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Decision Support System for Implementing Sustainable Relocation Strategies for Adaptation to Climate Change: Model Base

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Summary

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Abstract

Climate change is a reality which we are living. Global warming has caused human displacement and will continue to cause more places to become uninhabitable due to floods, sea level rise and other such events. As it stands, planned relocation being an adaptation measure seem a response that should be explored to save the population by moving a fraction of affected communities while others adapt to the changing climate. Examining one of the components of a Decision Support System (DSS), we devise a mathematical model, using multi-objective optimisation scheme which combine Analytical Hierarchy Process (AHP) and goal programming to estimate which fraction should relocate from affected area and those to retain. This process takes into account various cost; human preferences; and estimates priorities to compute overall objective. We illustrate the effectiveness of the model using simulated/hypothetical data to suggest that successful adaptation practice largely relies on costs while human involvement in the process is vital. Concepts of this nature are complex however it is plausible though with significant impacts on socio-economic development, this study emphasize on the strength of mathematical methods in environmental studies and also open new research directions in adaptation measures.

- Keywords: DSS; Climate Change; Relocation; AHP; Multi-objective Optimisation

Résumé

Le changement climatique est une réalité que nous vivons. Le réchauffement de la planète a provoqué des déplacements humains et continuera à rendre de plus en plus de lieux inhabitables en raison des inondations, de l'élévation du niveau de la mer et d'autres événements de ce type. En l'état actuel des choses, la relocalisation planifiée, en tant que mesure d'adaptation, semble être une réponse à explorer pour sauver la population en déplaçant une fraction des communautés affectées pendant que les autres s'adaptent au changement climatique. En examinant l'un des composants d'un système d'aide à la décision (SAD), nous concevons un modèle mathématique, en utilisant un schéma d'optimisation multi-objectif qui combine le processus de hiérarchie analytique (AHP) et la programmation des objectifs pour estimer quelle fraction doit être déplacée de la zone affectée et celles à conserver. Ce processus tient compte des différents coûts, des préférences humaines et des priorités estimées pour calculer l'objectif global. Nous illustrons l'efficacité du modèle à l'aide de *données simulées/hypothétiques pour suggérer qu'une pratique d'adaptation réussie dépend largement des coûts, tandis que l'implication humaine dans le processus est vitale. Les concepts de cette nature sont complexes, mais ils sont plausibles et ont un impact significatif sur le développement socio-économique. Cette étude souligne la force des méthodes mathématiques dans les études environnementales et ouvre également de nouvelles directions de recherche dans les mesures d'adaptation.*

Acronyms and Abbreviations

AHP **:** Analytic Hierarchy Process

BP : Budget Objective

COP : Conference of Party

CI : Critical Infrastructure

DSS **:** Decision Support System

DST : Decision Support Tools

ENSO : El Niño Southern Oscillation

GHG : Greenhouse gas

GDP **:** Gross Domestic Product

GP **:** Goal Programming

HP : Human Preference

IDSS : Integrated Decision Support System

IPCC **:** Intergovernmental Panel on Climate Change

LDCs : Least Developed Countries

LDSS : Land-use Decision Support System

MCDA : Multi-Criteria Decision Analysis

MCDM : Multi-Criteria Decision Making

NAPA **:** National Adaptation Programmes of Action

NE : Nutrient Expert

OP : Opportunity Budget

OWA : Ordered Weighted Averaging

ROC : Rank Order Centroid Weights

TOPSIS : Technique F or Order Performance by Similarity to Ideal Solution

UN : United Nations

UNCED : United Nations Conference on Environment and Development

UNFCC : United Nations Framework Convention on Climate Change

UNHRC : United Nations Refugee Agency

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Chapter 1: Introduction

1.1 Preamble

Climate change is indeed a threat in Africa, as it is in the rest of the world. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), temperatures across Africa are expected to rise by 2 to 6 degrees Celsius over the next century, while rainfall variability is expected to increase, resulting in frequent flooding. Africa's climate change impacts are so concerning that studies have ranked the continent as the most vulnerable in the world. For example, Africa was identified as one of the world's most vulnerable regions to the effects of climate change due to its high exposure and limited adaptive capacity (Field, *et al.,* 2014). Meara, *et al.*, 2015, noted that African countries are more vulnerable to climate change than other regions due to their heavy reliance on agriculture, citing insufficient financial, technical, and institutional capacity to adapt as contributing factors. While simulating the relationship between abrupt extreme climatic events (for example, floods) and development and migration can be challenging, some broad conclusions are possible.

Without a doubt, disasters result in large-scale human displacement, which inevitably undermines overall development. However, displacement is frequently viewed as a temporary measure, as displaced individuals frequently seek to return and restart their lives in familiar surroundings and with a lifestyle they are accustomed to (Wilkinson *et al.,* 2016; Islam and Shamsuddoha, 2017; Offner and Marlowe, 2021). Additionally, such movements are typically brief: few people displaced by long-term disasters cross an international border solely for survival. The patterns of movement are largely determined by the social networks, as people generally relocate to be near family and friends.

Dustmann and Görlach (2016) opined that following a rapid onset of disaster, migration into the affected area is able to intensify, at least momentarily, as displaced people return, accompanied by relatives who can assist them in their recovery efforts, personnel working with recovery agencies, and some other new migrants looking for work in the regeneration phase of a rising community. Thus, this type of reconstruction frequently results in significant, albeit temporary, economic growth, and there is a possibility that if done correctly, this can result in new and improved development processes that reduce vulnerability to subsequent extreme events.

"African countries serve as origin, transit, and destination countries concurrently. Labor migration is the most common type of migration in the region, followed by forced migration, irregular migration, and transit migration. Between 1980 and 1985, the continent experienced a net emigration rate of -0.8, or -2.1 million people. However, from 2010 to 2015, the net migration rate remained relatively stable at -0.5, or 2.9 million persons "(Kay and Nagesha, 2016). Additionally, Kay and Nagesha (2016) argue that political turmoil and insecurity have significantly contributed to net negative migration rates in the majority of the continents, resulting in net population loss due to migration. Additional reasons for migration would be development projects and natural resource extraction. Relocating people for environmental reasons is a complicated process that can disrupt social order in some cases unless it is well planned and takes into account a variety of factors, including but not limited to social, economic, humanitarian, and so on.

Where environmental change results in permanent migration, those with the financial means and social networks to relocate long distances may even relocate to another country, or, if sufficiently wealthy, to a developed country. However, the majority of people who are prone to such movement in response to such changes are members of the lower middle classes, who have enough money to move but not far (Islam and Winkel, 2017).

These individuals are most likely to relocate within a country, to rural and urban destinations, with their choices influenced by their perceptions of the risks associated with various destinations as influenced by their social networks, their skill sets, and their understanding of job markets and other income earning opportunities, as survival is critical in such situations.

In terms of the way climate factors affect migration, risk frameworks such as the one introduced by the IPCC aid in comprehending how climate hazards interact with social vulnerability. Climate hazards can be classified according to a variety of factors, including the location, timing, duration, and intensity of an event. Social vulnerability is defined by population characteristics such as the age distribution, sex, ethnicity, race, level of education, and source of financial and other resources. When people are more vulnerable and have a lower capacity to adapt in their areas of settlement, they are more likely to migrate in the face of climate hazards. Fast-onset events include wildfires, drought, and heat waves. Slow-onset events include blizzards, landslides, and heat waves. Rapid events include extreme climate conditions, like floods, storms, heat waves and drought. Changes to climate regimes, such as increased temperatures or extended periods of more variable rainfall, occur gradually, over time, rather than suddenly. Sea level rise, ocean acidification, glacial retreat, and related impacts are also slow-onset events. While each of these factors may bear some correlation to climate change, it is not possible to make definitive statements based on these connections. While slow-onset events drive permanent migration, fast-onset events are more likely to lead to displacement followed by a return to source areas. However, in the long term, repeated instances of fast-onset events may reduce the assets of the household and result in long-term migration.

Studies that focus on how climate change impacts migration across developing countries usually refer to migration in various forms, whether international or domestic or triggered by slow-onset or multiple rapid-onset events. As a result, migration serves several functions in this context. The first step in dealing with climate change is to move to a less risky or more stable environment, which will both help to reduce your personal exposure to climate hazards like recurring droughts that hamper agricultural yields, and protect the areas around you from floods. Second, at the individual level, migration can be a component of a livelihood diversification and risk reduction strategy, wherein the household receives financial stability in the form of remittances from those in the receiving region, in the event of risks, and eliminates other sources of income. Also, migration can raise assets within the household, thereby increasing the ability to handle changes brought on by climate change. A fourth benefit of migration is that it reduces the number of mouths to feed in a household, especially during agricultural regions when there is a drought or during the lean season. This can lead to higher food security for those who remain. Returning migrants have the ability to bring new skills and technologies back to the communities they left, making their community more prosperous and better prepared to face climate-related threats.

For many years, climate change research has tried to examine the relative influence of climate factors in prompting migration. Studies of both human perceptions of climate change and migration as well as demographic analyses using census or survey data that control for influences on migration and then introduce climatic factors to calculate their relative impact can be found here. Many large and growing bodies of research focus on the so-called "agricultural pathway," in which climate's impact on migration is tempered by changes in agricultural productivity. Concluding analyses that examined global effects of climate change and how it impacted people in Africa, South Asia, and Latin America showed that hotter or more variable weather with more extreme conditions was shown to negatively affect crop yields in ways that might cause migration. Despite this, the migration may only occur from specific locations, to specific destinations, and with certain people migrating.

1.2 Research Problem

The weight of evidence points to African nations bearing the effects of extreme weather, such as flooding, drought, deforestation, and land degradation, causing migration (Abebe, 2014; Kemp *et al.*, 2017). While Abebe (2014) speculates that increased levels of sea level rise, wetter coastlines, and drier mid-continental locations would lead to the gravest repercussions of climate change by compressing population movements, an area where sea level rise, wetter coastlines, and/or drier mid-continental regions could result in mass population displacement is indicated.

By investigating the relationship between biophysical changes in the environment and inter-provincial migration, Henry (2003) discovered that migration is influenced by environmental conditions. In Mali, because of decreasing rainfall, there were numerous crop failures, which resulted in thousands of farmers leaving their villages for the cities, many of whom went to Bamako, the nation's capital. This created a significant population increase from 600,000 in two decades to approximately 2 million in 2007. (Aid, 2007). The decline in precipitation in Africa has also increased rural-urban migration in Sub-Saharan Africa (Strobl *et al.*, 2003).
Nielsen (2010) stated that Africa's adaptation prowess stems from the continent's abundant natural resources, sophisticated social networks, and established traditional methods of vulnerability management. Consider, for instance, migration, crops, livelihood, diversification, and small-scale enterprises. It is uncertain how effective these strategies will be in preparing for future changes (Leary *et al.*, 2008).

Global warming has been linked to the inundation of low-lying coastal areas, with some areas becoming more prone to flooding while others experience decreased precipitation in arid and semi-arid regions. Due to these events, people have had to move to new locations, losing lives and property in the process. Adoption and relocation strategies can be found in various documents and publications in addition to planned migration strategies. Climate change effects today are predicted to make various locations less inhabitable, which will create new patterns of population movement. Because of this, some people will leave whether they want to or not, and those who are unable to financially support themselves will continue to face worsening conditions until their only option is to leave. In some cases, governments will relocate a community because it's in their best interest, or residents of the community deciding to relocate on their own. To this point, government is devoting resources to mitigation measures at the expense of mobility adaptation strategies, which is of great concern to humanitarian, development, and human rights groups.

1.3 Research Objective

1.3.1 Aims and Objectives

The aim is to devise an effective relocation plan to determine the number of families to be resettled. That would include locating those families in the area “where," as well as determining how many to resettle and where to locate them. To obtain this, the main objectives are to;

1. identify costs and constraints for multi-objective optimisation.
2. formulate a mathematical model using goal programming and the Analytic Hierarchy Process (AHP).
3. establish priorities (weights) for the decision criteria.
4. validate the results using standard metrics.

A major goal is to develop a strong solution capable of performing multiple functions.

1.4 Research Question

The central research question is: How can planned relocation be preconceived as a climate change adaptation strategy in order to develop sustainable strategic responses that address the challenges associated with whom to relocate? Following that, we should be able to answer the following questions based on the research findings:

1. How was planned relocation framed as an 'adaptation' approach and a ‘solution' to climate-induced displacement?
2. How can individuals be strategically relocated to a specific location with the goal of increasing resilience and adapting to climate change?
3. Using mathematical methods, is it possible to optimally identify a proportion of affected communities that should be relocated?
4. What is the degree of confidence in the obtained result?

1.5 Rationale for the Research

It is reasonable to assume that climate change will cause certain groups to be more negatively affected than others, such as groups that are in vulnerable locations or the poor, young, sick, or elderly. Cities that are especially vulnerable to various extreme weather impacts such as floods, landslides, and droughts place a significant burden on the general population. Individuals are accustomed to a range of normal conditions and are typically sensitive to extremes outside of this range. Several aspects of human existence, from social to cultural to natural, would be affected by ineffectual adaptation measures. Agriculture, fishing, and tourism are all impacted, which has a direct impact on a country's Gross Domestic Product (GDP). Most people who live in these regions are extremely poor and have a hard time adapting to the changes around them. They have limited financial resources to deal with their environment, relocate, or respond to rising food prices.

Relocations which have been carefully planned have been viewed in both developed and developing countries, with varying situations, including thousands of people relocating for good in more stable areas, as well as less grandiose efforts like that of a hundred people or less moving out of a vulnerable area. After the 2004 tsunami, for example, resettlement efforts were carried out in developed countries, and more extensive ones in developing countries. Many scholars assert that migrations are caused by natural events, such as floods and poverty, which necessitate relocation (Black *et al.*, 2011). The poor have historically used migration as an adaptation strategy in the face of extreme climate events (Abebe, 2014). "Migration is (and has always been) a critical mechanism for mitigating climate stress. In all cultures, there is a tendency to leave a water source when drought occurs. It is a regular part of life for pastoralist societies to migrate from a water source when drought occurs. But migration as a response to environmental change is not only for nomadic societies, but has now also been shown to be practiced by other groups as well "bringing these disparate concepts together (Brown, 2012).

