Chapter

Managing and Sustaining the Coupled Water-Land-Food Systems in the Context of Global Change: How Qualitative System Dynamic Modelling Can Assist in Understanding and Designing High-Leverage Interventions

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Abstract

The water-land-food system is essential for sustaining the basic human needs. While the demand for these resources is increasing rapidly, their sustainability has been hampered by a plethora of challenges, including rapid population growth, climate change, land-use change, and land degradation. To attain a sustainable supply and efficiently manage these resources, interactions between all resources and the factors constraining/sustaining them need to be understood. In this chapter, four systems archetypes based or grounded in the systems thinking framework and system dynamics approach were employed to explore and identify the key system drivers, factors, and processes that influence the behaviour and sustainability of water-land-food resources nexus in the Volta River Basin, West Africa. Development of the archetypes centered on a generic causal loop diagram constructed with stakeholders in previous studies capturing the linkages between the population, water system, environmental and socioeconomics. These system archetypes illustrate that the past and the current paradigm of water and land and agricultural production management is unsustainable. The results highlight key areas, which could be useful for the current and future sustainable management, even under uncertain system understanding or deficiencies in quantitative data.

Keywords: system dynamics, system archetypes, systems thinking, drivers of change, water resources management, agricultural production, Volta River basin

1. Introduction

Variability and global change are realities of the Earth system, and during the past few decades, there has been growing evidence that planetary-scale changes are occurring rapidly [1–4]. Indeed, change is one of the few reliable phenomena in coupled social-environmental systems [5]. The critical feature of these global changes is described as 'directional', because it is characterised by a constant pattern over time [6]. They occur in both biophysical and socio-economic systems and manifest across all levels – from local to global [7]. Global change processes have dramatic effects and consequences for social-ecological system on which human communities depend. However, how societies respond to these changes can equally affect many managed natural resource management systems. To build a clear understanding, Anastasopoulou [8] argued that it is imperative to recognise the "agents or drivers" of those changes, which are a fundamental part of human existence.

The fundamental agents of environmental change that are external to particular systems can be considered as drivers of that change (e.g., climate change and socioeconomic change, national or international policy [5, 9, 10]. Drivers of change represent either the past, current or future conditions that modify the environment [8, 9]. Although some changes are caused by natural processes, it is widely argued that human activities (e.g., agriculture and the burning of fossil fuels) are the underlying forces driving change [11]. During the past two centuries, anthropogenic actions have induced significant changes in many environmental systems [2]. According to ([12], p. 13), "as early as the fourth century BC, Plato persuasively described extensive and insightful human impacts on forests: Hills that were once covered by forests and produced abundant pasture now produce only food for bees." The Sahara Desert was also described as a landscape of lakes and forest 7000 years ago [13]. Several change phenomena are also caused by globalisation, described as the compression of space and time scales concerning the flows of information, people, goods and services [14]. These processes and activities give rise to the phenomenon of global change [15].

The influence of humans on the global environmental system is so profound and persistent that the Nobel Laureate Paul Crutzen observed that we are now in a geological age called the Anthropocene [2]. Indeed, it is widely recognised that sustainability is the theme of our times and represents the greatest challenge in the Anthropocene [16]. While the concept Anthropocene is manifested in the nature, scale, and magnitude of human activities in the world, its societal significance rests on how we can take advantages of the changes to inform future decision choices and actions [17]. Indeed, understanding the Anthropocene calls for systematic thinking concerning the future, as both drivers and the concomitant consequences of human activities intensify towards an unsustainable trajectory [2, 15, 17].

Against the backdrop of changing environmental and socio-economic conditions, decision-makers are confronted with the situation of whether to act reactively or proactively. Often, they consider these changes and challenges as simple problems. Occasionally, however, the change is large and complex, thereby limiting their ability to design sustainable solutions to address them. If this happens, decision-makers find us to be facing an enormous problem, which can lead to far-reaching consequences for life support systems. Thus, the issue of rapid change has raised concern among scientists that several of the social-ecological systems present today could collapse by the end of the 21st century [18]. The situation has, therefore, necessitated a focus on the identification of key drivers of change and the resulting system dynamics to consider if it is possible that existing societies will be able to avoid their own decline or demise [3, 19]. Consequently, there is an increase in socio-economic and environmental system analysis and modelling studies that seek to gain an understanding of the trends and drivers of change in natural resource systems in the context of a changing earth system. These generally aim to improve the theory and strategic management of problems inherent social-ecological systems. Thus, understanding the problem of global change and the associated drivers of change in social-ecological systems are an urgent and relevant focus of this study. Further, given the increasing multiplicity of drivers of change associated with global change, there is a pressing need to develop an improved understanding of the interactive effects of multiple drivers, factors, and processes to better understand their responses to a changing environment.

The issue of global change and the associated drivers have resulted in fundamental transformations of many water-land-food systems [15, 20], such as River Basin systems around the world, including the Volta River Basin (VRB), which provides the case study context for this study. The VRB is an important trans-boundary river system (or 'catchment') in West Africa. As one of the 60 river basins in Africa, it supports the production of food, fibre, hydropower, and other products that are vital to West Africa's economy and the livelihoods of 25 million people who depend on the availability of the water that flows through the river basin system. During the last four to five decades, demographic pressures, land-use change, high rainfall variability, climate change, and the increased competition for land and water have combined temporally and spatially to affect sustainable water resource management and agricultural development within the river basin [21, 22]. There is tension between the aspirations of socio-economic development and environmental sustainability. However, the management of any water resource system can be challenging and difficult because of the complexities arising from the functioning of hydrological cycles and biological systems [23]. This is exacerbated when multiple stakeholder 'perspectives, interest, values and concerns regarding the use of water for human-related purposes are involved [23–25]. It is important to mention that the complex problems and challenges in the VRM is not different from the situation in Lake Chad basin in West and Central Africa due to massive exploitation by Cameroon, Chad, Niger and Nigeria [26–29].

