Sustainable land resources management using goal programming MCDA model: evidence from best practice in natural resources management.

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Key words: Land resources, Land management, Natural resources management, Nigeria, Multi-criteria decision analysis (MCDA), Analytic Hierarchy Process (AHP) Goal programming,

SUMMARY

Land resources, particularly the soil from an *'agricultural standpoint'*, and built-up areas for *'residential purposes'*, are threatened by a combination of factors – climatic, ecological, and anthropogenic, which results mostly from an ever-increasing demographic pressure. This situation justifies rethinking the general attitude to land, and the ideation for sustainability and sustainable land management (SLM). Current land management efforts are insufficient given the new frontiers of global challenges and solutions which are endogenous to land. Planners and environmental experts face a somewhat difficult situation in land resources management when complex decisions and choices must be made from a range of competing alternatives. Multi-criteria decision analyses (MCDA) tools are being used to resolve such difficulties. Most of these tools for example the Analytic Hierarchy Process (AHP), fuzzy set theories, weighted and aggregation-disaggregation models possess severe limitation in how the outcomes of the aggregated variables resolve parametric uncertainties, and solutions not being *Pareto efficient*. So, the need to examine other MCDA models is exigent. This study, which is primarily a discourse on the application MCDA for LRM, considers the *goal programming* model. The study draws largely from natural resources management research to offer possible insight and novel research ideas and directions towards a proactive SLM. It will help to explore the varied potentials within land resources which will significantly improve the land economy, and foster breed realistic platform towards achieving the UN's sustainable development.

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Abbreviations

1.	AHP	Analytic Hierarchy Process
2.	CBD	Convention on Biological Diversity
3.	DP	Decision Problem
4.	DS	Decision Space
5.	FAO	Food and Agriculture Organisation
6.	FBT	Fuzzy based techniques
7.	GP	Goal Programming
8.	MCDA	Multicriteria Decision Analysis
9.	Rio	Earth Summit', in Rio de Janeiro, Brazil (3-14 June 1992)
10.	SDG-1	Sustainable development goal -1: No poverty
11.	SDG-2	Sustainable development goal -2: Zero hunger
12.	SDG-3	Sustainable development goal -3: Good health and wellbeing
13.	SDG-6	Sustainable development goal -6: Clean water and sanitation
14.	SDG-13	Sustainable development goal -13: Climate action
15.	SDG-15	Sustainable development goal -15: Life on land
16.	SLM	Sustainable land management
17.	TOPSIS	Technique for order of preference by similarity to ideal solution
18.	UN	United Nations
19.	UNCCD	United Nations Convention to Combat Desertification
20.	UNFCCC	United Nations Framework Convention on Climate Change

1. INTRODUCTION

According to the UN's Food and Agriculture Organisation, "land resources" *encompasses the physical, biotic, environmental, infrastructural, and socio-economic components of a natural land unit, including surface and near-surface freshwater resources important for management* (FAO, 2021). This explanation underpins a clear understanding of the whole extent of land available for a variety of uses including housing, agriculture, industrial, economic, taxation, conservation, and recreational purposes. So, beyond the surface expanses exhibiting rocks and soils, land resources incorporate no less than the solid minerals, wildlife, aquatic ecosystem, wetlands, and forests. Although land resources have been conceived long before the dawn of modern civilization and is profoundly ingrained in many historical tapestries, how to represent land as to not conceal its wide-ranging economic, social, geopolitical, and cultural significance within the context of sustainability and sustainable development is still contentious. De Soto (2000) intuits that there is a lurking mystery which needs to be debunked so that a general understanding and appreciation of land should supersede its somewhat restricted meaning as just a fixed asset for the mere necessity, creating the base for capital production, but in terms of the values, utilities, other assets that it can supply, and the legal basis that enables it to be fungible.

The UN's FAO in 2021 presented a series of documentary and synthesis reports on the state of the world's land and water resources for food and agriculture. The major findings of their analyses – summarised as existence of multiple stressors on land resources, and climate impacts transforming the trajectory of agricultural production – together form the basis of a new science of environmental change, and reveal two crucial areas of research interest:

1) Land resources in an age of evolving megatrends
2) Sustainability of land resources considering constraining climate change impacts.