Accordingly, Brown (2012) contends that large-scale migration may not be feasible, as there are likely to be significant societal costs and benefits to labour mobility. The remaining population may need to adjust to the shifting migration patterns. An important option to be considered alongside total migration is partial relocation, as it promotes continuity with regards to individuals pursuing new and/or existing opportunities in and around the community for the common good. Also, relocating communities are more likely to appreciate this effort when they are well informed, are given a say in the decision making process, and are provided with fair compensation (social and economic opportunities) (McAdam and Ferris, 2015). For those in leadership positions, as well as individuals, it is absolutely necessary to implement proactive measures in advance of planned relocation. Mathematical and operational research techniques are some of the tools that are utilized in order to accomplish such tasks as identifying, comprehending, and solving environmental issues. The traditional mathematical modeling approaches have given way to the implementation of a computer-based decision support system (DSS) (Zeidan, 2015). Körner and van Straten (2008) mentioned a decision support tool designed to help make an informed choice on climate regime control in order to gain the most amounts of sustainability and plant quality. Also, this was offered by (Blecic *et al.*, 2008) in the multi-objective evaluation model, and software tool for project selection and prioritization, in accordance with which multiple objectives can be considered.

Additionally, AHP has been applied in goal programming to solve problems in a variety of fields, including facility location-allocation (Sylla and Wen, 2002), quality control (Blecic *et al*. 2008), and information technology. The Mixed Integer Programming (MIP) model developed by Kim *et al.* (1999) in which the sequencing for precautionary priorities is programmed using the AHP to aid the media selection process. Santisirisomboon *et al*. (2005) investigated 15 study areas of effects, adaptation, and susceptibility to global climate change as well as greenhouse gas mitigation plans for Thailand to address global warming concerns. To ensure the complete representation of all stakeholders, all contributions from each stakeholder group were measured using the weighted geometric mean method and the total scores for the study areas were calculated. The AHP was used to measure four judgmental criteria in relation to importance, and four criteria were then used to create the importance index for each region.

Sarker and Al-Mahmud (2009) suggested multi-objective optimization DSS for planned relocation. The main driving factor for this research was based on a variety of issues. First of all, climate change is a global issue, and even though Africa is not necessarily considered as one of the major polluters, the fact that Africa must now mitigate and adapt to the effects of climate change cannot be disregarded. Although the current situation is not as grim as predicted, it will certainly get much worse in the future. People will have to move from the coastal areas as a result of rising sea levels, erosion, and other natural disasters. This will happen and will only increase in the future. Secondly, though considerable resources have been invested in studying the science of climate change, people's vulnerability due to relocations has gone relatively unstudied. This is an opportunity to complete a comprehensive examination of a proposed solution with the hope that it will, in the process, identify some obstacles and offer some new solutions to other significant emerging problems. Lastly, while much attention has been given to the roles of international agencies and states, very little publicity has been given to indigenous community-based research aimed at building community resilience and adaptation strategies. Community-based systems can be integrated with state approaches to provide a more holistic and diverse approach.

1.6 Theoretical Framework

Climate change has devastating impacts globally, which affect humans and animals and threaten their livelihoods. The Paris climate agreement was signed on December 12, 2015 at the UN climate change summit in order to help the world address the effects of climate change. To help build political support for the accord, each country had to submit plans for how they expect to reduce their greenhouse gas emissions to the UNFCCC (2008). Countries are working towards building global consensus around which types of impactful policy measures will be implemented in their respective countries, and collaborating with each other in international platforms. At the same time, the world is continuing to experience intense environmental challenges. If the increase in the number and severity of climate change disasters can be proved, this would imply the necessity for every country to intensify their mitigation efforts.

Even if ‘climate change' is now most commonly used to refer to the dramatic changes in modern climate brought primarily by humans, it will continue to be a powerful term to describe the change because of our global population growth. Climate Change discourse history demonstrates that it evolved from a purely scientific concern to a public agenda that is now more inclined to be a development issue Moser and Dilling (2004). Every time, there has been a complete paradigm shift brought about by transformations. This world's population faces perhaps the most serious environmental issue today. According to studies such as those conducted by Anne Vlassopoulos (2012), Seacrest *et al.* (2000), and Moser (2010), climate change has ceased to be a topic of discussion exclusively within the scientific community since its emergence in the early nineteenth century.

This issue has been elevated to the level of public concern. However, at the same time, it has been demonstrated that human activities have greatly exacerbated the current climate crisis, threatening numerous physical, socio-economic structures. It has been shown, however, that sceptics have shown compelling evidence to eliminate the human-induced climate change characteristics. Yet, the scientists persist in suggesting various ways to handle the pressing issue. Because of increasing public involvement in the Climate Change discourse, as well as their becoming aware of the various uncertainties associated with the issue, it has been studied and discussed from a variety of perspectives.

Sustainability, when it comes to relocation, is an important concept. The term "sustainable relocation" will be approached with caution and afforded a previously-determined term to assist readers and users. Then, we have a contextual definition for this work. Sustainable Development was defined in 1992 at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro as "development that meets current needs without jeopardizing future generations' ability to meet their own." These three forms of protection can be drawn from three different realms: environmental preservation, economic development, and social well-being. In this light, Sustainable relocation might be defined as "a process in which a number of individuals join together to relocate to a location while also protecting the environment, enhancing the local economy, and improving the community's social well-being for the time being, while leaving future generations with the freedom to follow suit." Also, we can define "Planned Migration" as a planned process in which people or groups of people move away from their residences or temporary lodging, to a new location, and are provided with the opportunities to rebuild their lives. Planed relocation takes place within national boundaries and is undertaken to guard the population against risks and impacts related to disaster, environmental change and the consequences of climate change, including national authorities, local and/or other level of authorities, including relevant institutions, as applicable. The move may be made at the individual, household, or community levels. The Guidance for planned relocation can be found in Appendix.

In devising an optimal resettlement plan, we have to determine how many families (who and how many) we need to resettle at various locations, which influences both social and cultural capital. It is anticipated that such an investigative study will lead to further research. Thus, we expect that relocation strategies will be required, and planning for achieving those objectives will need to be done strategically. We have a two-stage strategy: The first stage involves choosing how many families to resettle from various areas impacted by the disaster. Next, the plan will select which families to select, taking various human and social–cultural factors into consideration. At the latter stage, the composition of a family in terms of the number of elderly members, the family members' health status, and the number of children must be considered when determining the priority for selecting a family for relocation.

The adaptation strategies will entail investing resources (that is, costs) in order to make them feasible and successful. Various adaptation strategies for coastal climate risks include: barriers against rising sea levels, constructing elevated housing infrastructures (such as on pillars), creating islands of high land segments, and protecting them from erosion, redesigning crop mixes, and using biotechnology to produce new types of drought and salt-resistant plants and domestic animals, and irrigation systems that use renewable energy and maintain stable temperatures in housing.

In addition, to use any of these strategies, an organization will also have to adhere to an adaptation policy framework. Additionally, relocation of any group to a new location will necessitate resources for new housing, schooling, health care support, as well as the provision of planning for retraining and financial empowerment to help launch a new business or trade.

Chapter 2: Literature Review

2.1 Introduction

Rather than being speculative about the future, environmental displacement is a present-day reality. Migration fuelled by changes to the climate, particularly in Africa, has been identified as an undercurrent in the mass displacement discourse, as reported by experts. Climate change will cause mass migration across Africa due to its effects on agriculture, water resources, and infrastructure, and thus media companies, advocacy groups, and research organizations are collaborating to help spread awareness of the migration crisis. But how likely is it for ecological threats to prompt thousands of people or more to relocate? It is estimated that we will see four large-scale changes in climate take place, and these will continue to grow in intensity in the decades ahead. According to current projections, air temperature will rise by 2°C above pre-industrial levels by the year 2050. (IPCC, 2007). It is also expected that there will be increases in sea surface temperature. There is evidence that suggests that the temperature of the tropical sea has been rising over the past 50 years, with disastrous consequences for coastal ecosystems (Reaser *et al.,* 2000).

It is expected that precipitation will change, too. We can expect that increased rainfall intensity, frequency, and/or severity will be observed across a majority of locations. Thirdly, climate change is expected to result in rising sea levels. Such a report was the one made by Gerald A. Meehl and Taylor (2007), who, in their research, predicted that the rise in sea level will be between 18 cm and 59 cm by the year 2100. Nonetheless, it remains a significant degree of uncertainty with regard to projected sea-level rises, and this causes reason to believe that these estimates may be conservative. The fourth factor to consider is that a variety of environmental systems may undergo change, such as the El Niño Southern Oscillation (ENSO) phenomenon and the Asian monsoon. These two systems are expected to be followed by further changes in extreme events.

The outcomes of these changes will have a greater impact on the ecosystem goods and services people depend on. Sea level rise puts coastal populations at risk of land loss due to erosion and inundation. Additionally, coastal populations face the threat of increasing intensity of coastal flooding. Ocean warming and ocean acidification threaten coral ecosystems and the livelihoods of millions of people, especially in developing nations where artisanal, pelagic, and aquaculture fisheries support much of the country's food supply. Climatic change, in addition to decreases in mean precipitation, will negatively impact agricultural productivity, especially in many low-latitude countries.

Even in places that have experienced an increase in average global temperature above 3 degrees Celsius, food production is likely to be severely hampered in almost all locations (Pacetti *et al.*, 2017; Akukwe *et al.*, 2020). While some scholars have predicted an inevitable trend toward rising sea levels, climate-related extreme weather events, and an increase in environmental displaced persons (Nicholson, 2001; Fuller and Ottke, 2002; Epule *et al.*, 2012; Brown, 2012; Biermann and Boas, 2010), others argue against this environmentally deterministic view, arguing that climate change is only one facet of a complex interdisciplinary problem (Rowntree *et al.*, 2015; Vecchi and Soden, 2007; Epule *et al.*, 2015; Barnett and Webber, 2010; Tierney and Oliver-Smith, 2012) In the event that these uncertainties around causality prove to be legitimate, how people should be adapting and what they should be adapting to are open questions.

2.2 Climate Change and the Need for Adaptation

2.2.1 Global warming and challenges for human living conditions.

Global warming has to do with the fact that Earth is gradually warming, which is a change in the entirety of Earth's characteristics that is referred to as climate change. Along with observed changes in air temperature, climate change entails changes in precipitation patterns, winds, ocean currents, and other scientifically agreed-upon indicators of the Earth's climate. While it is normally defined as a combination of various natural forces taking place over varied timeframes, climate change is typically seen as a number of forces acting together at once. Since the dawn of human civilization, climate change has included an "anthropogenic," or entirely human-caused, component, and this component has grown in importance over the last two centuries during the industrial period. The phrase global warming refers to any warming that can be attributed to human activities over the last two centuries.

The gradual increase in average air temperatures near the Earth's surface over the last one to two centuries is what the scientific community refers to as global warming. Observations on different weather patterns and on climate influences (such as ocean currents and the atmosphere's chemical composition) have been recorded since the mid-20th century. These data indicate that the Earth's climate has changed on almost every conceivable timescale since the beginning of time, and that human activities have been intimately linked to the majority of events leading to climate change since at least the Industrial Revolution.

Selin and Mann through an online journal, Britannic special report produced by the IPCC in 2018, honed this estimate further, stating that human beings and human activities have been responsible for a global average temperature increase of between 0.8 and 1.2°C of global warming since preindustrial times, and almost all of the warming observed over the second half of the 20th century could be attributed to human activities.

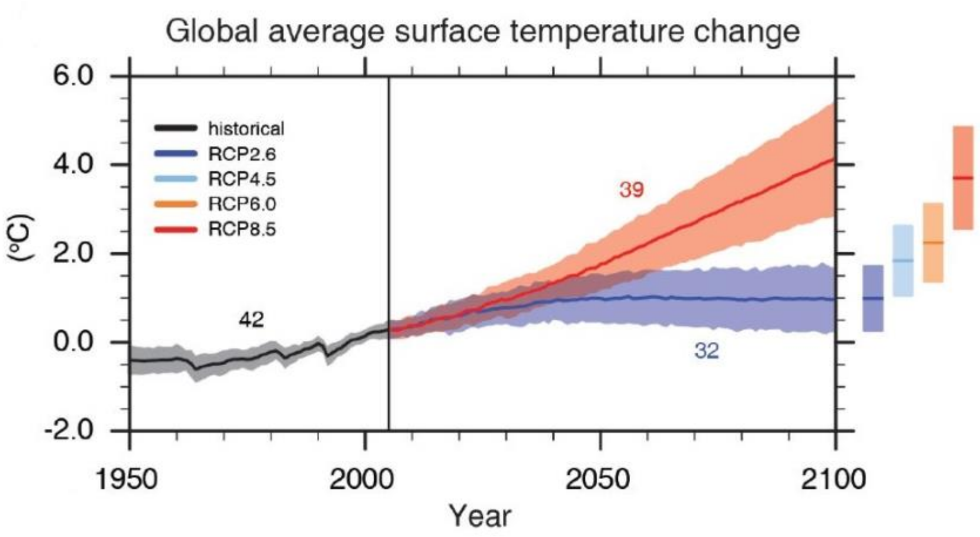

Figure 2:0:1 Different scenarios of change in global surface temperature

According to this model, carbon emissions will continue at their current rate and the global mean surface temperature will increase by about 4 and 5°C by the year 2100, relative to the average surface temperature during the period 1986-2005. Changes in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts are called adaptation. It refers to modifications to processes, practices, and structures in order to mitigate potential harm or capitalize on opportunities associated with climate change. To sum up, the current situation of climate change impacts as well as future impacts is putting pressure on countries and communities, which must come up with a means of adaptation and then carry out a plan of action to deal with these pressures. In the unique context of a community, business, organization, country, or region, this could take many forms.