As is often the case in many social-ecological systems or environmental systems, the most common approach to addressing problems in water resource systems is to adopt a linear cause–effect methodologies, reductionist, analytical approach (founded on positivistic understanding of science), where the focus is on only one or a few factors or parts of the system, and to accept that those explanations can only be partial [1, 24, 25]. However, the problems in most social-ecological systems, such as water resources systems are systemic, which means that biophysical and social systems are tightly interconnected and interdependent and cannot be understood in isolation [24, 25, 30]. They cannot be comprehended within the fragmented methodology characteristic of academic discipline and government agencies. This is because many current sustainability problems and challenges are closely linked in ways that challenge conventional linear causality [31]. As [32, 33] emphasised, such an approach will not resolve any of our difficulties but will tend to shift them around in a complex web of social and environmental relations. In sum, the problems and degradation of most catchments caused by several drivers of change continue to persist because they are rarely viewed, understood and managed using the systems approach. Consequently, actions to achieve sustainable goals will have to be based on an integrated modelling approach and a collaborative decision-making process.

In this chapter, we used systems archetypes based on system dynamics within the systems thinking to explore and identify the key system drivers, factors, and processes that influence the mode of behaviour and sustainability of water-land-food resources nexus in the Volta River Basin (henceforth, VRB), West Africa. The main aim to analyse and diagnose the difficulties in the management of sustainable development issues within the basin in order to find effective pathways to address these difficulties. Following this introduction, we present a brief definition of drivers of change (Section 2). A brief introduction to systems thinking and system dynamics modelling, and its associated tools are presented in Section 3, followed by methods and application of systems thinking framework and tool in Section 4. Section 5 presents the results, with a focus on the manifestation of the various system archetypes within the basin. Finally, the conclusion summarises the key results.

2. Defining and understanding drivers of change

The first step in system dynamics is the identification of the key issues and variables in the system whose behaviour over time defines the problem [31, 34, 35]. Accordingly, it is important to define what this study means by drivers of change. Over the past decade or so, a significant amount of work has emerged over the issue of drivers of system change [36]. The definition of a driver is aptly captured in two well-known frameworks – the Drivers-Pressures-State-Impact-Response (DPSIR) framework [37]; and the Millennium Ecosystem Assessment (MA) framework [38, 39]. Within the DPSIR framework, drivers are the underlying sources of environmental change that are exogenous to the system or region (e.g., climate and socio-economic change, national and international policy) [39]. They represent either the past, present or future conditions that lead to changes in the environment [9]. However, Tzanopoulos [40] argued that the usage of the term pressures in the framework seems to connote an implicit value and places emphasis on the negative impacts of human activity on environmental systems. Another noted limitation of the DPSIR framework is the dearth of constancy concerning its application to address environmental problems [9, 41]. According to ([41], p. 13), the DPSIR framework appears as "a deterministic and linear 'causal' description of environmental problems, which certainly overlooks the complexity of the environmental and socio-economic systems."

Thus, the definition of a driver captured in the Millennium Ecosystem Assessment framework appears to be one of the broadest and most widely used. In the MA framework, "a driver is any factor that changes an aspect of an ecosystem" [38, 39]. Different types of drivers are also distinguished in the framework: 'direct', and 'indirect drivers' of change. A 'direct driver' unequivocally influences ecosystem processes. 'Direct drivers' are predominantly physical, chemical, and biological, such as climate change, land cover change, air and water pollution, irrigation, use of fertilisers, harvesting, and the introduction of invasive alien species. An 'indirect driver' on the other hand, operates more diffusely by changing one or more direct drivers. These are mainly demographic, economic, socio-political, scientific and technological, and cultural and religious factors. 'Drivers' within the DPSIR framework are comparable to the 'indirect drivers' in the MA framework, while 'pressures' correspond to the 'direct drivers' of the MA [9, 40]. 'Direct' and 'indirect drivers' can be respectively be considered as proximate causes and underlying driving forces, according to [42, 43]. Regarding scale, proximate causes are seen to operate directly at the local level, while, underlying driving forces may manifest directly at the local scale, or indirectly, from the national or even global scale [42]. The categorisation of drivers based on the scale at which they operate has also been espoused [44]. However, the distinction between 'direct' and 'indirect drivers' may be difficult to delineate in some cases. For example, demographic variables can, for example, be direct drivers, but also represent underlying drivers (population growth) [45].

In several other studies, the factors or drivers of change in most ecosystems have also been variously characterised as 'exogenous controls', 'slow' changing variables and 'fast' changing variables [6, 46–50] or 'slower-acting', long-term drivers of change and 'fast-acting', short term drivers of change [51]. Exogenous controls are external factors such as regional climate or biota and global market conditions that strongly influence the properties of a system scale [6]. Critical 'slow' changing variables or processes are factors, such as population growth; income growth, soil fertility, household capital wealth among others, tend to act rather slowly and gradually over a lengthy time, and evolve in a somewhat predictable manner with impacts in the long-time period [46, 51]. In contrast, fast-moving variables or drivers of change (e.g. droughts, floods, rainfall variability, soil water content, crop yield, household disposable income, disease and pest outbreaks etc.) are variables that change very rapidly and might have influence on the agricultural system in the short time period [51, 52]. Slow-moving variables within natural resources systems greatly influence fast-changing variables at the same spatial scale [6].

In this study, the MA definition of drivers of change is used as it offers a flexible definition and analysis of drivers [40]. Thus, all types of drivers: direct, indirect, exogenous, endogenous, fast and slow-moving drivers or variables from both biophysical and socio-economic domains are considered, since most coupled social-environmental systems are not only affected by one individual driver, but rather a combination of different types of drivers at multiple scales [6, 52, 53]. "Drivers" are sometimes referred to as "variables". Thus, the two terms are used interchangeably. The focus here is to investigate how these drivers change over time and influence the sustainability of the VRB, particularly water availability and sustainable agricultural development.

3. Systems thinking and system methodology

For more than 60 years or so, systems thinking or systems approach [31, 34, 54–56] with its concomitant concepts and tools such as feedback, stocks and flows, time delays, and nonlinearity has evolved as one of the most promising approaches to confront this complexity. The idea of complex systems thinking can be traced back to Ludwig von Bertalabffy's General System Theory (GST) [57], and Ervin Laszlo's notion of systems philosophy [58]. Systems thinking approach is based on the notion that sustainability problems need to be informed by a holistic consideration of the system processes (biophysical, social, and economic), their dynamic interaction, and how they adapt to diverse changes [1, 59]. It challenges us to view the world as a complex system, in which we understand that "you can't just do one thing and that everything is connected to everything else." ([31], p. 4).