These findings and epistemological backgrounds may be of major concerns to the agricultural sector, but the overall pressure on land resources can be more obvious when cases are treated at local, country-level, and regional scales rather than taking the aggregates of the global. For example, in the developing countries such as Nigeria, we find that land resources face an army of dire and refractory threats including land degradation, uncontrolled anthropogenic activities, and land ownership tussles. Using land degradation as a case in point, it is easier to imagine the consequences of these threats on the local availability and quality of arable lands such as poor agricultural yields, global food insecurity, decline in the availability of water resources, disruption in the delicate ecological balances and loss of biodiversity (Iwuchukwu *et al.,* 2023; Adenle & Speranza, 2020; Eswaran *et al.,* 2019; Odemerho, 1992). In fact, this situation is also being compounded by regional conflicts, local land criminalities and weak political power to enforce a sustainable land reforms policy within the country (Nkwunonwo *et al.*, 2019). From extant research, the main culprits of land degradation are urbanisation, demographic pressures, improper agricultural practices, poor land management culture, and climate change which is in tandem with erosion, salinization, and desertification (Adenle *et al.,* 2022; Speranza *et al.,* 2019; Kiage 2013).

With respects to the UN's FAO and many research efforts, there are various proposals and recommendations for urgent actions to assuage land degradation through sustainable land resources management (SLM) or simply sustainable land management. The UN defined this as "*the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions*". This conceptualisation was reinforced by the TerrAfrica (2005) which defined the same subject as "*the adoption of land-use systems that through appropriate management practices enable land users to maximise the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources*". Another thoughtful idea is being offered by World Bank (2006) in a working guideline in which it posited that SLM refers "*to practices and technologies that aim to integrate the management of land, water, and other environmental resources to meet human needs while ensuring long-term sustainability, ecosystem services, biodiversity, and livelihoods".*

Most of what have been accomplished over years following the conceptualisation of SLM in the current literature are in accord with various global treaties including the Rio conventions (CBD, UNFCCC, UNCCD) and the sustainable development goals (SDG-1; SDG-2; SDG-3; SDG-6; SDG-11; SDG-15). SLM is a knowledge-based action that supports responsible natural resources' exploitation, responsible land governance, administration, and policy with multi-stakeholders' collaborations and political campaigns. A mini review of literature reveals that over the last few years and in fact in the recent times, practices of SLM encompasses land use planning, agricultural sustainability, mitigation of land degradation, preservation of soil and water, and cultural practices that promote ecosystem services (Schwilch *et al.,* 2011; Maisharou *et al.,* 2015; Haregeweyn *et al.,* 2023).

Critically, a clear science resides at the undertone of these efforts since despite being a real problem, SLM's solutions are nontrivial and require a rigorous and systematic endeavour and may involve making predictions, modelling, and testing of models. In the vast literature of SLM, researchers often aim to model the relationships between causes and effects and present a range of empirical findings from which policy makers must base their decisions. This is a scientific problem which requires a systemic knowledge and scaling of conflicting alternatives (Thomas *et al.,* 2018; Löbmann *et al.*, 2022). At least, a basic science of decision making from multiple criteria, parameterisation of variables, and simplifying underpinning theories, logics, factorials, and the characteristic complexities of criteria is evoked. Research has gained a significant prominence in this regard, in solving multi-criteria decision problems. In the literature relating to multicriteria decision analyses (MCDA) for SLM, a slew of approaches has been deployed including fuzzy-based techniques, weighted sum models, AHP, TOPSIS, etc (Löbmann *et al.,* 2022; Munier *et al.,* 2019; Saarikoski *et al.,* 2016). Evidently, a major limitation with these approaches lies in how outcomes of the aggregated variables resolve parametric uncertainties, their randomness and correlation with epistemological assumptions and solutions not being *Pareto efficient*. Such limitations and the overwhelming significance of creating a realistic model for SLM prompt the need to examine other MCDA models.