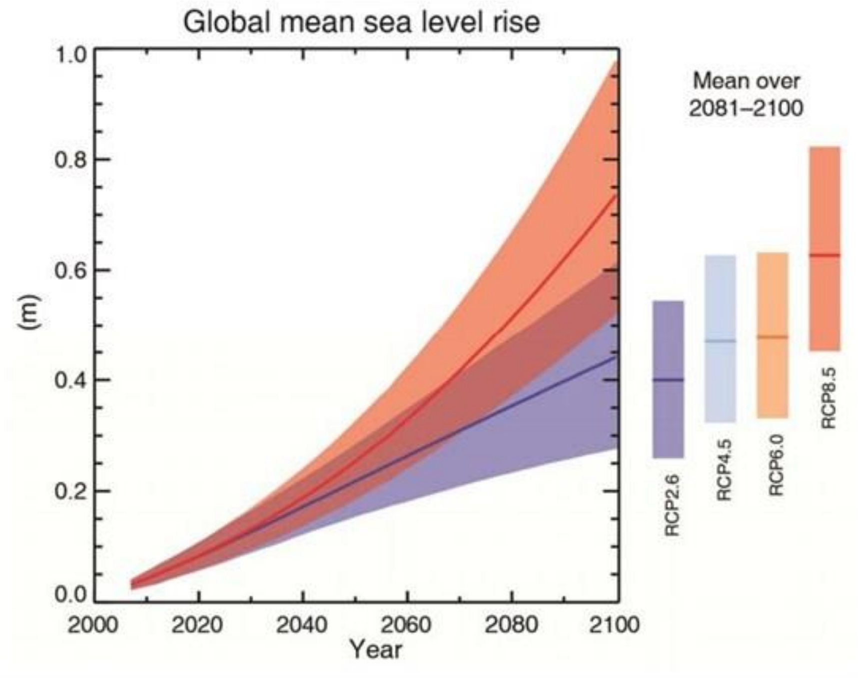

Figure 2:0:2 Different scenarios of sea-level rise

Source figure 2.1 and 2.2: IPCC (2014)

Flood defence, early warning systems for floods disasters, and a switch to drought-resistant crops are all parts of a unified adaptation. We also believe it is important to foster a robust and economically stable nation; however, the situation is worse, and the costs are much higher, as the risks now and in the future must be managed with considerable effort. Some types of adaptation activities rely on governments, but they also depend on other stakeholders like those active and motivated, as well as knowledge management that is effective. Adaptation to the effects of climate change can take place across multiple regions, sectors, and scales.

Adaptation is a global challenge that all parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement acknowledge as having local, subnational, national, regional, and international dimensions. A critical component of a long-term, comprehensive strategy to combat climate change is to ensure that people, livelihoods, and ecosystems are protected. Recognizing that adaptable policy initiatives are best guided by science-backed, country-specific, gender-responsive, participatory, and fully transparent approaches, that take into consideration disadvantaged groups, communities, and ecosystems, and is rooted in and follows an established methodology guided by the best available science, and when appropriate, relies on traditional knowledge, indigenous knowledge, and local knowledge systems, the world leaders declared that the ensuing work would comprise many steps and consist of a variety of different measures. A dedicated package of decisions to support least developed countries (LDCs) was adopted at the Conference of Parties (COP) 7 in Marrakesh in 2001, which Parties recognized the specific challenges faced by LDCs with regard to the impact of climate change, and further agreed to the implementation of a number of specific projects.

The LDC work program includes, but is not limited to; national adaptation action plans (NAPAs). Participation in NAPAs is a means for the LDCs to identify priorities for adaptation to their immediate and urgent needs.

Climate change, including fluctuations in rainfall, heat, and overall climate systems, poses risks to water supply. The effects of global warming and climate change continue to threaten communities all over the world. Floods, wildfires, and coastal erosion seem to be almost constant news. When climate change increases the likelihood of extreme events, what will happen? The ways in which climate change influences human activity and adaptations to those effects are shown in Table 2.1, which contains information on how various adaptive responses might appear in the context of climate change.

Table 2-0-1 Three Forms of Adaptation: Resilience, Transition, Transformation

Forms of Adaptation	Definition	Example
Resilience	Operating on the most confined level, seeking only change that can allow established functions and practices to survive, without addressing fundamental assumptions or power inequalities in society	The goal of adaptation is to reduce risk and protect people from harm.
Transition	To assert full rights and responsibilities rather than make changes in the regime," targeting governance structures that facilitate this (by holding the state and the international community equally	The objective of adaptation is to preserve additional rights, necessities, and interests beyond physical security.

	accountable)"	
Transformation	The most profound form of adaptation exemplified by transformation in the underlying political economic regimes and associated cultural discourses on development, security, and risk."	Addresses the core structural reasons that sustain vulnerability and inequity.

Derived from Peiling 2011

Research published in the past few year's points to the consensus that human mobility will be impacted by global warming, and that as a result, governments will need to alter their strategies in order to handle the related environmental changes associated to climate change. Warner *et al.* (2013) suggested that there are four main pathways by which climate change may limit human mobility either directly or, when combined with other variables, such as economic instability or governmental restrictions,

1. Climate change, which contributes to drying trends, and reduced access to resources like water, negatively impacts a variety of environment-related livelihoods, including agriculture, forestry, fisheries and so on;
2. Sea level rise, desertification, and other climate changes rendering coastlines, low-lying areas, and dry terrain inhospitable in the long run;
3. Rising frequency and severity of weather-related extremes like as floods and storms, which destroy infrastructure and livelihoods and necessitate relocation; and
4. Competition over water and land resources, which may cause conflict that, needs migration.

Food security and extreme events will be made worse by climate change, which will worsen infectious diseases such as malaria, diarrhoea diseases, and respiratory infections. Numerous studies, for example, estimate increases in the transmission of malaria, particularly in Africa, which is noteworthy considering that 11445 million people are already exposed to malaria each year in Africa, resulting in over 1.3 million deaths, Levy (2019); Salas *et al.* (2019); Tong and Ebi (2019); Caminade *et al* (2014). An increase in mortality due to climate change is anticipated to occur in a number of different ways: through the way in which weather conditions are worsened, such as through more extreme heat waves, flooding, and other disasters, as well as by impacts that negatively affect human and animal health, such as contaminated water, hunger, and vector-borne disease. For these studies, see Watts *et al.*

(2015), Roberts *et al.* (2017), and Page and Howard (2010).

Although these changes to water, food, and health have ripple effects on the livelihoods of people, the specific impact these changes have on water, food, and health differs from person to person. Perceived vulnerability among those whose livelihoods depend largely on natural capital, who have limited financial resources, and who tend to contribute less to environmental pollution, including farmers and fishers, is concentrated in those individuals who own or have a claim on limited financial resources, with their livelihoods most highly dependent on natural capital. Under such circumstances, a lack of resilience is even more apparent. The authors included Schlosberg *et al.* (2017), Ensor and Harvey (2015), Shi *et al.* (2016), and van Valkengoed and Steg (2016) in their paper (2019). Most of these groups have proven techniques for coping with fluctuation in natural resources. In most cases, they employ social capital and migration to get by. But, because changes in resource stock abundance and drop in mean conditions are persistent, these tactics will cease to be successful over time.

Resource dependent and low income rural areas are at risk, but it is not a simple case of either/or: being dependent on resources or income. It is important to realize that a large percentage of those whose earnings depend on primary resource sectors are also in danger. Indeed, climate change will have wide-ranging, long-term economic impacts on many different economic sectors and countries around the world, which will cause losses in both economic growth and economic output practically everywhere. Based on Cinner *et al.* (2018), climate change is predicted to produce an annual worldwide decline in consumption per capita between 5% and 20%. Climate change consequences will fall disproportionately and initially on the poorest people and the poorest countries.

2.2.2 Migration and planned resettlement.

The issue of human mobility has been examined by numerous authors in varied contexts. There exists a distinction between intensive and extensive hazards relevant in characterising the link between climatic risk and human mobility. Individuals' movements in response to intense dangers are quite distinct from those in response to extensive dangers. Researchers Warner *et al.* (2013) categorized these movements as (i) migration, (ii) displacement, and (iii) intentional relocation or resettlement. Even while the forced and voluntary migration can be thought of as two distinct concepts, the distinction between them is blurred, and the line between them is difficult to identify, particularly when individuals are moving out of concern for extensive risk. The term "planned relocation" is a distinct category, though the magnitude is very minor compared to other forms of climate-induced migration and displacement. Roughly one-third of the current total number of internally displaced persons (IDPs) resides in regions anticipated to be submerged owing to sea level rise. According to a report from the UN High Commissioner for Refugees (UNHCR, 2014), hundreds of thousands of people seeking refugee or stateless status have also relocated due to their national borders being threatened by rising sea levels. Where people move depends heavily on context, and while overall migration patterns tend to follow urban population growth, the size of that increase or decrease might vary from place to place (Adamo, 2010). Notably, of the two types of risk, impacts of climate change are most widespread. In general, climate-related stress and shock affect whole communities rather than individuals or families. Refugees and persons displaced due to climate change have also been called ‘climate change refugees'. Responding to climate danger may involve migration for some, while for others it may not (Adamo, 2010).

Others, on the other hand, may adapt without relocating. Some people will not be able to adapt to these changes, and they may opt not to migrate, and thus they may endure livelihood deterioration. Nonetheless, the number of individuals who cannot move because of climate change (because to variables such as poverty, remoteness, ill-health, or age) may significantly surpass the number who can, and therefore this humanitarian concern could be substantially more widespread, even though it will be spatially and temporally diffuse.

People's views of risks and rewards of remaining as opposed to moving will be influenced by changes in climate and social-ecological systems. Where climate change exacerbates illness, reduces income, and eliminates access to natural capital, individuals are more likely to move to regions they believe will provide them with opportunities for a better life. "To the degree that environmental change is implicated in migration, there are reasons to be concerned about increased migration in reaction to climate change. However, there is little knowledge about how many people will relocate, and where they will migrate from and to "being socially challenged (Anguelovski *et al.,* 2016).

Climigration is another term that is sometimes used in this context. A city-based exodus (also known as "climigration") is a planned evacuation of entire communities to new sites that are safer. This takes quite a lot to get a group to shift, though. Very extreme occurrences can do that to a society socially, economically, and physically. Bridges and other infrastructure are destroyed, community cohesion and morale are severely affected, and countless other aspects of daily life are irrevocably altered (IPCC, 2014). The first method of coping with the shock of an extreme incident is to have people respond in one of two ways. Many communities are attempting to restore the damage done to their homes and keep going on as they have been which is referred to as resiliency. Attempting to patch up and strengthen your assets in the face of future threats is known as "adaptation." Climigration is thus a sort of extreme adaptation to climate change. The majority of poor persons tend to remain in their home countries rather than move, particularly in economies where wealth and mobility are concentrated among the richest segment of the population.

However, impoverished people appear to be as likely to migrate as others, but the difference is that they only appear to move a short distance. The analysis of this evidence shows that while the resources brought home by migrants from low-income countries are tiny in comparison to the advantages, and these migrants' adaptive capability less apparent, the relative contribution to the financial security and capital resources of households is high and therefore makes a huge difference (Lucas *et al.,* 2006). Additionally, Lucas *et al.* (2006) found that there were information hurdles to migration, including a lack of understanding of where to go, how to get there, and methods of making a new life once they arrive. Once migrants have found new locations, they use their social networks to assist those who have faced difficulties obtaining the information or resources they need. The other side effect of this is that it also tests the feasibility of areas as locations for migrants, which in turn makes locations where migrants have established a life for themselves viable choices for other people who might contemplate moving.

From the foregoing, we can safely assume that migration has been largely an option for individuals or a group of people who are unable to receive support from the government. Migration has been a simple alternative for those who were not able to receive help from the government, but through acceptance and a proper awareness of planned relocation, nations will move forward via making the process of human movement much simpler. The particular persons who are in danger perceive their circumstances as being less dangerous, as a result of which they believe their prospects to relocate, are greater. For that reason, there are a lot of planning and precautions in place.

2.3 Impacts of Climate Change in West Africa

Due to the region's long coastline, heavily inhabited towns and commercial hubs are situated at the coast, facing a number of risks, including from increasing sea levels, coastal erosion, and flooding. Changes in temperatures and shifting rainfall patterns have already impacted a variety of people, including those whose livelihoods, food security, and governance stability are at risk. Climate impacts from transnational sources, which include implications on food security and water quality and availability, hazards to health due to poor air quality, disruptions to transportation networks, and an increase in migration, represent challenges to national security.

Figure 2:0:3 Map of West Africa

Source:https://www.nationsonline.org/oneworld/map/west-africa-map.htm

Coastal degradation and erosion are significant problems in West Africa. Erosion is currently progressing on around 56% of the coasts in Benin, Cote d'Ivoire, Senegal, and Togo, and this is anticipated to worsen in the future.

While sea level rise is not the primary driver at the moment, it is predicted to combine with other factors in the future to amplify the negative repercussions of environmental changes (Sylla *et al.*, 2018). Agriculture is a significant part of Africa's economy and supports a large percentage of the continent's population. Due to Africa's role as a climate change exposure and susceptibility "hotspot," the continent is susceptible to climatic variability and change impacts. IPCC issued forecasts in 2014 suggesting that warmer conditions could affect the world's crop productivity and food security. Some of the primary hazards to agriculture identified include reduced crop output as a result of stress caused by heat and drought, and an increase in insect outbreaks. A result of this is significant disruptions to food security and local livelihood. In the paper, it is anticipated that by the middle of the century, most cereal crops farmed across Africa will have decreased yields due to decline in yield potential. However, this will be the case across Africa with regional variances and variability. In West Africa, a 13% loss in mean yield is expected under the worst-case climate change scenario. Millet and sorghum have been determined to be the most promising crops, with a production loss by 2050 of just 5% and 8%, respectively, due to their superior tolerance to heat stress conditions, while rice and wheat are predicted to be the most affected crops with a yield loss by 2050 of 12% and 21%, respectively.

West Sahel is the most sensitive region of Africa to anthropogenic climate change, while the remainder of the region, especially West Africa, also sees intense, but less extensive, extreme weather. Anecdotal evidence and other earlier research have indicated that both the rainy season and the growing season will become progressively shorter, while also significantly increasing the odds of frequent drought, drought, and dry, semi-arid, and hot climates. Using the work of Sylla *et al.* (2016), it is estimated that around half of the nations in Western Africa will have to deal with shorter rainy seasons, generalized hot, arid and semi-arid conditions, longer dry spells, and more intense extreme precipitation. According to these conditions, agriculture, water resources management, ecosystem services, and urban areas planning can experience severe stress. However, it was argued that, when it comes to reducing stress, mid-level climate control may be beneficial. Agriculture in rural areas plays a key role in mitigating the negative effects of climate change in this region (Abebe, 2014).

Climate change's effect on human civilization will be felt much more drastically due to rapid population expansion, which will increase pressure on land, crop losses, and ecosystem services. There will also be greater stresses on water supplies due to progressive soil degradation and land loss. And as we look at the years ahead, we see an increasingly stressful climate (Kemp *et al.*, 2017).