A systems approach has arisen as natural resource managers have reflected upon the practical implications of being holistic in their analysis of complex environmental systems. In terms of its application and purpose, [60] aptly explained that a "systems approach is necessary to serve the decision-makers' needs to understand the working system, compare impacts among decision scenarios, analyse tradeoffs among options, ask 'What if?' questions, avoid the creation or transfer of problems in pursuing solutions to the problem at hand, adapt strategies based on future monitoring of the system, and respond to unintended consequences." The application of the systems approach to water resources management problems has been recognised as one of the most significant developments around water resources management [24]. In the context of natural resource management such as water resources planning, a systems approach is concerned with pursuing what can be described as an integrated environmental modelling (IEM) agenda, which is inspired by contemporary environmental challenges, policy-decisions, and facilitated by multidisciplinary science and computer capabilities – thus allowing the environment and its relationship to social systems and activities (i.e., social and economic) to be analysed as a complex integral whole [60, 61].

The idea of systems thinking provides a plethora of tools and methods for gaining a deeper understanding of sustainable development problems. One such tool is system dynamics [31, 34, 54]. System dynamics operate in a whole-system fashion using feedback-based object-oriented simulation is applied to explain and gain an insight into the complex behaviour and relationships between the key environmental, economic, social and institutional drivers, factors, and processes that determine the current and future dynamics of the Volta River Basin (VRB) water resource system in West Africa. System dynamics is an approach grounded in control theory and the theory of nonlinear dynamics [31]. System dynamics is a perspective and a set of conceptual tools that enable us to understand the structure and dynamics of complex systems [31]. It deals with "the time-dependent behaviour of managed systems as a means of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimisation" ([62], p. 10). According to [63], system dynamics models (even in their conceptual forms) are valuable learning tools that can assist us to increase our understanding of systems, allows modellers and stakeholders to integrate diverse knowledge, and enhance important systems thinking.

The field of system dynamics has focused on refining the classification of generic structures. These generic "infrastructures" are commonly based on stocks and flows [31, 64], generic "system archetypes" based on causal loop diagrams [55, 65, 66]. Stocks are accumulations characterising the state of the system and generate the information upon which decisions and actions are based [31]. Stocks (or levels) corresponds to accumulations of something (concrete or abstract) that can be measured at one point in time, whereas flow (inflow, outflow or biflow) refers to the activities that cause material or information to change over time [31, 35, 67]. System archetypes based on causal loop diagrammes are one class of system tools that can be used to capture the "common stories" or pattern of behaviour in system thinking – dynamic phenomena that repeatedly occur in diverse settings [55, 66]. They are generic system structures consisting of a common dynamic mechanism from which both unintended behaviour over time and discrete events emerge [68]. They are powerful tools for diagnosing problems and identifying high-leverage interventions that will create fundamental change [66]. In addition, system archetypes are particularly helpful in identifying rapidly- and slowly-changing variables and stabilising and destabilising forces [69]. Consequently, they can be used as a diagnostic tool to explain problems that recur over time. Senge [55] proposed nine system archetypes: (1) balancing process and delay, (2) limits to growth, (3) shifting the burden, (4) eroding goals, (5) escalation, (6) success to the successful, (7) tragedy of the commons, (8) fixes that fail, and (9) growth and underinvestment. Each system archetype is accompanied by a well-established set of strategies for dealing with the problematic behaviour through effective interventions in the underlying structure of the system [68].

These archetypes are generally presented in the form of a causal loop diagram (CLD) also referred to as dynamic hypothesis. A CLD typically consists of variables connected by arrows denoting the causal influences among the variables [31] . Variables are usually connected by link polarities (i.e., combinations of positive and/or negative links), which describe the structure of the system, and not the behaviour of the variables [31]. A positive link indicates "that if the cause increases, the effect increases above what it would otherwise have been, and if the cause decreases, the effect decreases below what it would otherwise have been, whereas a negative link denotes that if the cause increases, the effect decreases below what it would otherwise have been, and if the cause decreases, the effect increases above what it would otherwise have been" ([31], p. 139) (see **Figure 1**). CLDs are generally formal, flexible, simple, and largely qualitative [55, 65, 70]. Further, a CLD is characterised

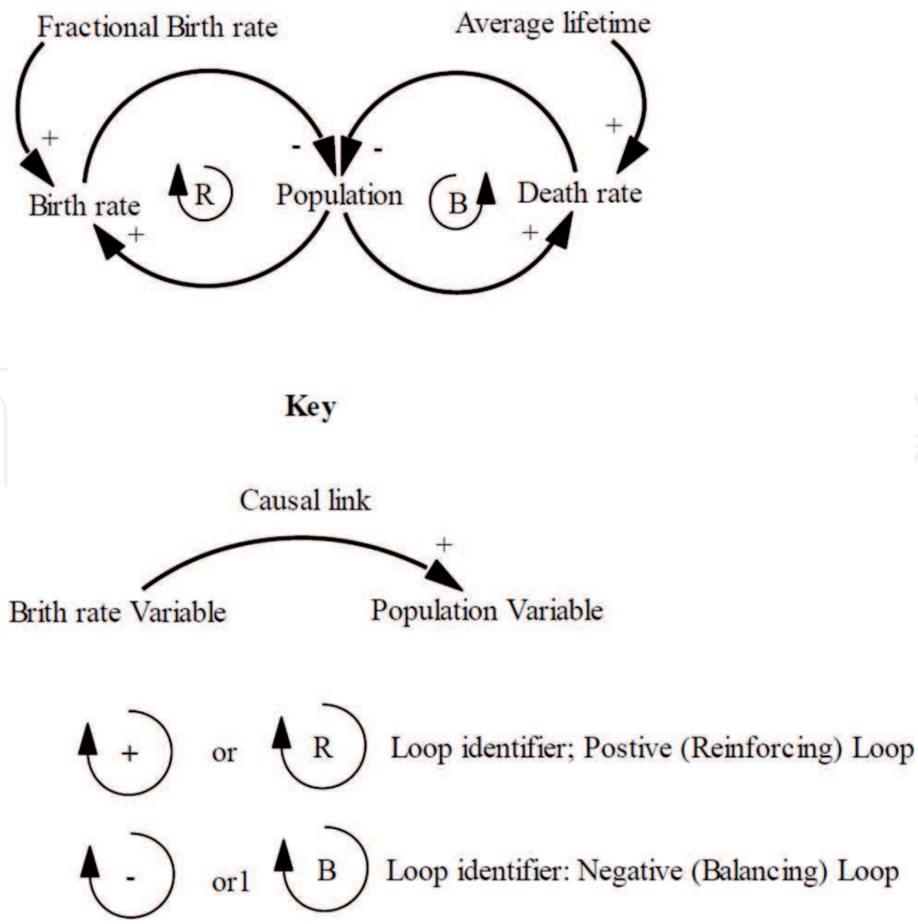

Figure 1.
Causal loop diagram notation (adapted from Sterman [31]).

by two fundamental feedback loops: reinforcing (positive) and balancing (negative) loops. Reinforcing (R) feedback loops are prevented from growing or declining uninterruptedly with balancing (B) loops, which create self-correcting processes that lead to stability and equilibrium and reaching a goal or objective [31, 35].

