building the development planning, the real estate planning is most ideal choice among all the possible plans of the development planning.

Conclusions, practical implications and future research

The research indicates that very little understanding of brownfield redevelopment exists with the relevant stakeholders, and no common definitions exist for brownfield development in Ethiopia. The research did, however, contribute a suitable definition of brownfield that can be used in the Ethiopian context. Due to health, environmental and public welfare risks associated with brownfield sites, it is convenient to design a framework to guide the theoretical and practical applications in brownfield redevelopment, which constitutes the main purpose of this study.

Under the umbrella of a grey incidence decision-making model, and with the consideration of multiple-stakeholders, tight environmental and economic constraints, the proposed research framework integrates different criteria from economic, social, environmental, technical and risk aspects into a grey incidence decision-making model, and gives useful guidance to control future brownfields on the African continent, particularly in Ethiopia.

Moreover, this research has a significant opportunity for African governments in following ways. First, this study will be helpful for African countries to utilise urban land effectively, long-term improvement in environmental quality, public and economic health. It will also be supportive in devising a strategy for employment, housing, taxation and environmental policy. Second, it identifies the potential for specific government policy frameworks for brownfield redevelopment to reduce city carbon emissions. Third, it recommends that government departments consider the coordinated facilitation of brownfield redevelopment. Lastly, it recommends brownfield redevelopment support from international development programmes. Above and beyond that identifying barriers to brownfield redevelopment, risk assessment using project life cycle, building up a comprehensive evaluation index for BRPs for African's situation, and evaluating BRP using grey system theory can be potential work in the future.

References

Alker, S., Joy, V., Roberts, P. and Smith, N. (2000), "The definition of brownfield", *Journal of Environmental Planning and Management*, Vol. 43 No. 1, pp. 49-69.

BenDor, T.K., Metcalf, S.S. and Paich, M. (2011), "The dynamics of brownfield redevelopment", *Sustainability*, Vol. 3 No. 6, pp. 914-936.

Brebbia, C. (2006), *Brownfields III: Prevention, Assessment, Rehabilitation and Development of Brownfield Sites (Brownfields 2006)*, Wit Press, Southampton.

Chen, Y., Hipel, K.W., Kilgour, D.M. and Zhu, Y. (2009), "A strategic classification support system for Brownfield redevelopment", *Environmental Modelling & Software*, Vol. 24 No. 5, pp. 647-654.

Chrysochoou, M., Brown, K., Dahal, G., Granda-Carvajal, C., Segerson, K., Garrick, N. and Bagtzoglou, A. (2012), "A GIS and indexing scheme to screen brownfields for area-wide redevelopment planning", *Landscape and Urban Planning*, Vol. 105 No. 3, pp. 187-198.

Darmendrail, D. (1999), "Personal communication".

De Sousa, C. (2005), "Policy performance and brownfield redevelopment in Milwaukee, Wisconsin", *The Professional Geographer*, Vol. 57 No. 2, pp. 312-327.

De Sousa, C.A. (2003), "Turning brownfields into green space in the city of Toronto", *Landscape and Urban Planning*, Vol. 62 No. 4, pp. 181-198.

De Sousa, C.A. (2006), "Unearthing the benefits of brownfield to green space projects: an examination of project use and quality of life impacts", *Local Environment*, Vol. 11 No. 5, pp. 577-600.

Delcea, C., Scarlat, E. and Mărăcine, V. (2012), "Grey relational analysis between firm's current situation and its possible causes: a bankruptcy syndrome approach", *Grey Systems: Theory and Application*, Vol. 2 No. 2, pp. 229-239.

Department of Environmental Conservation (2017), "What is solid waste", available at: www.dec.ny.gov/chemical/8732.html (accessed 15 August 2017).

Dixon, T. (2007), "The property development industry and sustainable urban brownfield regeneration in England: an analysis of case studies in Thames gateway and greater Manchester", *Urban Studies*, Vol. 44 No. 12, pp. 2379-2400.

Eckerd, A. and Heidelberg, R.L. (2015), "Public incentives, market motivations, and contaminated properties: new public management and brownfield liability reform", *Public Administration Review*, Vol. 75 No. 2, pp. 252-261.