According to the IPCC (2014) report, a sea level rise of up to 1 meter by the 2050s will flood almost 18,000km^2 of the coast of West Africa, displacing both farmland and transit routes. In West Africa, we have distinct ecosystems ranging from coast mangroves, rainforests, savannahs, interior deltas, and the nearby Sahel, where habitats are being degraded from global warming and changing rainfall patterns. In addition, flames can travel across borders, damaging land and water resources and the quality of the environment. Furthermore, habitats along the coasts are at a greater risk of inundation, coastal erosion, and saltwater intrusion. Water-related disasters in West Africa caused catastrophic infrastructure damage, considerable crop losses, and considerable soil erosion and degradation in 2007, 2008, and 2009, according to research.

There was a total of 9,300 hectares of farmed fields destroyed in Burkina Faso in 2009 (Sarr, 2012). Adding more constraints to the region's capacity to satisfy future food demands would be a result of more warming climate alongside expanding population and income. With alterations in monsoon strength, timing, geographical patterns, and temperatures, which have the potential to both positively and negatively affect agricultural output and the West African population's well-being, there will be variations in the monsoon's distribution, strength, timing, and spatial patterns. Therefore, a focused and intensified effort is needed in the appropriate directions.

2.4 Human Mobility as Adaptation Strategy: Sustainable Relocation

Several scientific papers on the issue of adaptation to climate change indicate that improved coordination and main streaming of adaptation efforts should be undertaken in order to enhance cooperation and mitigate risk. One such paper (the IPCC, 2014) noted that this recommended that cooperation and risk mitigation plans must be carefully prepared to avoid worsening vulnerability. Similarly, the report raises questions on adaptive options, restrictions, and limits.

Thus, by examining relocation decisions via the aforementioned lens, one can provide a solid foundation for assessing potential opportunities, limitations, and limits to adaptability. In their article on climate-induced mobility, McAdam and Ferris (2015) noted the following: Difficulties may be encountered when attempting to quantify environmental mobility, due to methodological challenges and a lack of common data gathering standards. Perhaps quantifiable statistics exist on population displacement within fewer West African countries, if any, and none across borders, as a result of natural disasters. Due to slow-onset environmental effects, the majority of existing data are qualitative and based on case studies, with only a few comparative researches. While these data gaps persist, the ways in which research is done continue to be improved upon. However, it can be difficult to determine when human movement is due to the environment, as opposed to other variables.

Environmental influences are frequently shown to be associated with social, political, demographic, cultural, and personal aspects that contribute to or inhibit mobility. It makes data collecting in the aftermath of an evacuation problematic, as demonstrated by Teye *et al.* (2018). There is little information about the individuals who are moving owing to gradual processes like sea level rise or salinization because that is a hard study to do. Movement is made even more simplistic into three levels, with each having their unique qualities:

1. People who need to be relocated from areas prone to sudden-onset natural hazards that are becoming more severe and intense as a result of climate change (e.g. flood areas);
2. People whose livelihoods are threatened by slow-onset effects of climate change (for example, increasing drought frequency, salinization of water as a result of sea level rise);
3. People who need to emigrate because their country or sections of their country may become unsuitable for habitation or supporting livelihoods as a result of climate change's negative effects (small island states facing sea level rise).

2.5 Decision Support System

In environmental research, many consequences are difficult to predict because of the complexity of the phenomenon and the way it is being managed. In order to analyse the possible impact of management actions on anthropogenic and natural occurrences, researchers and policy makers commonly employ computer models and associated software tools. An information system that assists in the making of decisions that require judgement, determination, and a series of actions is referred to as a decision support system (DSS). The information system helps by compiling and providing relevant information that can help solve problems and aid in decision-making (McCartney *et al.*, 2005; Sylla and Wen, 2002). A DSS can be manually powered, fully automated, or some mixture of the two. Information reports are created by decision support systems that use data to construct them. Data gathering and organization, and providing information in an understandable way are only a few of the uses for DSS.

DSSs can be used in numerous types of knowledge domains (Sarker and Al-Mahmud, 2009; Sugiyarti *et al.,* 2018). The real-time reporting offered by a DSS is one of the system's key applications. A DSS is very particular to the specific company or individual needs that are making the selection (Afolayan *et al.,* 2020; Zeidan, 2015). For numerous decades, complicated and long-term environmental management planning challenges have been solved using mathematical programming and computers. Ecological demand, rising exponentially, coincides with increasing DSS demand (Torres-Sanchez *et al.,* 2020; Blecic *et al.,* 2008; Körner and van Straten, 2008).

Sarker and Al-Mahmud (2009) defined a DSS framework's three primary components as follows:

a. Model Base
b. The software application's interface
c. A database of information

In their investigation, Rupnik *et al.* (2019) propose a system known as AgroDSS, which is designed to bridge the gap between traditional agricultural practices and state-of-the-art decision support methods, an integrated system, which also offers a cloud-based decision support toolkit enabling farmers to upload their own data, enable the use of numerous analytic methods, and obtain results. Predictive modelling, accuracy evaluation, time series clustering, and structural change detection are all used in practice, to better explain the relationships (interactions) in the user's domain, helping people foresee hypothetical scenarios and identify dependencies (interactions) in their area.

2.6 Review of Past Work

A study led by Rurinda *et al.* (2020) investigated these issues in sub-Saharan Africa. In the study, they took into consideration the many sources of nutrients, such as rainfall, soil moisture, crop management, and seed germplasm, as well as various soil nutrient levels, all within varying soil nutrient supply levels. It is shown in the research that the crop yield and fertilizer use efficiency both suffer due to unpredictability. Therefore, a framework for delivery of site-specific fertilizer recommendations is needed. Nutrient Expert (NE), a computer-based decision support system, enables extension advisers to develop fertilizer recommendations for specific fields or areas based on yield response to fertilizer and nutrient usage efficiency. They calibrated the model using data from 735 on-farm nutrient omission trials completed between the year 2015 and 2017 in Nigeria, Ethiopia, and Tanzania. After these studies concluded in 2018, they started another series of experiments between 2016 and 2018, this time employing 368 on-farm nutrients omission across these countries, comparing NE-generated suggestions to soil-test-based suggestions.

Clarke *et al.* (2017) use the Integrated Decision Support System to evaluate the multi-dimensional implications of adopting new technologies in agriculture at the farm/village and watershed scales in Sub-Saharan Africa (IDSS). Simultaneously measuring production, environmental, economic, and nutritional repercussions is made possible because of the integration of several models into one integrated modelling system. The technologies that were used were implemented in one of the regions of Ethiopia, where scarcity of resources and agro-environmental effects are of crucial importance for agricultural productivity on small farms, and thus they were applied to look into the repercussions of various agricultural technology interventions. In terms of income and nutrition, the findings of this study demonstrate that sustainable increases in both family income and nutrition are possible with the use of water-harvesting technology, adequate fertilizer application, and improved seed types, while also sustaining the environment by controlling soil erosion and silt accumulation. Further demonstrating the effectiveness of the IDSS technique is accomplished through the use of this as a forecasting and assessing device that can be employed to plan for and measure the monetary and ecological effects of implementing new rural improvements that aim to boost the financial well-being of resource farmers.
The Sahel-Sudan region of West Africa saw a similar study done by Rader *et al.* (2009) in which stochastic mixed integer programming DSS was used to assist farmers in the region.

This yields top-rate planting strategies that help to lessen the caloric deficit of a household while also maximizing revenues from labour given a forecast of the season's expected rainfall and a hazard level that the farmer possesses. The suggestions given through the DSS were submitted to sensitivity studies that took into consideration factors including labour availability, pricing, and hazard level. The output of the DSS, which were gained from a case study (Bonam Village of Burkina Faso) was also applied as a comparison to survey data from that village. This shows that the DSS embraces many of the intricacies of agricultural management, such as the diversification strategy. To summarize, the study concluded that such optimization may have future purposes in West Africa to aid agricultural decision making and explore weather forecasts and food security enhancement theories.

The growing hazards in agricultural land usage and engineering due to modern agricultural techniques were addressed in Changsha County, a significant grain-producing area in central and southern China. Li *et al.* (2020) provided a technique for managers to receive reliable information to aid in decision-making by utilizing certain methodologies that enable them to create an economically, socially, and ecologically sustainable environment, which is critical for coordinating the development of agricultural land-use patterns, referred to as an agricultural land-use decision support system (LDSS), uses ecological environmental constraints to help managers allocate land resources using a scientific design methodology.

LDSS's framework is a tool to aid managers in allocating and formulating appropriate land-use policy. It is made up of a land quality assessment module, an eco-economic coupling module, and a land-use optimization module. This establishes a system to model the total benefit relationship of land use. After having done all of that, it goes on to examine the risks of soil, water, and ecological security, as well as how these risks arise in the process of land use; it does simulation, and demonstrates the mechanism of occurrence; and completes the correlation equation expression between natural-economic-social indictor and land use risk. Constraints on the design of various scenarios are derived from ecological environmental risk factors.

Finally, multi-objective linear programming is used to calculate the optimal comprehensive benefits of land use and optimal land-use structure based on the constraints of the rural ecological environment. They came to the conclusion that the LDSS framework is viable, straightforward to operate, and very straightforward to advertise, until recently, there have been several DSTs, including Smart Forest (an NIS initiative), which have been created to address worldwide changes in forest management practice. Sadly, the majority of these systems primarily describe the complexity of the scientific knowledge produced, which results in practitioners having a difficult time understanding and using them. In a 2019 article written by Cristal et al. in dealing with the intricacies of climate change and its link to the issues forest managers experienced in applying modern-day innovations, the authors urge information sharing for those who are interested in forestry. The decision support software tool was created with the goal of facilitating the assessment of forest management and climate change impacts on several ecosystem services (ESs) at a stand level. SORTIE-ND is a spatially explicit tree-level simulator for projecting stand dynamics that is responsive to climate change, is incorporated into the decision support tool, and is utilized as the simulation engine for stand development. To increase interaction design and overall user satisfaction, the usability of the system was conducted in an early stage of development for a management-oriented approach with user-centric interface design, and the product's use is critical in supporting education in the field of forest management. The results of the study revealed that there are five primary elements that are involved in the workflow and which determine the decision support tool: the information base, the alternative generator, the forest simulator, the ecosystem services calculator, and the visualization component.

Taraglio (2019) introduced a new risk analysis methodology that accounts for and supports all aspects of the risk analysis process, including event forecast, dependable and accurate damage scenarios, and Critical Infrastructure (CI) estimation. Used in two modes: in operational mode, or in simulation mode to generate risk analysis, building simulations of natural calamities and then evaluate the resultant chain of events (damages, impacts and consequences). Additionally, it provides an estimate of the costs in terms of service degradation and impact on citizens, metropolitan regions, and manufacturing operations, which is critical for mitigating adverse events. However, due to the majority of the DSS models being obtained as well as the chemical data, that information may simply be incorporated into the DSS framework. The further use of DSS is in the field of facility location, where it is used as a multi-criteria decision process that has substantial operational and economic consequences and when the criteria used are ambiguous and fraught with uncertainty.

In his paper, Zeidan (2015) presented selecting a particular location as an MCDM problem that is burdened by several conflicting criteria. The analysis analysed opposing tangible and intangible variables (land cost, building construction cost, traffic access, location characteristics, and market opportunity), as well as additional intangible factors (such as climate, pollution, living expense, and traffic congestion). The site selection choice is a reviewed process, where it goes through several reviews, including AHP and the newly proposed assessment methodology for site selection. Combining AHP and the approach for order performance by similarity to ideal solution (TOPSIS), where the AHP is applied to calculate the weights of the selection criteria and the TOPSIS algorithm is used to provide a final ranking An actual, though somewhat extreme, hypothetical case study was employed to demonstrate the proper usage of the model.

More recently, Botchway *et al.*, (2021), did a study in which they scrutinized software quality from the standpoint of the user and developer, as demand in software quality is at an all-time high. To choose the best software quality attribute, AHP was used with a multi-criteria decision-making assessment on the responses from questionnaires to carry out a decision-making assessment on software quality attributes for the development of the proposed quality model to meet both users and developers' software quality requirements. The assessment's findings indicated that maintainability is the most critical quality attribute.

Chapter 3: Methodology

3.1 Preamble

This chapter serves as a preface to the prior chapter; it provides detailed explanations of the strategies used to achieve the outcome addressed in the subsequent chapter The approaches used in this work required largely mathematical formulas, but also included some more specific information which helped in understanding how applicable they are in situations like relocation and optimization in problem-solving situations.

3.2 Optimization Techniques: Multi-objective optimisation

In decision making, what are referred to as optimization methods is used to determine the optimal value / best option. These include determining the maximum or minimum value (where applicable) or utilizing a single or multi-objective function(s). This sort of problem frequently arises in daily life, such as in mathematics, engineering, social studies, economics, agricultural, aviation, automotive, environmental science, and others. Numerous solution methods are used to solve the many types of multi-objective optimization problems; for example, Sadeghian (2019); Bhattacharya *et al.* (2018); Costa and Pereira (2010) discuss how to convert plural objectives into a single objective by minimizing the distance between multiple reference points and viable destinations.

Additionally, by combining all of the objectives into one, the weighted-sum approach (Stanimirovic *et al.*, 2011; Marler and Arora, 2010) is utilized. In this particular scenario, the number of weights is typically normalized to one. Despite its apparent simplicity and easiness, there are two hidden issues with the weighted-sum approach. To begin, it is challenging to assign weights to objective function of varied magnitudes. When looking for a trade-off solution, there will be a bias towards finding an ideal answer. Additionally, another issue arises if the optimized plural objective is not convex. In order to solve these challenges, the constraining methodology is employed. When applying constraint method optimization, only one objective function is considered per time, while the other issues are translated into limits (Pérez-Cañedo *et al.*, 2020). The vector (ϵ) is determined and uses the upper limit (for minimization). By optimizing all of the objective function, this approach will find an optimal solution for the given vectors. A number of optimal solutions are obtained by varying the vector. The disadvantage of this strategy is that there is no feasible solution for some vectors.

(Du *et al.*, 2014), in their report strongly recommends that, decision-makers should only use their absolute interests to govern objective functions. The optimization procedure is done on each target in order of relevance. If just one solution is returned after maximizing the most important objective, then the solution is the optimal one. On the contrary, optimization will continue on the second objective, this time with additional constraints on the solution derived from the first objective. Until the last target is met, this will go on.