There is also the presence of delays, which relates to the time it takes diverse groups of stakeholders to make decisions (information delays), the time it takes to implement processes (material delay), or time required for various processes to occur [35]. CLDs are useful for mapping, inferring, and visualising what contributes to growth, decline, delay, or stability, and mostly used at the strategy level r [35]. Although the individual feedback loops are critical to enabling informed decision-making, from the management point of view, it is the system's governing archetypal behaviour that can help managers recognise patterns of behaviour that are already present in a system [71–73]. Thus, reinforcing and balancing feedback loops are principally the basic system archetypes [73]. In this chapter, system archetypes have been used to better understand the feedback structure and long-term behavioural patterns of interacting elements of biophysical and socio-economic issues in the VRB.

4. Methods: application of systems thinking framework and tool

4.1 Characteristics of the study area

The systems thinking approach and its concomitant tool (system archetypes) based on System dynamics was applied in the Volta River Basin, which is in West

Africa. It is the 9th largest in sub-Saharan Africa. It occupies an area of about 400,000Km^2 within the sub-humid to semi-arid West African Savannah zone (**Figure 2**). It extends approximately between latitude 50.30 N–140 30 N and between 20.00 E and 50.30 W. The widest stretch is roughly on longitude 50 30 W to 20 00 E; however, it becomes narrower as it enters the sea (the Atlantic Ocean) at the Gulf of Guinea [74, 75]. It is a trans-boundary river basin shared among six riparian West African countries: Burkina Faso, Ghana, and Togo, Benin, Cote d'Ivoire, and Mali, making it an ethnically and culturally diverse basin. The basin's population stood at 23.8 million in 2010; however, this is expected to reach 56.1 million by 2050 [22]. The spatial distribution of the population within the basin varies with an average population of about 58 persons/km^2; however, this average masks differences between riparian countries [21]. Subsistence or small-holder agriculture and livestock production is the mainstay of the basin economy. The main challenge is how to manage the natural resources of the basin to improve food security, reduce poverty and promote economic development, without further degradation of the natural ecosystems for present and future generations [21].

4.2 Construction of the system model

In this study, the development of the system model followed three steps as follow: a general definition of the system boundary, the identification of the problematic issues (drivers or critical variables), and modelling of the interactions between the key drivers and components (generic CLD). Models of system dynamics are delineated by closed boundaries (causally closed models) where endogenous components and factors (those originating from within) are assumed to form the system structure and predominantly dictate the behaviour of the system [35]. Defining a study boundary encompasses selecting a scale/boundary of analysis by drawing artificial boundaries

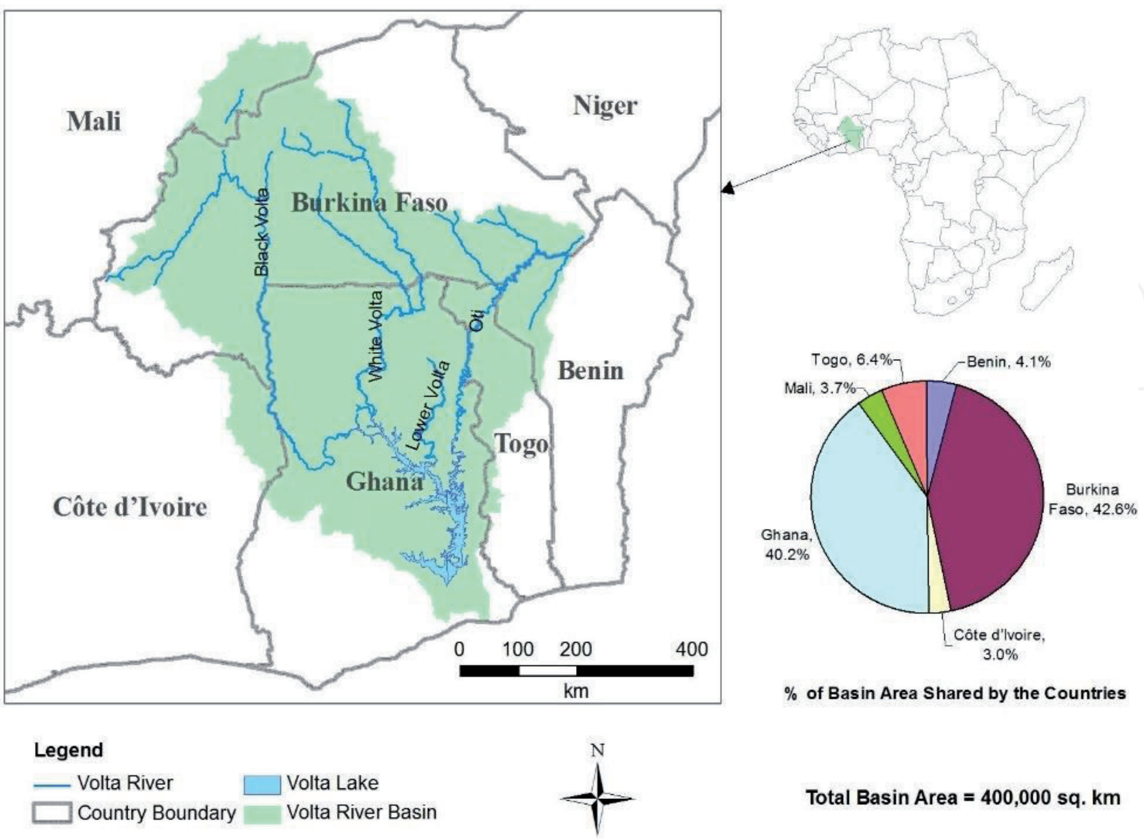

Figure 2.
The Volta River basin showing important political boundaries [76].

around it [77]. Also, the establishment of boundaries is necessary for a simpler, more tractable, and more feasible approach [78] to the phenomenon under investigation. The place or scale selected then becomes the focus of the study, with an understanding that processes at smaller and larger scales, in addition to historical and future trajectory, are crucial for gaining adequate insight into the sustainability of natural resources systems [77]. As [79] suggest, scaling or boundary issues can be partly be addressed appropriately "bounding" social-ecological systems. Thus, the geographical boundary of this study is restricted to the Volta River Basin of West Africa.