Federal Democratic Republic of Ethiopia (2011), "Ethiopia's climate resilient green economy, green economy strategy", Addis Ababa, September, pp. 1-3.

Ferber, U., Grimski, D., Millar, K. and Nathanail, P. (2006), *Sustainable Brownfield Regeneration: CABERNET Network Report. The Concerted Action on Brownfield and Economic Regeneration Network (CABERNET)*, Cabernet, Nottingham, available at: www.Cabernet.Org.Uk_2014-12-01

Freier, K. (1998), *Clarinet Working Group 1: Brownfield Redevelopment Workplan*, German Environmental Agency, Berlin.

Gebreslase, M. and Zhu, Y. (2016), "The application of grey-incidence decision making in the analysis of Brownfield redevelopment project", *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC), IEEE*, pp. 773-778.

Gray, A. (2017), "These are the world's fastest-growing economies in 2017", World Economic Forum, available at: www.Weforum.Org/Agenda/2017/06/These-Are-The-World-S-Fastest-Growing-Economies-In-2017-2?Utm_Content=Buffer30bc1&Utm_Medium=Social&Utm_Source=Twitter.Com&Utm_Campaign=Buffer (accessed 15 August 2017).

Greenberg, M., Lowrie, K., Mayer, H., Miller, K.T. and Solitare, L. (2001), "Brownfield redevelopment as a smart growth option in The United States", *The Environmentalist*, Vol. 21 No. 2, pp. 129-143.

Guo, P., Liang, Y.H. and Zhu, Y.M. (2010), "Multi-hierarchical grey evaluation of the brownfield redevelopment project based on combinational weight", *Operations Research and Management Science*, Vol. 19 No. 5, pp. 129-134.

Gwilliam, M. (1997), "Something old, something new (brownfield sites)", *Planning*, Vol. 1233 p. 23.

Hou, D., Al-Tabbaa, A., Chen, H. and Mamic, I. (2014), "Factor analysis and structural equation modelling of sustainable behaviour in contaminated land remediation", *Journal of Cleaner Production*, Vol. 84, pp. 439-449.

Liu, S. and Forrest, J.Y.L. (2010), *Grey Systems: Theory and Applications*, Springer.

Liu, S., Forrest, J. and Yang, Y. (2012), "A brief introduction to grey systems theory", *Grey Systems: Theory and Application*, Vol. 2 No. 2, pp. 89-104.

Nachmias, D. and Nachmias, C. (2008), *Research Methods In The Social Sciences*, Worth Publishers, New York, NY.

National Round Table on the Environment and the Economy (2003), *Cleaning up the Past, Building the Future: A National Brownfield Redevelopment Strategy for Canada*, National Round Table.

Plater-Zyberk, D. (1998), "Architects and town planners: glossary of terms".

Potts, L. and Cloete, C.E. (2012), "Developing guidelines for brownfield development in South Africa", *WIT Transactions on Ecology and the Environment*, Vol. 162, pp. 389-399.

Schädler, S., Finkel, M., Bleicher, A., Morio, M. and Gross, M. (2013), "Spatially explicit computation of sustainability indicator values for the automated assessment of land-use options", *Landscape and Urban Planning*, Vol. 111, pp. 34-45.

Simons, R.A. (1998), "How many urban brownfields are out there?: An economic base contraction analysis of 31 US Cities", *Public Works Management & Policy*, Vol. 2 No. 3, pp. 267-273.

USEPA (2002), "Brownfields homepage", available at: www.epa.gov/ebtpages/cbrownfields.html 2015

Ushakov, I.A. (2007), *Histories of Scientific Insights*, Nanjing, Lulu. Com.

Van Rooyen, E. (2001), "Integrated development and the brownfields phenomena", *Journal of Public Administration*, Vol. 36 No. 1, pp. 61-80.

Van Vliet, D. (2003), "Book review of brownfield sites: assessment, rehabilitation and development", in Brebbia, C.A., Almorza, D. and Klapperich, H. (Eds), *Canadian Journal of Urban Research*, Vol. 12, pp. 147-148.

Wang, B., Ke, R.Y., Yuan, X.C. and Wei, Y.M. (2014), "China's regional assessment of renewable energy vulnerability to climate change", *Renewable and Sustainable Energy Reviews*, Vol. 40, pp. 185-195.