In this research, only multi-objective optimization will be discussed. This optimization deals with finding the best possible solutions for many goals. The reason for utilizing this optimization method is that it does not require intricate equations, which simplifies the task. Applying decision-making techniques in the context of multi-objective optimization allows for compromises (trade-offs) on topics that may be in conflict.

The original proposal of this approach of optimization was made by Francis Ysidro Edgeworth, who further developed it through the efforts of Vilfredo Pareto. Every function of the solution vector is a vector of the objective function. Because of this, there is no single optimum answer for every application, but multiple approaches that each addresses a specific problem. For the multi-objective optimization problem, the equations can be described mathematically as follows.

Maximise

$$f_1(x), f_2(x), f_3(x), \dots, f_r(x) \tag{3.2.1}$$

Subject to:

$$g_j(x) \leq 0$$

Where

X: The decision variable $= x_1, x_2, x_3, \dots, x_n$

$gj(x)$: Constraints with $j = 1,2, \dots, n$

Determine an optimal solution for each of the objective function which could be linear or non-linear.

Minimise / maximize

$$f_r(x) \tag{3.2.2}$$

Subject to:

$$g_j(x) \leq 0$$

Multi-objective optimization has a multi-dimensional space of the objective function vector and a solution vector. For every decision variable x there is a point on the objective function space. According to De Weck (2004), there are two approaches to solving the multi-objective optimisation problem: the Pareto technique and scalarization. The scalarization method is a performance indicator component that incorporates a scalar function to generate a scalar function. While the Pareto approach is utilized when diverse solutions and performance indicators yield a compromise result and can be presented as the Pareto optimal front. This study used the scalarization method. Using this strategy, a single solution is generated and the weight is fixed before the optimization process. It includes multi-objective functions like this:

$$F(x) = w_1 f_1(x) + w_2 f_2(x) + \ldots + w_n f_n(x) \qquad (3.2.3)$$

$$\sum_{i=1}^{n} w_i = 1$$

The weight assigned to an objective function determines its solution and indicates its priority in terms of performance; assigning a big weight to an objective function indicates that it has a higher priority (important) than those with a lower weight. Weights can be computed in this scenario using one of three methods: equal weights, rank order centroid (ROC) weights, or ordered weighted averaging (OWA).

3.2.1 Goal programming

In order for an individual to be totally rational in decision analysis, he must be capable of attaching a distinct preference to each possible consequence of different alternative courses of action, and should be able to identify the exact consequences by utilizing scientific analysis. There is unfortunately no concrete evidence that any single individual is capable of handling a complex decision problem with the kind of exactness required. In actuality, the decision maker may have just a hazy understanding of what constitutes the optimal outcome in the aggregate. Also, poor analytical capacity frequently prevents one from recognizing the ideal option due to either the difficulty of the situation or limited capacity to discern complex problems. Cultural cues can lead people to make decisions that they might not in the long run want to make, especially when guided by someone with different epistemological assumptions, such as the epistemological assumptions of Schniederjans (1995). As a result, it is acceptable to assert that the most perplexing challenge in decision analysis is the management of many conflicting objectives. The crux of the matter is that competing interests must be balanced. Regardless of the nature of the situation, answering such queries as "What should be done now?" is nearly impossible. What may be held? What further can be done? What priorities should the objectives have? As a result, achieving equilibrium in such settings is a critical and difficult part of any decision problem. When one goal must be weighed against the others to reach a stable state, achieving that delicate balance is important.

Goal programming, which is a unique method to decision making, was created as a solution to deal with complex multi-objective decision making. Goal programming is a subfield of multi-objective optimization, itself a subfield of multi-criteria decision analysis (MCDA). It can be viewed of as a generalization or extension of linear programming in that it allows for the management of many, normally conflicting objective measures. All of these objective metrics are given an objective (target) value that must be reached. In a performance metric, unwanted deviations from the set of target values are then minimized by means of an achievement function. This can be a vector (weighted sum) dependant on the goal programming version that is being utilized. Using goal programming in place of other strategies that are used in handling real-world choice problems offers a benefit in that it is a more accurate reflection of decision makers' decision-making styles. Goal programming is one of the mathematical tools which depend on the well-established and proven methodology of linear programming, built for specific scenarios. By enabling the incorporation of environmental, organizational, and management factors into models, it gives businesses and organizations the opportunity to set goals and prioritize. Though, on the whole, far from a cure-all, it frequently represents a major improvement in the study and modelling of real-world situations.

The scope of goal programming has increased significantly, currently covering any linear, integer, zero-one, or nonlinear multi-objective problem, with the possibility of pre-emptive priorities being set. Just as in linear programming, the goal programming model is formed from an ordered set of variables and constraints that together define a goal. However, in addition to all the variables and constraints, all the objective functions must be entered. An important principle in goal programming is that the objectives are defined not just as standard restrictions but also as constraints that constrain the problem. In order to achieve the goals set forth, the objective function seeks to minimize the deviation from the stated goals. As it might be impossible to completely meet every goal, the objective function works to minimize the total of the absolute values of deviations from stated goals. All deviations that are identified in line with priority set to the various goals are given a weight in accordance with their importance, as shown by their coefficients. So long as the linear programming model is used, sensitivity analysis is viable.

Additionally, two types of variables (choice variables and deviational variables) and two categories of constraints (structural/system constraints and goal constraints) are employed in the formulation of goal programming. The structural restrictions are constraining, similar to classical linear programming, which involves expressing the original functions with their associated target goals, with priority and deviational variables that have values of either positive or negative. The goal programming paradigm can be classified according to the relative relevance of the goals, and then sorted from most important (goal 1) to least important (goal m).

The decision maker can identify the importance of each objective or sub objective and order them in an ordinal sequence. No objective can be fully attained. So in general, regardless of whether the decision maker has a specific aim or not, the decision maker will prioritize the achievement of that goal.

The general goal programming model can be mathematically represented as follows:

Minimise

$$z = \sum_{i=1}^{m} (d_i^- + d_i^+) \qquad (3.2.3)$$

Subject to the linear constraints:

Goal constraints:

$$\sum_{j=1}^{n} a_{ij} x_j + d_i^- + d_i^+ = b_i$$

$$for\ i = 1,2, \dots, m$$

System constraints:

$$\sum_{j=1}^{n} a_{ij} x_j \begin{vmatrix} \leq \\ = \\ \geq \end{vmatrix} b_i$$

$$for\ i = 1,2, \dots, m$$

$with\ d_i^-, d_i^+ \geq 0, x_j \geq 0$ for $i = 1,2, \dots, m;\ j = 1,2, \dots, n$

Where there are m goals, p system constraints and n decision variables

Z = objective function = Summation of all deviations (weighted sum)

a_{ij} = the coefficient associated with variable j in the ith goal

x_j = the jth decision variable

bi = the associated right hand side value

d_i^- = negative deviational variable from the ith goal (underachievement)

d_i^+ = positive deviational variable from the ith goal (overachievement).

It is impossible for both achievement and non-achievement of an objective to occur concurrently. Thus, one or both of these must have a null value; that is,

$$d_i^- . \ d_i^+ = 0$$

Both variables apply for the non-negativity requirement as to all other linear programming variables; that is,

$$d_i^-, d_i^+ \geq 0$$

As with the Linear Programming model, the Goal Programming (GP) model in equation 3.2.3 has an objective function, restrictions (goal constraints), and the same non-negative restriction on the decision variables. Goals are established by those who make decisions in order to compete for limited resources. However, achieving these aims may be a challenge. Thus, to ensure the satisfaction of conflicting goals, an appropriate hierarchy of priorities needs to be established. Once all of the important goals have been met, there is no purpose in pursuing goals that are of lower priority. As a result, one does not simply try to maximize or minimize the objective criterion, but instead tries to minimize the discrepancies between goals and what can be accomplished with the current set of constraints.

3.2.2 Analytic hierarchy process approach

A popular MCDM is AHP, first presented by Saaty in 1980. Decision-making is measured using AHP, which measures, orders, ranks, and evaluates the choices. This has been widely used in real-world scenarios to help solve difficulties. AHP uses pair-wise comparisons of criteria weights to estimate them and boosts the precision of the results. Pair-wise comparisons are used to establish precise ratio and scale priorities. It is a robust method for quantitatively transforming the judgments of decision makers into numerical values. Some of the advantages of this strategy are its simplicity in managing many criteria. There is a degree of inconsistency that is allowed by the AHP process, and that inconsistency may crop up during the pairwise comparisons of criteria and other decision aspects.

The process utilized in common-sense decision making bears a striking resemblance to the method utilized in applying AHP. This methodology, however, cannot accommodate the degree of uncertainty associated with the preference ratings for scoring the criteria. Although there are a variety of multi-criteria decision making procedures, there are no better or worse strategies, but some strategies better suit to particular decision issues than others do. It is possible to utilize the AHP technique, which integrates judgments on intangible qualitative criteria alongside tangible quantitative criteria, to include intangible qualitative and quantitative factors. According to Dadeviren *et al.* (2009), the AHP technique is centred on three guiding principles: model structure, comparative evaluation of alternatives and criteria, and priority synthesis.

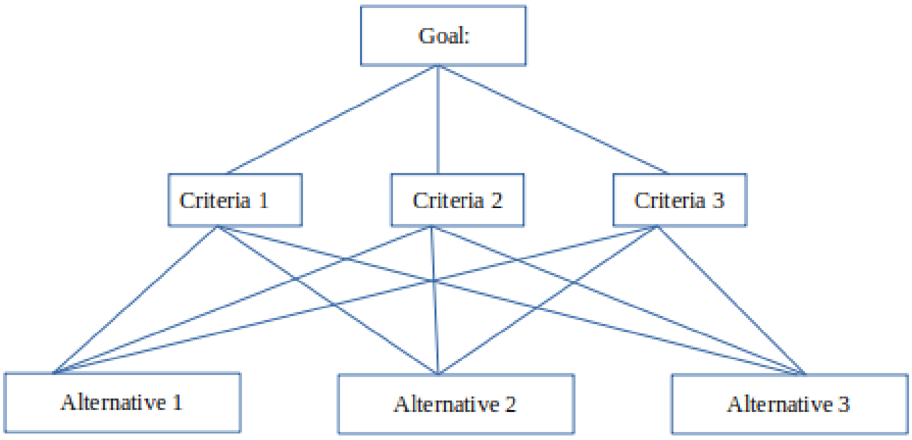

Figure 3:0:1 General AHP Hierarchy for Computing Priorities of Goal Objectives

To begin, a complex decision problem is organized hierarchically. AHP begins by decomposing a complex multi-criteria decision-making problem into a hierarchical structure of interconnected decision factors (criteria, decision alternatives). Where the objectives, criteria, and alternatives are structured like a family tree. Typically, the hierarchy has at least three levels: the general aim of the problem is at the top, followed by the many criteria that identify alternatives in the middle layer, and finally, decision options at the bottom. The following stage involves a comparison of the alternatives and criteria. Prioritization begins when the problem has been deconstructed and the hierarchy has been defined. At the second level, you have a pairwise judgment that goes from one alternative to the next, going on to the lowest level of options. Each level is compared pairwise to determine influence on the criteria, and the criteria at the upper level are evaluated based on the listed criteria for that level. Table 3.1 shows a standardized comparison scale of nine levels to be used for numerous pairwise comparisons in AHP.

Table 3-0-1 Intensity of importance scale and its description

Definition	Intensity of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2,4,5,6,8
Value of inverse comparison	$\frac{1}{3}, \frac{1}{5}, \frac{1}{7}, \frac{1}{9}$

Let $C = \{C_j | j = 1, 2, .., n\}$ be the set of criteria. The result of the pairwise comparison on n criteria can be summarized in an $(n \times n)$ evaluation matrix A in which every element a_{ij} $(i, j = 1, 2, ..., n)$ is the quotient of weights of the criteria:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \ddots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (3.2.4)$$

Where; $a_{11} = 1, a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0$

In the final phase, the mathematical procedure begins to normalize and balance the matrix. The relative weights are specified by the right eigenvector *(w)* of the biggest eigenvalue(λ_{max});

$$A_w = \lambda_{max} W$$

The consistency index (CI) is:

$$CI = \frac{(\lambda \max - n)}{(n-1)} \quad (3.2.5)$$

Finally, consistency ratio (CR) is used to decide whether the evaluations are sufficiently consistent. It is calculated as the ratio of the CI and the random index(RI):

$$CR = \frac{CI}{RI} \quad (3.2.6)$$

Table 3-0-2: Random index Saaty (1988)

n	1	2	3	4	5	6	7	8	9	10

RI	0	0	0.58	0.90	1.2	1.24	1.32	1.14	1.45	1.59

The accepted upper limit for CR is 10% that is,0.1. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency. The measurement of consistency can be used to evaluate the consistency of both the decision makers and overall hierarchy.

3.2.3 Conceptual foundation of the planned relocation model

The purpose is to design an optimal relocation plan to calculate the number of families who need to be resettled. Thus, we would evaluate a variety of costs and incorporate family preferences impacted by social and cultural capitals while designing a multi-criteria decision-making methodology. This becomes a requirement for relocation strategies and will necessitate suitable planning in order to achieve the best results. We deduce a solution by applying the aforementioned methodology, which involves implementing a two-stage technique. The first stage entails identifying how many families' should be moved to particular target areas and from which affected locales. The second and final stage of the plan will follow which families will be picked taking into consideration the differing socioeconomic and cultural circumstances of each family. One thing that we have to examine in relation to family composition is how many elderly, if any, are in the family and whether the old people are in good health. Then, we must determine if the elderly in the family have children, if so, what their respective ages are.

This study focuses on planned population group relocation (resettlement or retreat) as a sustainable solution applicable to many types of climate threats. Even, in extreme instances, full-scale migration may become the only adaptive strategy available. This proposed model stresses that in many instances, it may not be necessary to relocate the entire affected population; rather, selective resettlement of segments of the population may boost the adaptive capacity of the remaining population. And, over time, such a strategy may even lead to the return of those migrants, as their adaptation technologies and procedures become more accepted. Reduced population loads on communities have alleviated pressure on scarce resources and improved the manageability of adaptive capacity since their start. New opportunities may develop when old ones have been destroyed. For instance, when low-lying coastal areas are swamped by rising sea levels, increasing fishing (in cages or through traditional methods) may compensate for lost agricultural prospects. Additionally, raising ducks may be a better option than hens. Further-stress[ing] water sources and land owing to climate change could allow new livestock species to be introduced. Throughout thousands of years, mankind have been able to accommodate climatic fluctuation over the long term.