The second next stage of the analysis involved exploring and identifying the environmental and socio-economic drivers of change and processes, with a focus on understanding how such changes influence sustainable agriculture development within the Volta River Basin (VRB) [80]. To do this, a combination of comprehensive review of existing studies, semi-structured interviews and structured expert judgements technique (see [81–83]) was used to identify and characterise the key biophysical and socio-economic drivers and processes of change within the Volta River Basin, West Africa. Specifically, interviews were conducted with farmers, extension officers and scientists working in the areas of water, soil, environmental science, rural geography, agricultural science and economics, rural sociology and political science. Overall, these individuals identified 51 drivers of change as most critical to the sustainability of the basin (see **Figure 3**).

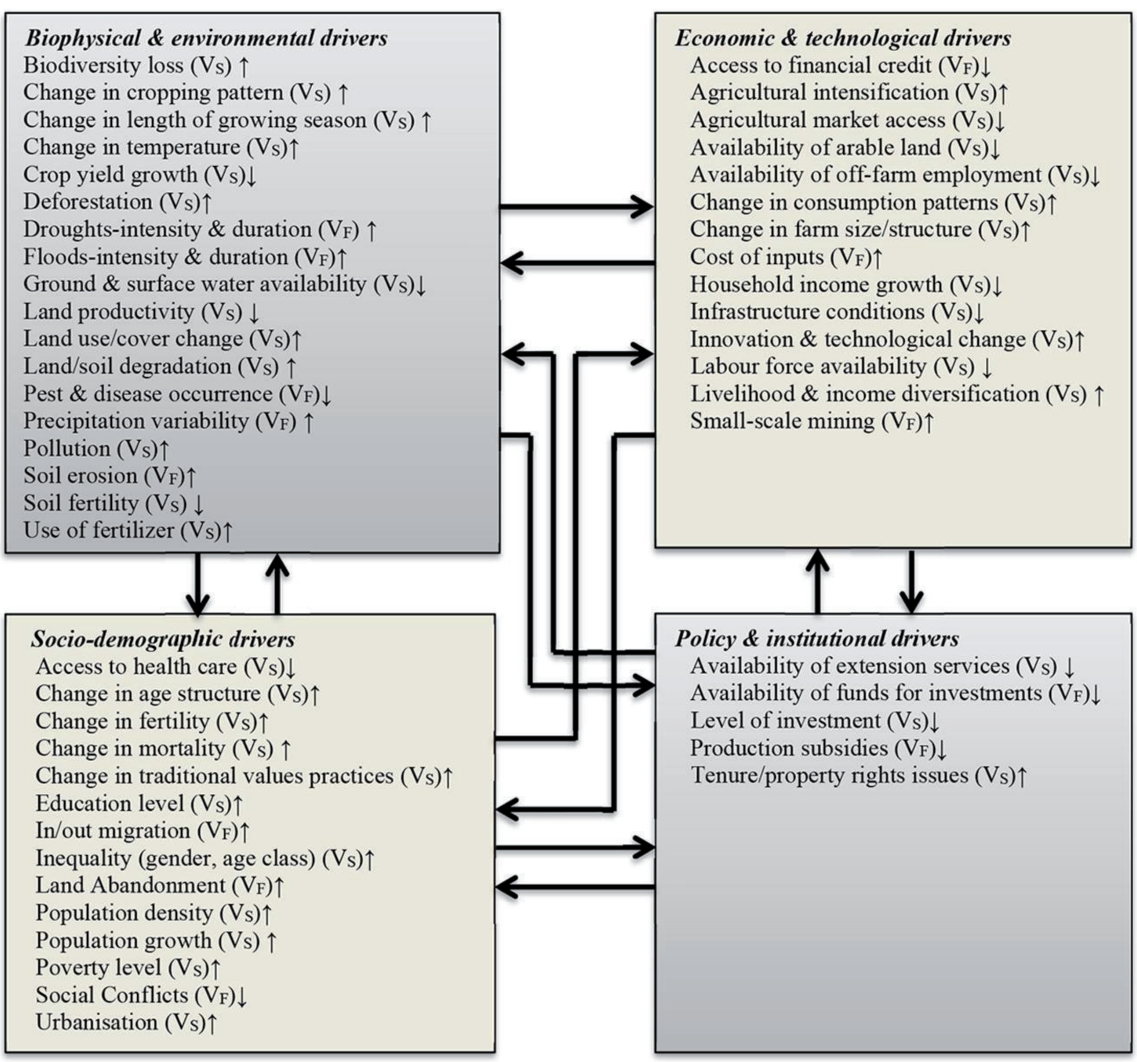

Figure 3.
A simplified model of drivers of change identified in the Volta River basin and their interactions. VS denotes "slow changing variables", while VF denotes "fast changing variables". ↑ indicates increasing trend in the driver, while ↓ indicates decreasing trend [80].