The purpose of this paper is to describe an MCDA tool which can foster a more realistic SLM approach. This paper considers goal programming model, existing methods, and applications in SLM. It also considers how goal programming has been used to stimulate SLM in the focus areas in which SLM is being widely practiced. The study's objectives are tailored towards a treatise on the applications of GP for SLM. The study is much of a theoretical discussion and draws extensively from evidence in the literature of natural resources management. It will critically examine how the use of GP will impact positively on the overall ideology of SLM.

2. METHOD AND DATA

This is a conceptual study with the intention to shed light on an alternative way of improving the science of SLM by solving land decision problems from multiple criteria. Figure 1 below described the methodological approach of this study. In this study, the goal programming tool is chosen and discussed extensively based on its historical background, how it has featured in the academic literature relating to SLM, its strength and weaknesses along with how it is being formulated and applied in SLM. These themes are the focus of the next sections of this paper.

Figure 1: Framework of the study's Methodological design

The data for this study is mostly publications from previous research in journals with proven academic quality. Our literature search is extensive as we aimed to understand the application trend and true implication of GP in SLM. Major academic database including Scopus, Web of Science, PubMed, ERIC, IEEE Xplore, ScienceDirect, Directory of Open Access Journals (DOAJ), JSTOR formed the core of our literature search. We also accessed reports from United Nations, World Bank and major global treaties and conferences.

3. RESULT AND DISCUSSIONS

Goal programming is a multi-objective and multi-criteria decision tool which was developed and first applied in the 1950s. Goal programming is used to solve problems involving multiple criteria, multiple variables and with priorities which must not be overcome b decision maker's instincts and biases. Its true value lies in in its contribution to the solution of decision problems involving multiple and conflicting objectives and criteria.

Goal programming has been extensively applied in the physical, biological, and social sciences and the results are clear evidence of significant values for operation. There are two important categorise of the goal programming model. One is the non-pre-emptive (lexicographic) which is widely used and adapted in various studies. In this category, goals are assigned priorities, so that goals at a certain priority (let's say g-1) level are considered substantially more relevant than the goals at the next level (let's say g-m). The other category is the Archimedian model in which weights or penalties are specified for failing to achieve targets, and the model aims to minimize the sum of weighted impossibilities. This paper only presents concise description of the goal programming MCDA tool enough to enable a better grasp of its application in the sustainable land resources management. Detailed discussion can be found in Ignizio (1978), Tamiz *et al*. (1995; 1998), and Jones & Tamiz (2010).

3..1. Background of goal programming model

Goal programming provides definite, favourable, and real solutions to multicriteria decision problems. It was originally employed by Charnes *et al*. (1955) in a series of optimal estimation studies, although the first published volume in which it was mentioned is credited to Charnes & Cooper (1961). Evidently, many influential research works have been conducted around goal programming, altogether establishing an important trajectory in operations research and decision theory. Prominent among these studies are Ijiri (1965), Lee & Clayton (1972), Ignizio (1978), Gass (1986), Romero (1997), Ignizio & Cavalier (1994). Much of what these studies achieved was to further develop the original model of goal programming, as can be intuited from the various literature reviews that has shed some light on its current state. Some featured reviews include Tamiz *et al*. (1995) which provided an update of goal programming and the sprawl of its applications. Unveiling the current usability of GP in enhancing decision making was the focus of Tamiz *et al*. (1998). Other reviews, including Caballero *et al*. (2009), Jones & Tamiz (2016), Colapinto *et al*. (2017), Gür & Eren (2018), Guggeri *et al*. (2023), and the annotated bibliography of Jones & Tamiz (2002) underscored the overwhelming promise of GP in virtually all aspects of human endeavour involving multi-objective optimisation and multi-criteria decision including management, engineering, and biological sciences.