It will require resources to implement the adaptations listed in table 3.3. It is necessary to incorporate these strategies within an adaptation policy framework in order for them to be effective. Just as is the case with community relocations, relocating to a better area would necessitate such infrastructures as: (a) accommodation, (b) education, (c) health care, (d) retraining, and (e) financial aid for beginning enterprises or trades. We need to keep in mind these three points to develop the detailed model.

Table 3-0-3: Some adaptation strategies

Irrigation powered by renewable energy and temperature-controlled housing.
Innovative drought and salt-resistant plants built using biotechnology.
Building additional islands and shielding them from erosion.
Produce multipurpose fuel-efficient marine vehicles.
Building facilities for harvesting and storing rainwater
Constructing high-altitude housing
Develop innovative aquaculture technology.
Construct Barriers against coastal flooding.
Engage water conserving utility systems.
Modifying crop mixes.

3.3 Sustainable Relocation Decision Support System

3.3.1 Mathematical Model

The model considers N affected locations where a part of the population may have to be relocated to M target areas. Figure 3.2 is a schematic diagram of the human relocation problem. We have N affected locations against M target areas. We however would have to consider keeping families together while relocating. From the onset we assume an average family size f .

The current population (by family) in ith impacted area is pop_i, but jth target location has room for up to rc_j additional families. Additionally, the afflicted location is still capable of supporting s_i average families given new and current possibilities, hence; $s_i < pop_i$. By making sure that the planned migration benefits everyone, we break them into several groups C, and each category may be characterized as a group of families with common interests such as holding jobs or running businesses. In this situation, the relocated region is not limited to a single category, as it may contain elements of multiple categories. Thus, let x_{icj} is the number of families of category c transferred from place i to j.

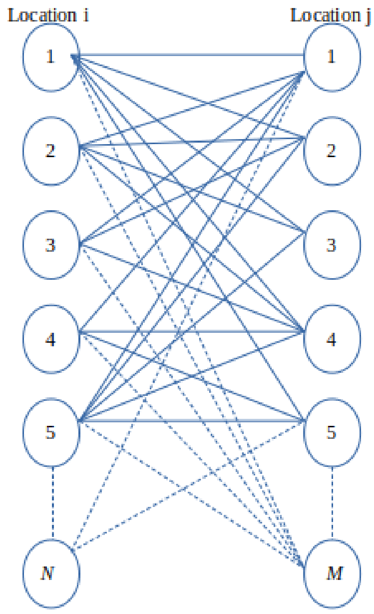

Figure 3:0:2 The relocation problem

a. Capacity limit at the target area: In each category, total number of families relocated to any of the identified target area will be up to its climate change capacity (carrying capacity of the area) CC_{cj} and not exceeding. Therefore, we impose the constraint:

$$\sum_{i=1}^{N} x_{icj} \leq CC_{cj} (j \in M, c \in C) \tag{3.3.1}$$

Here,

$$\sum_{c=1}^{C} CC_{cj} = rc_j (j \in M)$$

We have defined rc_j earlier to be the number of new families' jth target location can accommodate. However, some of the CC_{cj} may be zeroes.

Minimum requirements:

$$\sum_{c=1}^{C}\sum_{j=1}^{M} x_{icj} \geq MR_i(i \epsilon PL) \tag{3.3.2}$$

MR_i denotes the bare minimum number of families required to be relocated from the affected site

PL is a collection of high-priority locations within the set of N places. By constraining the numbers of families to be relocated to both locations, we ensure that the number of families that will be moved from i to j is always greater than or equal to the minimum allowed for each location. MR_i cannot of course, exceed $pop_i - s_i$.

b. Limit on number relocated: Although we acknowledge that some families will not be forced to relocate, it is nevertheless crucial that families in the community explore new opportunities and benefit the local economy in some way. To put it another way, we express the opportunity loss (having fewer than s families remaining at location i as a factor of opportunity objective (OP). expressed in the form of;

$$\sum_{j=1}^{M}\sum_{c=1}^{C} x_{icj} + sd_i^- - sd_i^+ = pop_i - s_i \quad \forall i \tag{3.3.3}$$

sd_i^- and sd_i^+ are deviational variables.

$pop_i - s_i$ is the aspiration level for this goal objective. Since we have an equality constraint, both deviational variables are undesirable, thus minimised in the objective function.

c. Limit on the number of available families: Additionally, the impacted population is classified into categories, with PC_{ic} defined as the number of people falling into category c at location i, thus,

$$\sum_{i=1}^{N}\sum_{c=1}^{C} PC_{ic} = pop_i \tag{3.3.4}$$

The restriction in this case will be to ensure that the cumulative number of people displaced from affected locations in various categories do not surpass the number of people in each group at the affected locations.

$$\sum_{j=1}^{M} x_{icj} \leq PC_{ic}(i \epsilon N, c \epsilon C) \tag{3.3.5}$$

Also, some of the PC_{ic} may be zeroes.

d. Preferences: The idea is to use planned relocation to help save towns. Each impacted place thus has to have a collective score for the target regions according to preference for their own judgment of how well they will fit in a location to the best of their interests, employability, and skill use. Individual family belonging to a certain category may have a preference when it comes to the target locations, but the total scores of all families in that category will be aggregated and the target regions will be awarded a combined score that represents the decisions of the group as a whole.

Let p_{icj} be the normalised preference of category c in location i for relocating to target area j.

$$\sum_{j=1}^{M} P_{icj} = 1 \ (i \in N, c \in C)$$

We can then define G as the total number of people that are targeted to be relocated shown as,

$$G = \sum_{i=1}^{N} (pop_i - s_i) \quad (3.3.6)$$

Where the total preference is a goal constraint; human preference objective (HP)

$$\frac{1}{G} \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{c=1}^{C} x_{icj} P_{icj} + pd^{-} - pd^{+} = P \quad (3.3.7)$$

Such that, the expected preference is at least equal to P and thus pd^{-} is the undesirable deviational variable to be minimised. We then estimate P as follows;

Let $\bar{P}_{ic}$ average of top three priorities assigned by the people of category c at the affected location i to three of the possible target areas (we assume $M > 2$). We identify them as $(P_{icj})^{***}, (P_{icj})^{**}, (P_{icj})^{*}$ $(j \in M)$, and expressed as,

$$\bar{P}_{ic} = \frac{1}{3} \left[(P_{icj})^{***} + (P_{icj})^{**} + (P_{icj})^{*} \right]$$

$$P = \frac{1}{NC}\sum_{i=1}^{N}\sum_{c=1}^{C}\bar{P}_{ic} \qquad (3.3.8)$$

e. Costs:

tc_{ij} : transportation cost per family from i to j

sc_{ij} : settlement cost for settling each average family from i to j

ac_i : adaptation cost for family staying back at location i for adaptation

lc_i : loss of opportunity cost at location i due to excess of $pop_i - s_i$

For families who stay behind i in excess of s_i families, the opportunity cost is also equal to the opportunity gain they are providing to the economy and should be considered. This is the net additional contribution that a family could make as a result of adaptation, in addition to the typical contribution that they could have produced in the target locations if they were relocated. That is, if rc is a family's average economic contribution after being moved to a target area, and nc_i is the maximum economic contribution a family can make at location i then $lc_i \approx nc_i - rc$.

We take the sum of the costs being the total cost as the budget objective (BP), expressed as,

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{c=1}^{C} x_{icj}\left(tc_{ij} + sc_{ij}\right) + \sum_{i}^{N} ac_i\left(pop_i - \sum_{j}^{M}\sum_{c=1}^{C} x_{icj}\right) + \sum (sd_i^{+} - sd_i^{-})lc_i + bd^{-} - bd^{+} = B \qquad (3.3.9)$$

As we wish to keep the overall expenditure lower or equal to the budgeted sum B, we will try to minimize the unfavourable deviational variable bd^{+} in the goal programming target function. B is estimated by taking into account the opportunity gain provided by the families who wanted to remain in the impacted area. While we are aiming to determine the optimal relocation strategy for the various goals listed above, we want to underline that, like with any goal programming problem, distinct objectives may have varying priorities.

Let W_1, W_2, W_3 be the relative priorities for *OP, HP* and *BP* respectively. The deviational variables in equations 3.3.3, 3.3.7, and 3.3.9 have different units and scales of magnitude, as to make them equal, we divide them by P , B, and G, respectively, in the goal programming objective function.

The objective function is

$$MIN\ Z = \frac{W_1 pd^-}{P} + \frac{W_2 bd^+}{B} + \frac{W_3 \sum_{i=1}^{N}(sd_i^- - sd_i^+)}{G} \qquad (3.3.10)$$

This function provides optimal solution, further than satisfying all the constraints simultaneously, it provides the best value of the objective function, max priority, min budgetary allocation and desired population.

3.3.2 Sensitivity Analysis

When doing sensitivity analysis, it is important to consider "what if" questions to assess the resilience of the ideal solution. It has a good chance of indicating the preferred alternative. Although this does not necessitate a quantitative comparison of the decision-making objectives, it does expedite the process. During decision making process where there is not explicit preferences indicated by decision makers between the objectives, perhaps due to individual bias or running over control process, then analyst provide means to capture multiple scenarios. Furthermore, with the option of having several decision makers, there will be multiple possible decisions, and several possible interpretations of each choice, leading to opposing options and viewpoints, which make the use of sensitivity analysis critical

In other words, in order to ensure that selected alternatives maintain their stability, we underline the importance of sensitivity analysis. Here are some of the questions that this procedure has answered;

1. Suppose the weights of the three objectives are adjusted from w to w' , what would happen?
2. How sensitive are these weight change choices?
3. What is the smallest change in weights that would result from a selected alternative?
4. Can there be a collection of values for which alternative(s) weight(s) are the highest?
5. What is the smallest weight difference required to elevate an alternative?

When answering these questions, new aspects of AHP analysis emerge. This could enhance the users' trust in adopting a solution or pinpoint which solutions are more sensitive to changes in weights. However, the process is cumbersome due to the repeated calculation of rankings. We estimate an overall value of an alternative by taking weighted average under stated objectives. We denote the vector of the final values by $c = i: 1,2, \dots, n$. In order to make the process easier to follow, we have provided a formula for a situation in which there are two criteria.

$$c_i = \sum_{i}^{n} w_j b_{ij} \qquad (3.3.11)$$

$$c_i = b_{i1}w_1 + b_{i2}w_2$$

$b_j = (i, j = 1,2, \dots, n)$ is a column vector and denotes the principal eigenvector of the comparison matrix under objective *j*.

As a function of a single variable w_i, final value of the alternative would follow a

$$c_i = b_{i1}w_1 + b_{i2}(1 - w_1) = (b_{i1} - b_{i2})w_1 + b_{i2} \qquad (3.3.12)$$

To show the values of c_i for all alternatives in (c_i, w_1) space, we could use a graphical display for a complete sensitivity analysis. For a combination of weights, we can obtain alternatives with the highest ranking as well as ranking of others. In using software like Expert choice for this, users are at liberty of varying the weights of one of the alternatives between 0 and 1 while keeping ratio between others constant. Thus for any given pairwise comparisons with original weights as w_1, w_2, w_3 the value of the alternative is expressed as;

$$c_i = b_{i1}w_1 + b_{i2}w_2 + b_{i3}w_3 \qquad (3.3.13)$$

We are interested in varying w_1, we define $p = \frac{w_2}{w_3}$ to have

$$w_1 + w_2 + w_3 = w_1 + pw_3 + w_3 = 1 \qquad (3.3.14)$$

$$w_3 = \frac{1 - w_1}{p + 1} \qquad (3.3.15)$$

$$w_2 = pw_3 = \frac{(1 - w_1)p}{p + 1} \tag{3.3.16}$$

Substituting equation 3.3.16 into equation 3.3.13 we have;

$$c_1 = b_{i1}w_1 + \frac{b_{i2}(1 - w_1)p}{p + 1} + \frac{b_{i3}(1 - w_1)}{p + 1} \tag{3.3.17}$$

as a function of w_1. Even though this is limiting, having a constant ratio assumption between the second and third weights, implies having a 1-dimensional sensitivity analysis in a two dimensional space. Overall, the sensitivity analysis can be useful in eliminating alternatives, improving group decision process, or provide additional information as regards the robustness of a decision.

Chapter 4: Results and Discussions

4.1 Preamble

From the model formulation as earlier extensively discussed in the previous chapter, the three criteria used in the process to determine who to relocate is Human consideration (HC), Economics Consideration (EC) and Technical Consideration (TC) using a single decision maker for model testing and analysis, we work through the Lingo software to achieve results presented and discussed in this chapter. The alternatives used are Human Preference (HP), Opportunity Objective (OP) and Budget Objective (BP).

4.2 Weights for Analytic Hierarchy Process

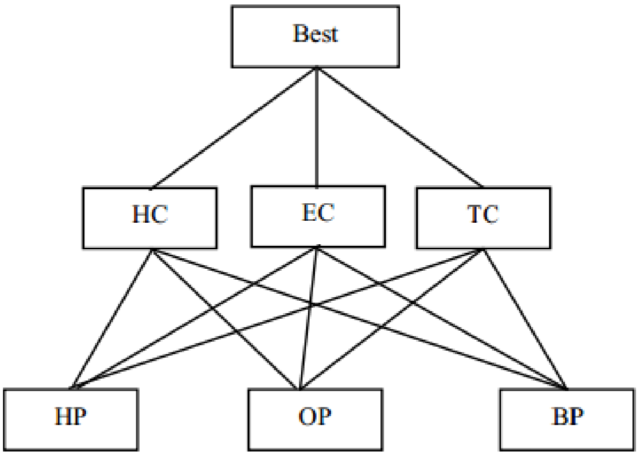

Figure 4:0:1AHP Hierarchy for Computing Priorities of Relocation

Using the scale of relative importance (Table 3.1) we compute pairwise comparison matrix. We need to determine how important the criteria relative to our goal are. How important is human consideration to relocation? How important is economic consideration to relocation? How important is Technical consideration to relocation? To compute this, we determine how important each criterion is with respect to another. Therefore, how important is EC with respect to HC? Here, we have that HC has strong importance than EC. We can assume that $EC = x$ thus, $HC = 5x$. Also HC has a moderately strong importance than TC, thus while $TC = x$ we have $HC = 4x$. Similarly, EC has equal to moderate importance than TC, therefore if $TC = x$ we have $EC = 2x$. We obtained values for each cell by dividing row elements by the column elements.