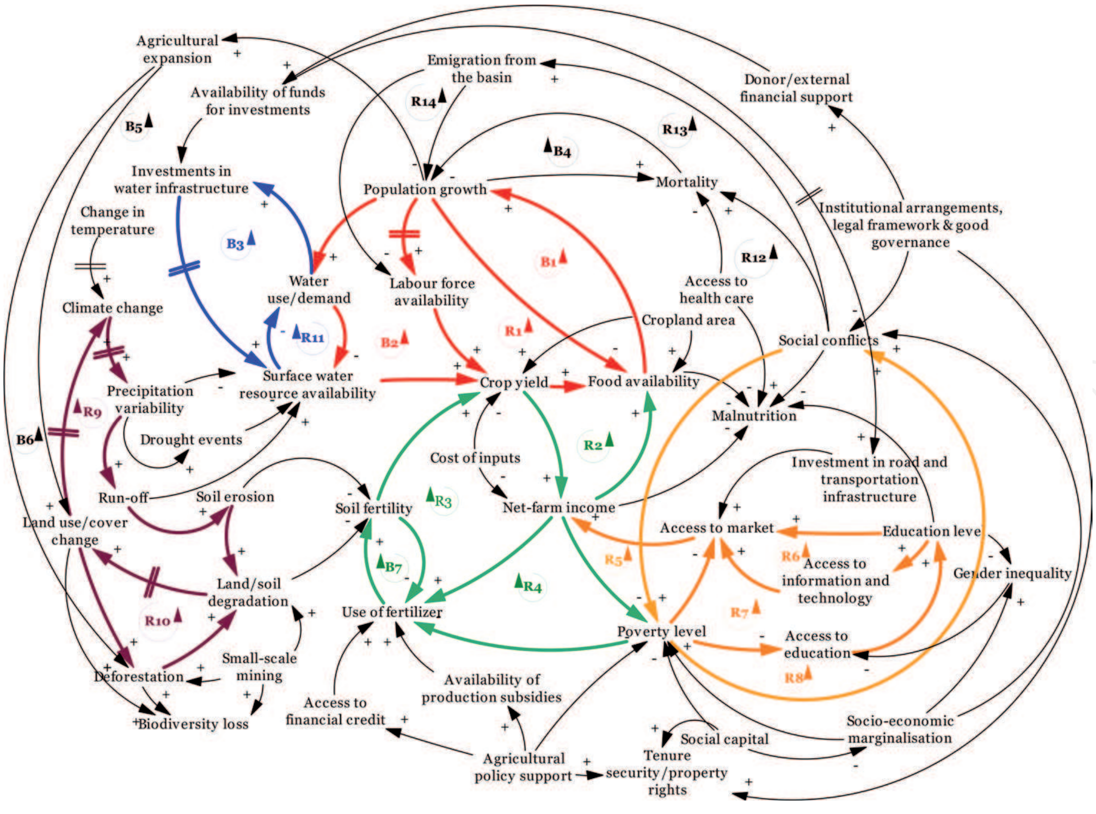

Figure 4.
Integrated conceptual model of the Volta River basin. ("+") indicate a positive link; ("–") indicates negative link. (R) Denotes a reinforcing (or positive) loop; (B) denotes a balancing (or negative) loop. \\ (delay marks) on the arrows denotes time delay perceived to be relevant to the dynamics of the system [84].

Third, and finally, a conceptual system model in the form of a causal loop diagram (CLD), was constructed through participatory modelling exercise to capture the structure and function of the VRB, indicating the cause–effect relationships and feedback loops between the important drivers of change and key variables based on the information from the driver identification (see **Figure 4**). In this chapter, CLD is referred to as the generic model. The description of the main drivers giving rise to problem symptoms and issues identification process is detailed in [80], while the methods underpinning the construction of the generic model is provided in [84]. Here, the main interest is to present five main system archetypes, which can be identified from the generic CLD to assist in sustainable natural resources and agricultural development.

5. Results and discussion

An in-depth examination of the generic CLD (**Figure 4**) revealed four forms of system archetypes which serve as diagnostic tools, describing or predicting the system's long-term behaviour. These are Limits to growth" Shifting the Burden", Fixes-that-Fail, and, and Tragedy of the Commons.

The first mode of behaviour that can be observed from the conceptual model is "Limits to Growth" hypothesis, which states that a reinforcing process of accelerating growth (or expansion) will always be counteracted (or pushed back) by a balancing process [85]. This archetype consists of a reinforcing and a balancing loop, as illustrated in **Figure 5a**. In this example, it appears that water shortage induced by climate variability and change (e.g., high rainfall variability, droughts) appear to be the limiting factors constraining agricultural production and water availability

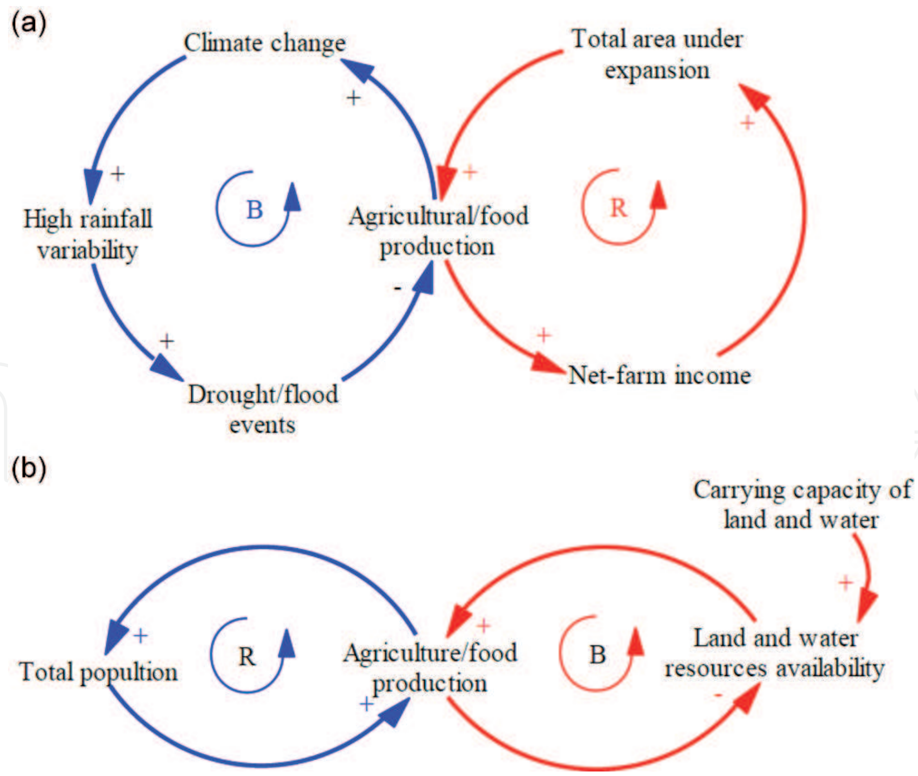

Figure 5.
Limits to growth archetypes in VRB for climate change and agricultural production (a) and population dynamics and agricultural production (b).

in the basin. The dominant management strategy and policy within the basin has so far, been focused on increasing agricultural production while neglecting other productive sectors (e.g., tourism). However, as depicted the resources (such as water and land) required to support sustainable agricultural production may reach their limits (i.e., carrying capacities) due to population growth and climate change. **Figure 5b** also illustrates how agricultural development and food production stimulated on by population growth is limited by the unavailability of water and land, once the system reached carrying capacity. Overall, these limitations may lead the system to the path of unsustainability or functional collapse, thereby exacerbating food and water insecurity. In its simplest form, "Limits to growth" could be seen as highly resilient, because the system's ability to shift to an alternate state is non-existent. However, few systems are this resilient. Thus, the management lesson learned from this archetype is that some element always pushes the system back, so that 'if we do not plan for limits, we are planning for failure [55, 71].