3.2. Mathematical formulation of goal programming model

The formulation of goal programming model takes the form of a linear programming problems including mathematical programming with multiple objectives, only that in goal programming, goals and associated primacies are considered explicitly (Tamiz *et al.*, 1995; Ignizio, 1978). Objective functions are always minimised and must be composed of deviational variables only. In goal programming, two types of variables are used – decision variables and deviational variables – along with two categories of constraints: structural or system constraints and goal constraints, which are expressions of the original functions with target goals, set priorities and positive and negative deviational variables.

From the original works of Charnes (1955), Charnes & cooper (1961; 1977); Schniederjans, (1984) and subsequent seminal studies, we can identify the expressions below:

$$\text{Minimize: } Z = \sum_{i=1}^{N} w_{kl} P_k (d_i^+ + d_i^-) \text{ --------------------------(1)}$$

$$\text{For } k = 1\ldots, K; i = 1, \ldots. L$$

where there are N goals, and *i* is the index of constraints index, k is the priority rank index, and l is the index of the deviation variables within priority rank. In the objective function, Z is the summation of all deviations, the w kl are optional mathematical weights used to differentiate deviation variables within a kth. d_i^- = negative deviational variable from the *i*th goal, d_i^+ = positive deviational variable from the *it*h goal

3.3. Applications of goal programming in SLM

The scope of this literature review is limited to applications of goal programming in SLM. It only presents a synopsis of the relevant literature covering the last 10 years, highlighting the precise land resources problem addressed and the method being used within the context of goal programming. Only studies published in English, and which presented a novel implementation of goal programming method were selected. Literature search and analyses excluded literature review studies, conference proceedings and studies that are published as preprints of various journals. Overall, 25 studies that covered a mix of SLM focus areas passed the literature selection requirements, as shown in tables 1 and 2. Ten of these studies presented conservation of ecosystem services. Of these, seven presented agricultural sustainability. Four out of the eight remaining focused on conservation of water and soil, while three were in land use planning. The remaining lone study focused on land degradation.

There were cases where an overlap existed in the studies in term of the SLM focus areas. These were in such studies as Gosling *et al*. (2020), Zheng *et al*. (2017) and Elliot *et al*. (2019). These studies both referred to land degradation, ecosystem services, and conservation of soil and water (see figure 2). But the implementation of the developed goal programming model informed the researchers' choice of the dominant SLM focus area. Studies that focused on goal programming for land degradation were lacking from the literature search over the period of time under review. This cause of this situation was far from the idea that land degradation has not received much attention in the literature, since there is a large body of studies spanning over five decades that have discussed land degradation extensively. Most of the studies that attempted land degradation from the point of view of goal programming tool are scarce, while a few of them for example Zheng *et al*. (2017) were more focused on the spatio-temporal indicators of land degradation. So, an area of research that needs to be developed is how goal programming can be used to address land degradation issue such as erosion, soil contamination, suitability analyses of landfills and municipal solid waste management.

Table 1: Selected studies that applied goal programming, to Sustainable Land Management.

S/No	**Study**	**SLM focus area**
1.	Srivastava & Singh (2017)	Sustainable agriculture
2.	Felix *et al.* (2019)	Land use planning
3.	Nechi *et al.* (2020)	Land use planning
4.	Phinyoyang & Ongsomwang (2021)	Agricultural sustainability
5.	Najafabadi *et al.* (2023)	Agricultural sustainability
6.	Joolaie *et al.* (2017)	Agricultural sustainability
7.	Musa (2021).	Conservation of soil and water
8.	Petridis *et al.* (2018)	Conservation for ecosystem services
9.	Gosling *et al.* (2020)	Land degradation mitigation
10.	Ren *et al.* (2018)	Conservation of soil and water
11.	Bakhtavar *et al.* (2023)	Conservation for ecosystem services,
12.	Xavier *et al.* (2018)	Agricultural sustainability
13.	Corrigan & Nieuwenhuis (2016).	Conservation for ecosystem services
14.	Etemad *et al.* (2019)	Conservation for ecosystem services
15.	Kamaludin *et al.* (2021)	Agricultural sustainability
16.	Ma & Zhao (2015).	Land use planning
17.	Jana *et al.* (2016)	Agricultural sustainability
18.	Zhou *et al.* (2016)	Conservation of soil and water
19.	Aldea *et al.*, (2014)	Conservation for ecosystem services
20	Bagdon *et al.* (2016)	Conservation for ecosystem services
21.	Sacchelli & Bernetti. (2019)	Conservation for ecosystem services
22	Zheng *et al.* (2017)	Conservation for ecosystem services
23	Elliot *et al.* (2019)	Conservation for ecosystem services
24	Qu *et al.* (2019)	Conservation of soil and water
25	Groot *et al.* (2018)	Conservation for ecosystem services