Table 4-0-1: Pairwise Comparison matrix of criteria

	HC	EC	TC
HC	1	$\frac{5x}{x}$	$\frac{4x}{x}$
EC	$\frac{x}{5x}$	1	$\frac{2x}{x}$
TC	$\frac{x}{4x}$	$\frac{x}{2x}$	1

Table 4-0-2: Pairwise Comparison matrix of criteria

	HC	EC	TC
HC	1	5	4
EC	0.2	1	2
TC	0.25	0.5	1
Sum	1.45	6.5	7

To obtain a normalised matrix, we divide each cell by the sum of each column.

Table 4-0-3: Normalised pairwise comparison matrix

	HC	EC	TC
HC	0.6897	0.7692	0.5714
EC	0.1379	0.1538	0.2857
TC	0.1724	0.0769	0.1429

Hence we estimate the criteria weight (CW)

$$CW = \frac{row\ sum}{number\ of\ items\ on\ row} \quad (4.2.1)$$

Table 4-0-4: Criteria weight

	HC	EC	TC	CW
HC	0.6897	0.7692	0.5714	0.6768
EC	0.1379	0.1538	0.2857	0.1925
TC	0.1724	0.0769	0.1429	0.1307

We then proceed to consistency check based on the pairwise comparison matrix. First estimate the weighted sum (WS) (Table 4.5), it is the sum of the rows in the normalised matrix. Also, we take the ratio of the weighted sum value to the criteria weight.

Table 4-0-5: Criteria estimated parameters

	HC	EC	TC	WS	CW	Ratio
HC	0.6897	0.7692	0.5714	2.0303	0.6768	3
EC	0.1379	0.1538	0.2857	0.5774	0.1925	3
TC	0.1724	0.0769	0.1429	0.3922	0.1307	3.0008
SUM						9.0008

We estimate the $\lambda_{max} = \frac{sum\ of\ ratio}{number\ of\ criteria}$

$$\lambda_{max} = 3.0003 \qquad (4.2.2)$$

Using equation 3.2.5 and 3.2.6 we estimate the consistency index and consistency ratio respectively.

$$CI = 0.00015$$

To use equation 3.2.6, we need Random Index (RI) as shown in Table 3.2

$$CR = \frac{0.00015}{0.58} \qquad (4.2.2)$$

$$= 0.00026$$

To make an informed decision CR must be less that 0.1 (10%), otherwise, we cannot proceed. Here, CR is less than 0.01,

$$0.00026 < 0.1$$

We then move on with the next step. For each of the criteria we, carry out the alternative judgement selection matrices.

HP and OP has equal importance, BP has moderate importance than OP while HP and BP has equal importance relative to criterion HC, therefore we have,

Table 4-0-6: Pairwise Comparison matrix alternatives for HC

	HP	OP	BP
HP	1	2	1
OP	1	1	$\frac{1}{2}$
BP	2	2	1
Sum	4	5	2.5

Table 4-0-7: Normalised comparison matrix (HC)

	HP	OP	BP
HP	0.25	0.4	0.4
OP	0.25	0.2	0.2
BP	0.5	0.4	0.4

Table 4-0-8: Criteria weight, Weighted Sum, Ratio (HC)

	CW	WS	Ratio
HP	0.35	1.05	3
OP	0.2166	0.65	3.0009
BP	0.433	1.3	3.0023
SUM			9.0032

With

$$\lambda_{max} = 3.00107, CI = 0.000533, CR = 0.000919$$

HP has moderate to strong importance than OP, BP has moderate importance than HP while it has strong importance than OP relative to criterion EC, and therefore we have,

Table 4-0-9: Pairwise Comparison matrix alternatives for EC

	HP	OP	BP
HP	1	4	$\frac{1}{2}$
OP	$\frac{1}{4}$	1	$\frac{1}{5}$
BP	2	5	1
Sum	3.25	10	1.7

Table 4-0-10: Normalised Comparison matrix (EC)

	HP	OP	BP
HP	0.3077	0.4	0.2941
OP	0.0769	0.1	0.1176
BP	0.6154	0.5	0.5882

Table 4-0-11: Criteria weight, Weighted Sum, Ratio (EC)

	CW	WS	Ratio
HP	0.3339	1.0018	3.0003
OP	0.0982	0.2945	2.999
BP	0.2108	1.7036	3.0421
SUM			9.0414

With

$$\lambda_{max} = 3.0138, CI = 0.0069, CR = 0.011$$

HP and OP has equal importance, BP has strong importance than HP while BP has moderate importance than OP relative to criterion TC, therefore we have,

Table 4-0-12: Pairwise Comparison matrix alternatives for TC

	HP	OP	BP
HP	1	1	$\frac{1}{5}$
OP	1	1	$\frac{1}{2}$
BP	3	2	1
Sum	5	4	1.7

Table 4-0-13: Normalised Comparison matrix (TC)

	HP	OP	BP
HP	0.2	0.25	0.1176
OP	0.2	0.25	0.2941
BP	0.6	0.5	0.5882

Table 4-0-14: Criteria weight, Weighted Sum, Ratio (TC)

	CW	WS	Ratio
HP	0.1892	0.5676	3
OP	0.248	0.7441	3.0004
BP	0.5627	1.6882	3.0002
SUM			9.0006

$$\lambda_{max} = 3.0002, CI = 0.0001, CR = 0.0002$$

Throughout, the consistency index is clearly less than 10%, this implies that the judgement is within acceptable range and the judgements are undoubtedly consistent. Figure 4.1 shows the overall ratio criterion, where Human Consideration ranks highest in the decision making criteria with total aggregate weight of 0.689 and Technical consideration has the least weight of 0.127.

Figure 4:0:2 Contribution of Criteria to the main goal

4.3 Criteria Weight Sensitivity Analysis

We then proceed to show the effect of altering different parameters of the model on the main goal (relocate). Figure 4.3.1.1 is the sensitivity graph of the main factors with respect to the main goal. We wanted to be able to answer the questions already highlighted in 3.3.2 regarding the criteria and alternatives. First we have the graphical representation of resulting contribution of main criteria to main goal.

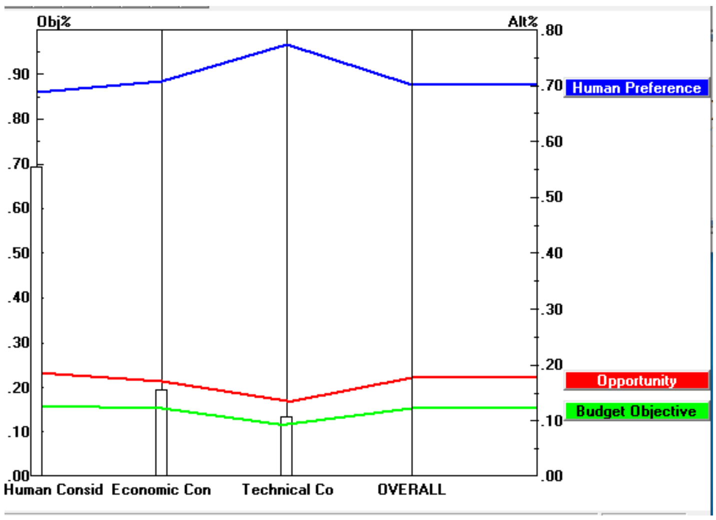

Figure 4:0:3 Sensitivity graph showing main criteria with respect to main goal

A look at the graph to examine human consideration; it is observed that it took 68.7% share of the main goal, causing the model to favour human preference with a score of 70.1% while opportunity and budget objective follows respectively.

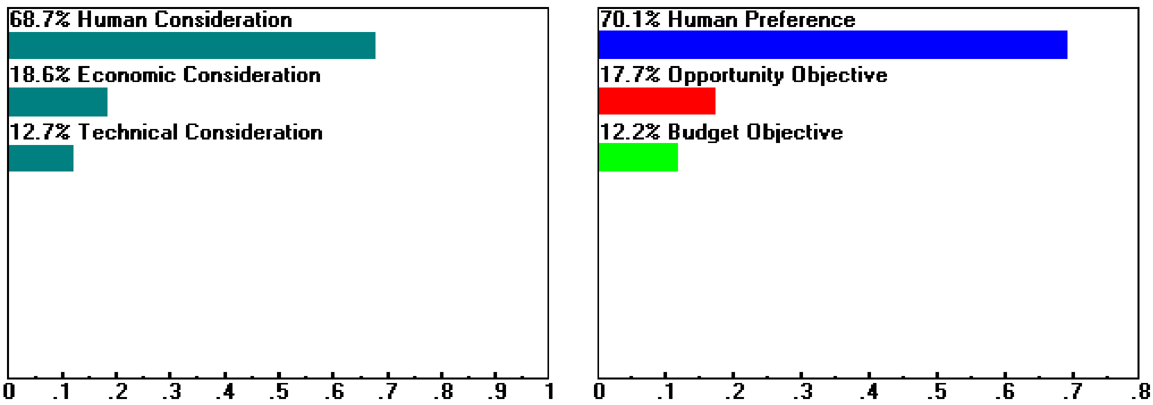

Figure 4:0:4 Sensitivity graph of Human Consideration, with respect to main goal

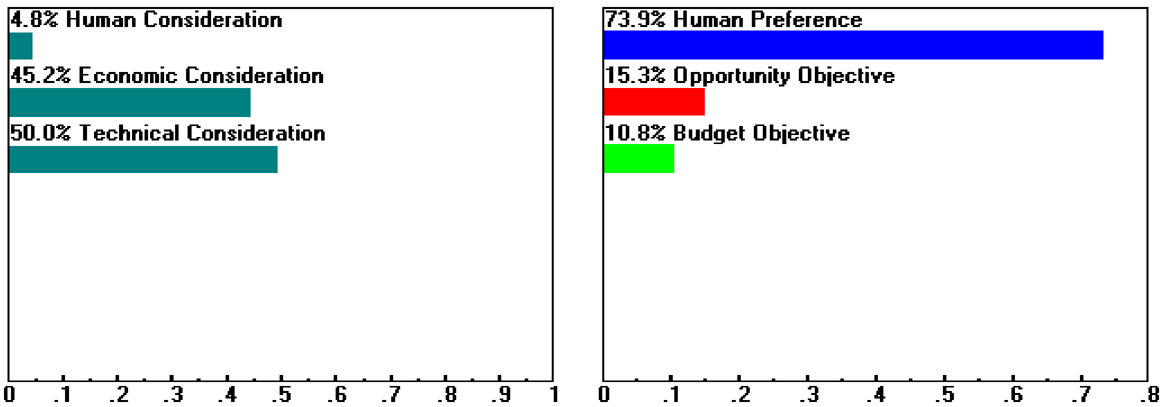

Figure 4:5 Sensitivity graph of Technical Consideration, with respect to main goal with NEW assigned weights (left) and resulting alternative scores (right)

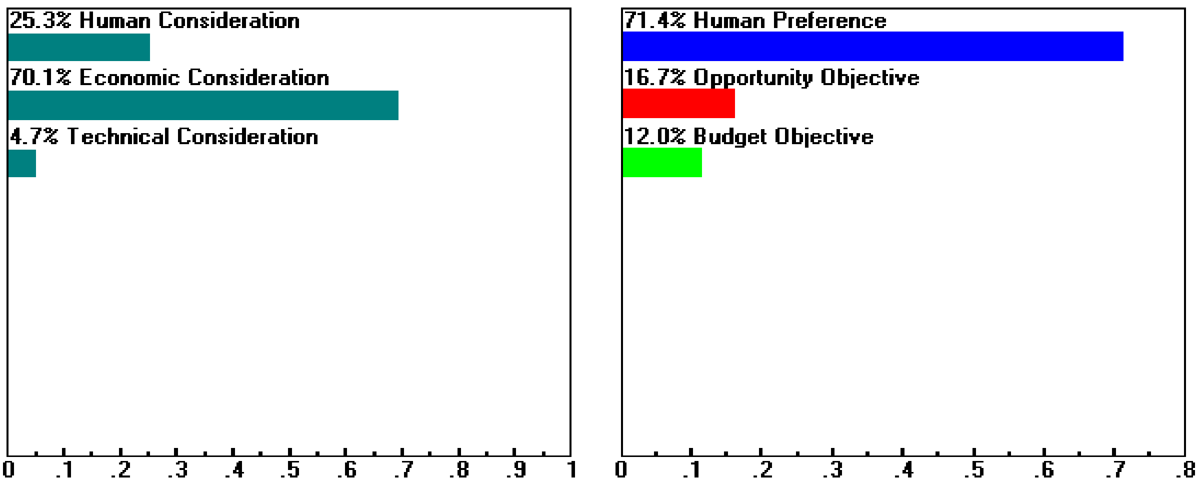

Figure 4:6 Sensitivity graph of Economic Consideration, with respect to main goal with NEW assigned weights (left) and resulting alternative scores (right)

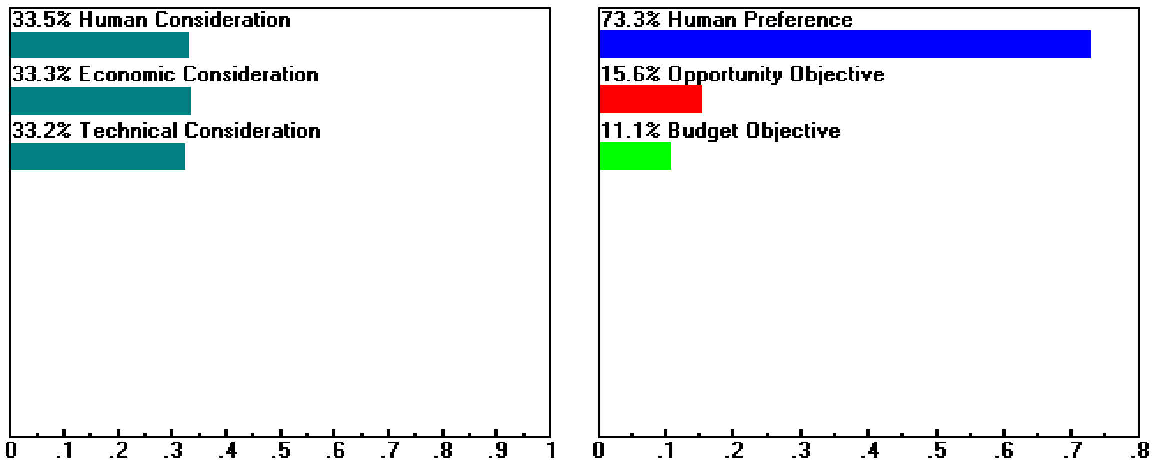

Figure 4:7 Sensitivity graphs of all factors having equal scores with respect to goal and the resulting alternative scores

The sensitivity graphs all demonstrates consistency such that all points to human preference for the decision making. The choice would remain same even if there is a significant change on the criteria weights, which has been justified by the consistency in the judgements between the main goal and the pair-wise comparisons. Let's not forget that AHP analysis demonstrate an efficient knowledge based approach to help qualify expert knowledge to qualitative analysis that help in multi-criteria decision making.