This is even more so, given recent analysis in the basin which predicted that water availability will be further decreased by elevated temperatures and increased evapotranspiration [86]. In order to anticipate future problems and eliminate them before they become a threat, the growth engines and potential limiting or constraining forces need to be identified and addressed. In this regard, supporting adaptation strategies and investment in water infrastructure efforts will help to alleviate the problem in the longer term. There is a need for a long-term approach, to foresee the best strategies for adaptation to climate change and manage risk in the variable environment of the basin [87, 88].

Available evidence indicates that farmers within the basin have traditionally pursued shifting cultivation in response to population growth and declining soil fertility. As population pressure increased, they opened new land by extending farming into forests, wetlands, hillsides, and pastures. In the short term, this strategy has increased food production but the implications of agricultural expansion as "quick fix" is gradually emerging as continued expansion is leading to other undesirable environmental consequences (e.g., land/soil degradation, deforestation) which is exacerbating the problem of low agricultural production and food insecurity. In the systems thinking realm, this behaviour demonstrates quick fixes "Fixes that Fail" mode of behaviour archetype (**Figure 6**). The theory of Fixes that Backfire archetype posits that short-sighted solutions that relieve the symptoms of a problem without addressing the root causes create a weak balancing loop that will entail unintended consequences [72]. The quick-fix solution triggers a stronger reinforcing loop, which causes the problem to re-erupt in the future in an aggravated form, often with challenging unintended consequences. Douxchamps et al. [88] provide a good illustration of how the archetype of "Fixes that Failed" manifested in the basin in their analysis of some policy failures within the basin. For instance, in attempt to control persistent erosions in the 1960s, agriculture water management strategies were promoted throughout the basin for cash crop production in large scale state projects relying on technology transfer as means of dissemination. However, after the first wave of droughts of the 1970s and the associated food shortages, the focus moved to staple crop production and promotion of soil and water conservation techniques through large scale projects. This was attributed to approaches that were too much top-down, with experts as exclusive actors, projects were too shorts with "silver bullet" solutions, there was a lack of consideration for farmers' preferences and traditions.

Consequently, when the second wave of droughts retuned in the 1980s, the smallholders were not better prepared and once again they were severely impacted by loss of yields and income. To avoid this problem in future, there is the need for decision-makers to think in terms of participatory approach and pay attention to indigenous knowledge [88, 89]. The analysis indicates that to move forward, policymakers and stakeholders should pay more attention to fundamental solutions rather than quick fixes that often create unintentional consequences [68]. This mode of behaviour also suggests that we need to identify high-leverage interventions that minimise investment while still resolving the fundamental problem.

Since the early 1980s, policymakers have persistently relied on donor and external financial support to address the issue of chronic poverty, water scarcity, and low agricultural production2050 [22]. As depicted in **Figure 7**, this is a classic case of 'Shifting the Burden' to the donors and external funders rather than finding innovative solutions to the problems. The Shifting the Burden archetype rest on the linear reductionist thinking, which characterises a situation where managers tend to implement an

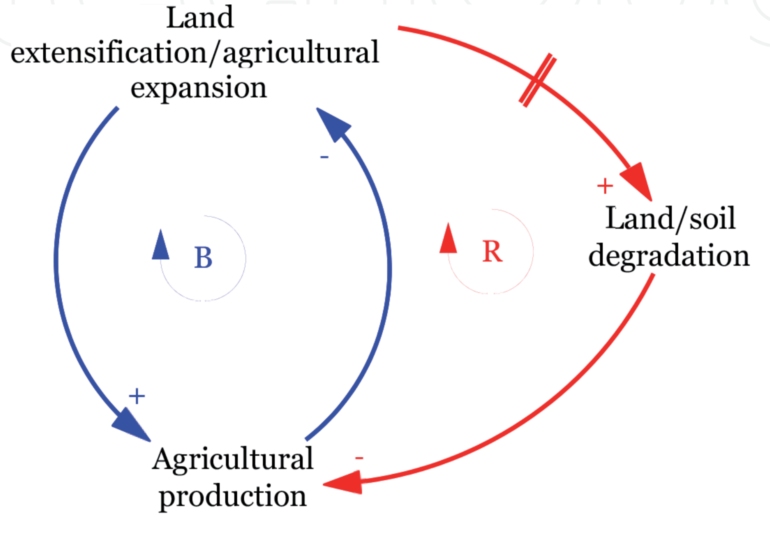

Figure 6.
"Fixes that Fail" archetype in relation to agricultural expansion and land expansion in the VRB.

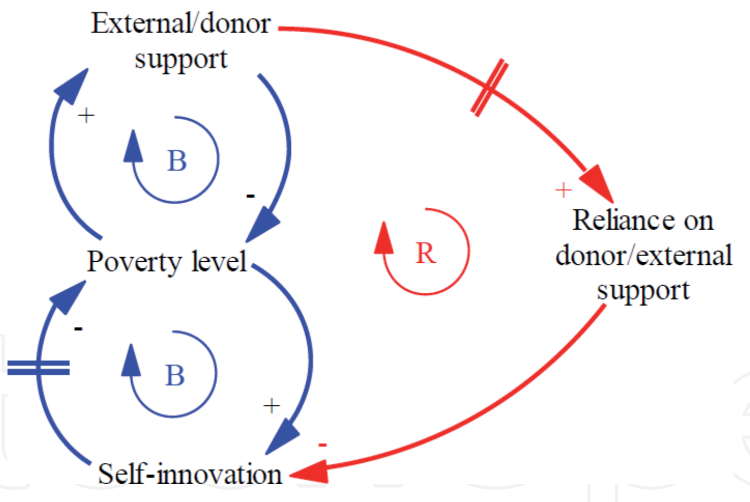

Figure 7.
"Shifting the Burden" archetype for poverty reduction in the VRB.

'easy fix' to a problem, rather than a finding a sustainable long-term solution. The Shifting the Burden archetypes indicates how a problem can exacerbate when we depend so much on donor, NGO or external support model of development instead of self-innovation or capacity development to address socio-economic problems. The situation does not look good given that currently, donor support within the basin is waning and issues of poverty, food and water insecurity, and low agricultural production are retuning, therefore, exacerbate the real problems. Further, this archetype demonstrates while it is undoubtedly true that donors have had a positive role in providing support for natural resources programmes, a narrowly focused policy can make the situation worse, especially if they generate policy resistance [90, 91]. Policy resistance results from the tendency for an intervention to be jeopardised by the system's response to the intervention itself [31, 64, 90].