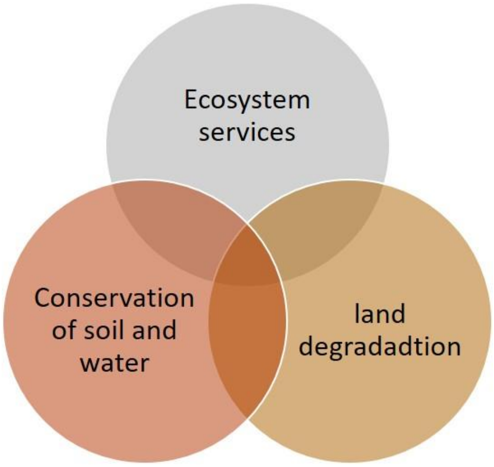

Figure 2: Overlapping areas in goal programming application in SLM

Table 2: Ranked application of goal programming in sustainable land management focus areas

S/No	**Study**	**Goal programming model formulated**	**Land Use Planning**	**Agricultural Sustainability**	**Water and soil**	**Land degradation mitigation**	**Ecosystem services**
1.	Srivastava & Singh (2017)	Weighted goal programming model		✓			
2.	Felix *et al.* (2019)	priority based fuzzy goal programming model.	✓				
3.	Nechi *et al.* (2020)	Coupled goal programming and satisfaction function	✓				
4.	Phinyoyang & Ongsomwang (2021)	Regional composite indicator, based on goal programming		✓			
5.	Najafabadi *et al.* (2023)	Designed a new interval meta-goal programming		✓			
6.	Joolaie *et al.* (2017)	Fuzzy multi-objective goal programming		✓			
7.	Musa (2021)	Integrated goal programming and demand function			✓		
8.	Petridis *et al.* (2018)	Weighted goal programming mixed-integer linear programming (WGP MILP)					✓
9.	Gosling *et al.* (2020)	Linear goal programming model				✓	
10.	Ren *et al.* (2018)	Multiobjective stochastic fractional goal programming model			✓		
11.	Bakhtavar *et al.* (2023)	Fuzzy cognitive-based goal programming					✓
12.	Xavier *et al.* (2018)	Coupled ecosystem services and regional composite indicator		✓			
13.	Corrigan & Nieuwenhuis (2016).	The biophysical linear goal programming model					✓
14.	Etemad *et al.* (2019)	Goal programming and fuzzy analytic hierarchy process					✓
15.	Kamaludin *et al.* (2021)	Multiple objective linear goal programming		✓			
16.	Ma & Zhao (2015).	multi-objective artificial immune optimization model	✓				
17.	Jana *et al.* (2016)	A hybrid probabilistic fuzzy goal programming approach		✓			
18.	Zhou *et al.* (2016)	Multilevel factorial fractional goal programming			✓		
19.	Aldea *et al.*, (2014)	Participatory goal programming					✓
20	Bagdon *et al.* (2016)	Simulation modelling with goal-programming					✓
21.	Sacchelli & Bernetti. (2019)	Multi-objective analysis and metaheuristic approach					✓
22	Zheng *et al.* (2017)	3-level multichoice goal programming					✓
23	Elliot *et al.* (2019)	A combined multi-objective integer goal programming and LULC performance scores					✓
24	Qu *et al.* (2019)	Weighted goal programming models			✓		
25	Groot *et al.* (2018)	Pareto-based multi-objective programming approach					✓

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