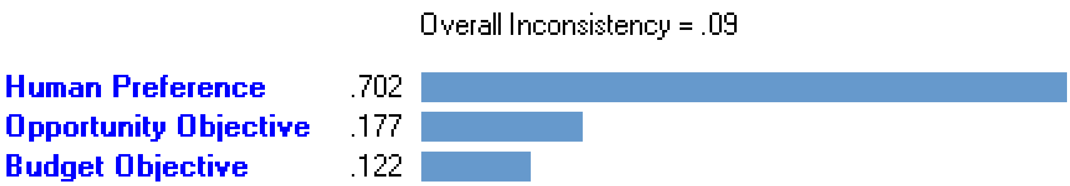

Figure 4.3.6 Final ranking of alternatives

It is perceived from the results that there is a major control human preference would have on planned relocation and should be assigned higher importance relative to other factors as it would have overall contribution of 70% of its relevancy to parent criteria. A final complete hierarchy of goals and objectives with the corresponding aggregate weights shows that human preference contributes for the most in terms of factors to hierarchy weights.

We proceeded to check the robustness of the designed model using LINDO with aggregate relative priorities, criteria weights and its local priorities from the results obtained from AHP analysis done in Expert Choice.

Table 4-0-15: Criteria weights, Local Priorities and the Aggregate Priorities

	Criteria			
Objectives	HC(0.687)	EC(0.186)	TC(0.127)	Aggregate
HP	0.4111	0.5679	0.6404	0.5398
OP	0.2611	0.0982	0.2369	0.2213
BP	0.3278	0.2108	0.1781	0.2389

The values in the last column were those used in the objective function of the goal programming model. The numerical illustration of the model performance is presented next using hypothetical sample data.

We use N=4 (affected locations from where families should be relocated), M=6 (proposed location where families should be moved to). Based on jobs, skills and employability the families were categorized into 3 ($c = 3$), putting into account the accommodating capacity at the 6 target areas.

Table 4-0-16: Categorized data of families at affected locations ('000)

Location i	1	2	3	
1	1	1.5	2.5	5
2	1.5	2	3.5	7
3	2.5	2	4.5	9
4	1	3	0	4
Total (pop_i)				25

Table 4-0-17 : Categorized data of capacity in target area ('000)

Location j	1	2	3	
1	4	3	0	7
2	1	1	3	5
3	2	1	1	4
4	5	0	4	9
5	1	1	1	3
6	3	2	3	8

				36

Table 4-0-18: Operational Cost for relocating families in affected location

	1	2	3	4	
ac_i	18.5	27.5	25.5	19.5	Million USD per 1000 families
lc_i	19	21	18	16.5	
s_i	0.5	1	1	1.5	'000
MR_i	0	5.5	7	2.75	

As defined earlier in the mathematical model formulation the variables above at adaptation cost, loss of opportunity cost, the number of families expected to stay at affected location *i*, and the expected minimum number of families that should be relocated from *i*.

Table 4-0-19: Transportation cost from location i to j (million USD per families)

	1	2	3	4	5	6
1	0.5	2	0.5	1	0.25	1
2	0.85	0.75	1.5	2	3	2
3	2.1	2	1	2.1	2	0.75
4	2.1	2	2	0.9	1.3	0.25

Table 4-0-20: Settlement cost for relocating from i to j (million USD per families)

	1	2	3	4	5	6
1	13	20	12	10	18	17
2	14	9	16	25	30	25
3	12	31	21	20	21	14
4	20	22	19	11	17	17.5

From here we already have an estimate for G:

$$G = \sum_{1}^{4} pop_i - s_i = 25 - 4 = \ 21\ (thousands)$$

Relocation preferences were randomly generated.

Table 4-0-21: Preference of families in affected areas (i) on target location (j)

		j					
Categories	i	1	2	3	4	5	6
	1	0.30	0.09	0.05	0.16	0.33	0.08
	2	0.17	0.21	0.07	0.05	0.25	0.25
	3	0.14	0.29	0.09	0.05	0.27	0.15
	4	0.01	0.23	0.17	0.26	0.32	0.01
	1	0.17	0.08	0.53	0.08	0.05	0.10
	2	0.22	0.09	0.19	0.25	0.01	0.24
	3	0.18	0.13	0.27	0.23	0.02	0.17
	4	0.05	0.18	0.15	0.21	0.21	0.2
	1	0.27	0.18	0.13	0.13	0.21	0.09
	2	0.11	0.23	0.21	0.08	0.28	0.09
	3	0.14	0.07	0.19	0.25	0.17	0.18
	4	0.05	0.17	0.23	0.1	0.11	0.34

By using equation 3.3.8, we estimate P from these preferences to be 0.33416667, we assumed B = 200 (million USD). These default data were inputs used in the goal programming for LINGO 18.0 and the output are as follows:

Table 4-0-22: Optimisation output from LINGO 18.0

$pd^{-} = 0.012$	lc_i = 2.5
$bd^{+} = 162.75$	ac_i = 54.75
$s_4^{-} = 0.32$	sc_{ij} = 268
$bd^{+} = 0$	tc_{ij} = 19.25
$pd^{+} = 0$	Opportunity gain = 18.25

(lc_i, ac_i, tc_{ij}, sc_{ij} and Opportunity gain are in million USD). Implying that the total cost for relocation for the default data used for this model test is 362.75 (million USD), the model shows the budget deviated with over 162.75 (million USD; $bd^{+} = 162.75$). We have established during the model formulation that for budget we are interested in keeping the total cost either less than or equal to the budgeted amount (B). From the result we could decide which of the input data to trade-off in order to achieve the desirable goal. Furthermore, the objective function calculated was given as 0.2510905. Hence we present the breakdown of families relocated from each affected location to our target areas.

Table 4-23: Number of families relocated (‘000)

	Location *j*						
Location *i*	1	2	3	4	5	6	Sum
1	0	0	1	1.5	2	0	4.5
2	1.5	3	1	0	0	0	5.5
3	4	0	0	0	0	3	7
4	0	1	0	0	2	1	4
Sum	5.5	4	2	1.5	4	4	**21**

From table 4.3.22, this shows the total number of families for all categories that’s relocated we have a total of 21 (thousand) families. This is same with the estimated G when we take the difference between the populations in the affected location and its capacity limit. As earlier stated we could vary values of parameters to further access changes in the output. While this could serve as a means to perform sensitivity analysis, the model already goes to show, robustness at handling environmental decision making as regards relocation.

Chapter 5: Perspective and Conclusion

5.1 Preamble

Through a detailed review of vulnerability and impacts of climate change, we have been able to improve our understanding of the possible repercussions of climate change on human and economic circumstances. In accordance with the concept of sustainable development for human societies and economic development, this work proposes adaptation for some members of affected communities while relocating others to a different environment that can provide them with opportunities in the long or short term to alleviate stress on the affected region. One of the key emphases of this study, which aligns with the general objectives of adaptation, is to raise an appreciative and ready population who are capable of transitioning to a new lifestyle, living situation, or opportunity. This is probably due to being relocated or waiting behind while everyone else is moved to a new place, as these environmental and working conditions will vary.

This study tried to consider one of the primary components of DSS (model base), which was to develop a mathematical model (methodology) to estimate the percentage of who should relocate and who to leave behind. To account both the cost and benefit of relocating families, this model uses preferences of relevant authorities in urban and regional planning to accomplish planned objectives and also accommodating capacities of the proposed and impacted places. We also included in costs like relocation, adaption, transportation, settling, and loss of opportunity. We have created a multi-objective optimisation problem by combining goal programming and the AHP technique.

5.2 Research Gaps and Recommendation

We have proposed a model that is aimed at guiding decision makers on exploring mass relocation as a means to adapt to climate change. Given the diversity and complexity of events around West Africa at this time, real world data to assess the scenarios were not used in model testing. A default data set was used only to demonstrate the practicability of this model, and it shows that to have a successful optimal relocation is dependent on cost; relocation, transportation, adaptation, opportunity. We, however, could use several simulated data sets which would serve as a form of sensitivity analysis and strengthen the model performance. The notion could further extend into the other two components of DSS (knowledge base and user interface) to allow for non-scientific user experience the reliability of the proposed mathematical model. Since the system's functionality is meant to interact with databases, models, and optimization tools (which in our case is LINGO 18.0), it is important that the user interface be fashioned in a way that provides access to them.

The further step would be to expand the restrictions employed in the model formulation; for example, we may include career, school, and employment choices, as well as particular housing needs for families with specific requirements. In addition, a wider range of conditions can be used in the overall preference computation. However, because the problem is considered to be highly sensitive to the values of nearly all of the parameters involved, it is best deplored as an interactive software tool that may be used to assist actual and dynamic situations.

Another interesting context this research could follow is to consider one of the very dynamic situations in West Africa with nomads; these are people who have lived by their own rules for a long time, invading territories without known boundaries. How do we then involve them in adaptation? How does the government identify them in clusters and bring modern development to them? Can this model be optimal when we have to consider other physical constraints, cultural preferences, social and economic constraints? We need to however carefully introduce new parameters into the model; this would of course alter the model design but could be worth the effort.

5.3 Conclusion

Environmental problems have evolved from a merely scientific concern to a public agenda, and are one of the several stressors on land and human habitat. Climate change has had an impact on the ecosystem, health, infrastructure, food security, and water availability, but perhaps most significantly; it has forced a large number of people from their homes. Human displacement is a crucial indicator of climate change impacts, the majority of which are sudden, causing many members of the afflicted community to lose lives and property while relocating. It is possible to better manage disasters and risk using proper tools as a result of advanced studies in early warning systems, floods, droughts, land use and land cover, mathematical modelling, and other fields of research.

When it comes to climate change, environmental difficulties are a big topic of discussion. To combat the effects of climate change, several techniques of adaptation and mitigation are being proposed. It is necessary, however, to create increasingly effective techniques of lowering climate hazard susceptibility, including the development and implementation of adaptation strategies that address climate change through the use of mathematical approaches and related instruments. Because of this, the efficiency of adaptive measures is highly dependent on the context in which they are deployed.

This work provides a mathematical framework that could serve as the foundation for future research in decision making in the context of planned relocation to give protection against the prospect of forcible displacement. Relocation, as an aspect of adaptation, development, and sustainability, is a tool for the subject of resilience. While it imposes some responsibility on individuals, it also serves as a technique of governance in situations where managing a population movement as a response to the apparent inevitability of environmental change becomes a necessary requirement.

This research aspires to add a new dimension to the much-discussed solutions that are already accessible in order to develop real revolutionary ways to adaptation, while also leaving open the possibility of new and current opportunities in the areas highlighted. However, while we are not aware of a universally applicable solution to human displacement, we have advocated planned relocation in the impacted areas. When implementing a planned system of relocation, it is necessary to designate a fraction of the affected population that will be relocated in order to minimize stress in the impacted areas.

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Appendix

Basic Principles of Planned Relocations

1. Planned Relocation is undertaken for the benefit of Relocated Persons and in a manner that respects and protects their rights and dignity.
2. States bear the primary responsibility under international law to respect, protect, and fulfil the human rights of people within their territory or subject to their jurisdiction. This includes the obligation to take preventive as well as remedial action to uphold such rights and to assist those whose rights have been violated.
3. States must have compelling reasons, robust evidence, and a sound legal basis for undertaking Planned Relocation.
4. States should ensure sufficient and sustainable funds for Planned Relocation.
5. Persons or groups of persons at risk of, or affected by, disasters and environmental change should have the right to request Planned Relocation, as well as the right to challenge Planned Relocation before a court of law.
6. Planned Relocation should be used as a measure of last resort, after other risk reduction and/or adaptation options have been considered in a timely manner and reasonably exhausted.
7. Planned Relocation should be carried out within a rights-based framework that safeguards both individual and collective civil, political, economic, social, and cultural rights of Relocated Persons and Other Affected Persons throughout all phases. The rights to self-determination, preservation of identity and culture, and control of land and resources are important, particularly for indigenous communities.
8. Relocated Persons and Other Affected Persons should be informed, consulted, and enabled to participate in decisions on whether, when, where, and how a Planned Relocation is to occur, as appropriate.
9. The agency, resilience, and empowerment of Relocated Persons should be recognized, promoted, and enhanced throughout a Planned Relocation.
10. The specific rights, needs, circumstances, and vulnerabilities of Relocated Persons and Other Affected Persons, as applicable, should be taken into consideration and addressed in all phases of a Planned Relocation. These specific rights, needs, circumstances, and vulnerabilities, may be linked, inter alia, to:
    a. Demographic and health characteristics;

b. Socio-economic characteristics;
c. Membership of a marginalized group;
d. special dependency on, and/or attachment to, land or local/localized resources/opportunities;
e. Direct and indirect impacts of disasters or environmental change; or prior experiences of displacement.

11. Planned Relocation should provide opportunities and conditions to:
    a. enable Relocated Persons to improve, or, at a minimum restore, their living standards;
    b. enable Host Populations to maintain their pre-existing living standards, or to attain the same living standards as Relocated Persons, whichever is higher; and
    c. Mitigate adverse impacts related to the Planned Relocation that may affect Persons Who Live in Close Proximity.
12. Planned Relocation shall be carried out in a manner that respects and upholds the principle of family unity. Planned Relocation should also be carried out in a manner that respects and maintains household, community, and social cohesion as well as kinship ties.
13. Relocated Persons shall:
    a. enjoy, in full equality, the same rights and freedoms under international and domestic law as other similarly situated persons in their country;
    b. not be discriminated against in the enjoyment of any rights and freedoms on the grounds that they have taken, or will take, part in a Planned Relocation; and
    c. Have the right to freedom of movement and the right to choose their place of residence.

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