The final system archetype identifiable from the overall conceptual model is Tragedy of the Commons". In the tragedy of the commons archetype, a reinforcing loop is created by the activity of system actors with the aim of the intention of increasing rewards for themselves. However, an unintended consequence is that the activity results in overuse of and damage to the environment, which reduces the magnitude of the outcome for all [65]. As stated earlier, the water resources in the Volta Basin contribute significantly to the economic development of the six riparian countries. This is the case particularly for Burkina Faso and Ghana, where more than 60% of the area of each country is located within the VRB [89]. Interestingly, but not surprisingly, rising demands on the resources have resulted in intense competition between the two countries. For example, while Ghana uses the water for industrial purposes, such as hydropower generation, Burkina Faso uses it for agricultural purposes.

In the Tragedy of the Commons archetype, the two competing countries (Ghana and Burkina Faso are represented (**Figure 8**). Each of these countries is involved in the use of the common resources, which in this case is the water resource available in the basin. As both countries activities go up, their net gains also go up. In other words, initially, the reinforcing loops R1 and R2 drive the system such that each country achieves some level of socio-economic development. Consequently, increasing their level of activities to the resources the reinforcing loops allows the countries to achieve more significant gains all the time. All the activities sum up to the total activity. Thus, an increase in the total amount of water used reduces the water available per user, thus making both countries more vulnerable to disruptions of the water supply. This occurs because the total activity is greater than the resource limits. The tragedy occurs, therefore when the resource is depleted,

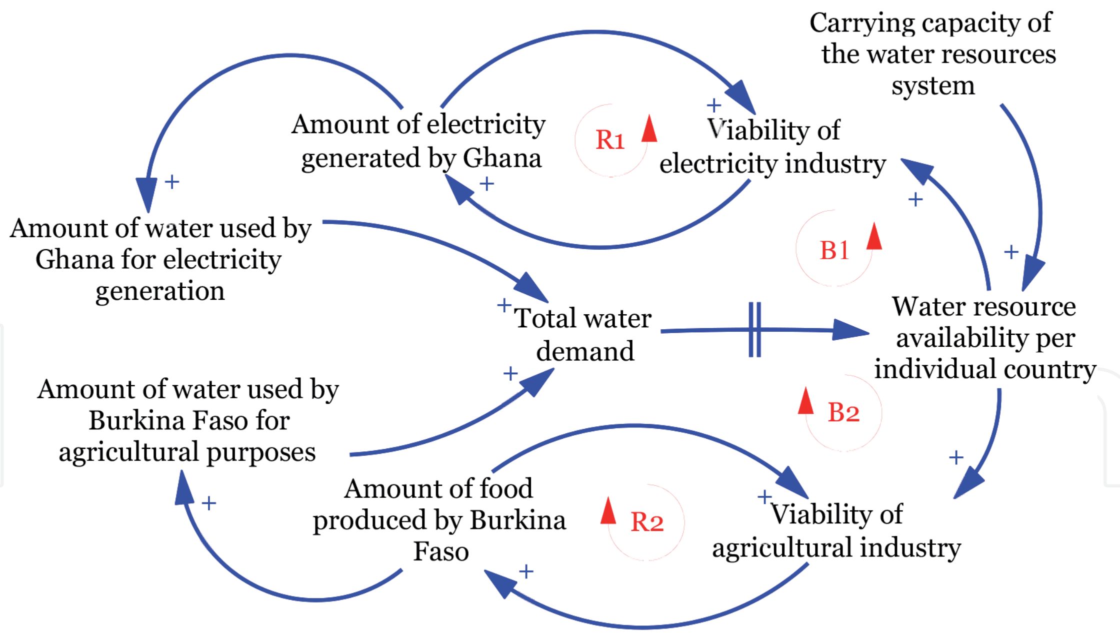

Figure 8.
Water resource usage "Tragedy of the Commons" archetype.

suggesting the need set up a joint management strategy. At this point, the balancing loops B1 and B2 dominate the system's dynamic behaviour. This archetype demonstrates how the development ambition of these countries could be hampered, which, in turn, could exacerbate poverty in the basin.

In this situation, there is a substantial risk of a further tragedy of the water commons unless the two countries work closely together in terms of using the available water resources. There is also the need for a mechanism, which promotes the coordinated development and management of water, land and related resources, without compromising the sustainability of vital eco-systems. There must also be an agreement to share and sustainably use the available resources.

6. Conclusion

In this chapter, generic system structures (system archetypes) based on system dynamics is used to integrate the relationships between the environmental, economic, social and institutional factors feedbacks driving the behaviour and viability of the Volta River Basin in West Africa, particularly as they relate to water resources management and agricultural production systems. Specifically, four common systems archetypes: Limits-to-Growth, Fixes-that-Fail, Shifting the Burden" and Tragedy of the Commons" are used to illustrate how system structure works. These system archetypes illustrate that the past and the current paradigm of water and land and agricultural production management is unsustainable. The analysis showed how decisions in one part of the system might impact decisions at other parts. For example, the limit to growth archetype illustrates the effect of climate change, population growth on water, and agricultural production and land availability. The "Shifting the Burden" and "Fixes that Fail" highlight the implication of using long-term rather than short term solutions to solve problems involving the interaction between water, food and agricultural systems. The "Tragedy of the Commons" mode of behaviour pointed how different development goals pursued by various countries in the basin (Ghana and Burkina Faso) have the potential to lead to depletion of the available water and land resources and economic returns for countries. It has also been shown that decision-makers need to be aware that synergies and trade-offs between sectors need to be considered in the management and allocation of water and land and food resources.

The chapter also provides a practical demonstration of how common patterns of dynamic behaviours may be used to support water resource management decision-making exemplified in the VRB, including planning for the systemic problems before they become a threat, limiting the reliance on donor support, avoiding an easy and quick fix to the underlying problems, promoting coordinated development and management of water. As with many system tools, the conceptual model developed in this study is the simplification of real problems in the basin. They are not comprehensive models of the very complex reality in the system. Nevertheless, they can serve as useful diagnostic tools for improving decision-makers' ability to analyse and foresee potential systemic problems and, communicating such issues with others and developing strategies to cope with them effectively.

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