Zeng, B. and Luo, C. (2017), "Forecasting the total energy consumption in China using a new-structure grey system model", *Grey Systems: Theory and Application*, Vol. 7 No. 2, pp. 194-217.

Zhan, H. and Liu, S. (2015), "An analysis of intermediate inputs influencing the gross products of agriculture and its composition based on grey incidence analysis: taking Huangshan City as example", *Grey Systems: Theory and Application*, Vol. 5 No. 2, pp. 206-221.

Zhang, K., Ye, W. and Zhao, L. (2012), "The absolute degree of grey incidence for grey sequence base on standard grey interval number operation", *Kybernetes*, Vol. 41 Nos 7/8, pp. 934-944.

Zhu, Y. and Hipel, K.W. (2007), "Life span risk management in brownfield redevelopment", *IEEE International Conference on Systems, Man and Cybernetics, 2007, ISIC, IEEE*, pp. 4052-4056.

Zhu, Y., Hipel, K.W., Ke, G.Y. and Chen, Y. (2015), "Establishment and optimization of an evaluation index system for brownfield redevelopment projects: an empirical study", *Environmental Modelling & Software*, Vol. 74, pp. 173-182.

Further reading

C.R.G. Economy (2011), "Ethiopia's climate-resilient green economy, green economy strategy", FDRE, Addis Ababa.

Michael Palomino (2013), "Groundwater 02: pollution and contamination", available at: www.geschichteinchronologie.com/welt/wasser-u-grundwasser02-groundwater-pollution-contamination-ENGL.html

About the authors

Mikiale Gebreslase Gebremariam is Senior Doctoral Researcher under "Sustainable Development Research Platform", focussing on Climate Change, Sustainable Cities and Communities, and Good Health and Well-being at Northwestern Polytechnical University Xi'an, China. Control Engineering became his passion after he received his BSc in Electrical Engineering from Bahir-Dar University, Ethiopia in 2010. His continued interests drove him to further improve his education, and in 2014 he

gained MSc in Control Theory and Control Engineering from Northwestern Polytechnical University, China. After he completed MSc, Northwestern Polytechnical University awarded him a full university scholarship to continue his PhD in Systems Engineering in 2014. He is also very much concerned about environmental issues such as climate change and pollution, which are affecting the whole world. He has authored several peer-reviewed articles and has attended many international conferences. Mikiale Gebreslase Gebremariam is the corresponding author and can be contacted at: garabandal1221@mail.nwpu.edu.cn

Yuming Zhu is Professor at the School of Management Science and Engineering at Northwestern Polytechnical University, China. His research interests are in Managerial System Engineer, Corporate Strategic Management, and Project Management. Zhu has written several articles for peer reviewed journals, and has attended many international conferences. He has several awards, and he is a member of the Youth Scientist Commission of NPU.

Naveed Ahmad is PhD student in the School of Management, Northwestern Polytechnical University, Xi'an, China. He did his Masters of Marketing in 2013 from Mohammad Ali Jinnah University, Pakistan. His areas of interest are sustainable development, brownfield redevelopment projects, knowledge management, reverse logistics, luxury marketing, green innovation, corporate social responsibility and new HRM practices. He has published many research articles in different reputable journals including: *Journal of Cleaner Production*, *International Journal of Environmental Sciences and Public Health*, *Sustainability*, *Journal of Advanced Manufacturing Systems*, etc. He has taught in different institutes including Bahaudin Zakaria University, Multan and Government College University, Faisalabad.

Dawit Nega Bekele is Research Fellow and Senior Hydrogeologist at the Global Centre for Environmental Remediation (GCER) at the University of Newcastle, Australia, conducting and directing environmental projects and research in the assessment, remediation and management of contaminated sites. He has qualifications in Civil Engineering (BSc), Water Resource Management (MSc) and Environmental Public Health and Remediation (PhD). With over ten years' experience in the environmental field, he specialises in providing strategic environmental advice to clients relating to brownfield site assessment and remediation, including the assessment of contaminant fate and transport. His current research focusses on adding new dimensions in vapour intrusion risk assessment and mitigation at volatile hydrocarbon impacted grounds. He is lead contaminant hydrogeologist, soil and groundwater remediation at GCER. His area of research includes risk-based approaches to the clean-up or management of contaminated sites.