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Nexus planning as a pathway towards sustainable environmental and human health post Covid-19

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ABSTRACT

The Covid-19 pandemic has exposed the fragility of linear and monocentric approaches in addressing today's complex, cross-cutting, and interconnected challenges. Experiences from the Covid-19 have shown that focusing on one sector during a crisis only aggravates the stresses in other sectors as decision-makers often view the world from a linear perspective, with the thought that a click of a button would get the economy and society back on track. This study argues that linearity forgets the interconnectedness of systems and how their systemic properties shape their interactions, interdependencies, and interrelationships, whereas nexus planning integrates and simplifies socio-ecological systems, indicates priority areas for intervention, and reduces risk and vulnerability. The lockdowns implemented during the peak of the Covid-19 pandemic resulted in job losses, company closures, and economic recessions, demonstrating that linear approaches often over-emphasise on a limited set of attributes of a system, notably efficiency, at the expense of other aspects. While linear approaches have been beneficial to some extent for long, the Covid-19 pandemic exposed how they transfer stresses to other sectors, and compromise resilience-building initiatives, allowing failure to cascade from one sector to the other. Nexus planning emphasises on cross-sectoral sustainability and enhances socio-economic resilience against future shocks.

1. Introduction

Lives and livelihoods have changed drastically from before and since the early days of the Covid-19 pandemic (WHO, 2020). The interconnectedness of the challenges currently facing humankind has reignited the discussion on the importance of transformative approaches in achieving sustainability in a world beset with a host of problems (Burch et al., 2019). The capability of transformative approaches to address complex problems and their polycentric nature has increased their value and prominence in recent years (Nhamo et al., 2020). Nexus thinking and scenario planning have been widely advocated for, before and during the Covid-19 pandemic and the subsequent lockdowns (Mabhaudhi et al., 2020). Research and policy have witnessed dynamic changes in the way of doing things from linear to integrated or from monocentric to polycentric approaches as evidenced by deliberations during meetings and research reports dedicated to enhancing collaboration and addressing issues in an integrated manner (Nyström et al., 2018). Both research and policy-making have committed to break the 'silos' and turn nexus theory or rhetoric into practice (Mabhaudhi et al., 2020). Research collaborations and data sharing during the Covid-19 pandemic have initiated the breaking of existing silos as the research community is working in unison to develop a vaccine for the coronavirus (Blomberg and Lauer, 2020). Befittingly, the $6.7 billion Covid-19 Global Humanitarian Response Plan (GHRP) promotes such collaborations, and the use of integrated approaches in ensuring human health and achieving sustainable development (UN, 2020).

Today's age, called the 4th Industrial Revolution (4IR), relies on complex, cross-cutting, and interconnected systems to deliver goods and services (Allen and Prosperi, 2016; Lee et al., 2018). Although this has come with considerable advances and opportunities for development, it has also exposed the systems to disruptions and shocks of severe magnitude, as evidenced by the disruptions in global supply chains during the Covid-19 pandemic (Bonilla et al., 2018). As what happens in complex systems, tensions always manifest between efficiency and resilience, the ability to anticipate, absorb, recover, and adapt to unexpected disruptions (Hynes et al., 2020; UNEP and ILRI, 2020). Thus,

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sector-based or system-specific resilience initiatives such as military or health systems, are often associated with systemic risks, which emanate from strategies that lead to suboptimal efficiencies in one sector at the expense of other sectors (Hanefeld et al., 2018; Nhamo et al., 2018; WHO, 2020).

The Covid-19 pandemic has not only caused immeasurable losses and casualties in the health sector but also in the global economy, with high social and environmental costs, demonstrating the fragility and unreliability of some of the man-made systems such as globalisation and linear or sector-based approaches (Nicola et al., 2020). The level of unpreparedness manifested through shortages of test kits, ventilators, and other essential items at a time they were needed the most. The initial reactive responses inadvertently aggravated the stresses in other sectors as evidenced by the company closures and job losses in the aftermath of the lockdowns (UN, 2020). The challenges saw a cascading collapse of the global economic system, including massive disruptions in production, finance, health, and transport, due to a colossal combination of demand and supply shocks (McKee and Stuckler, 2020). National governments struggled to cope with the challenges as, in their reactive responses, they tried to address the immediate needs brought about by the Covid-19 pandemic and at the same time attempting to address longer-term issues it exposed such as restoring economies and achieving the Sustainable Development Goals (SDGs). This underlined the urgency to address intricate trade-offs between health, economic, social, and national goals (Hynes et al., 2020), and highlighted the importance of transformative approaches (nexus planning, circular economy, sustainable food systems, and scenario planning) in informing coherent policies and strategies that address the systemic origins and impacts of shocks in an integrated manner (UNEP and ILRI, 2020).

Therefore, the Covid-19 pandemic reignited the need to address current interlinked challenges in an integrated manner, other than through singular or linear approaches (UN, 2020). This study, therefore, establishes a water-human health-environment-nutrition (WHEN) nexus and integrates associated sustainability indicators through a multi-criteria decision making (MCDM) method. The MCDM was used to establish numerical relationships between distinct but interlinked WHEN sectors for easy interpretation and understanding. The resultant quantitative relationship is critical for formulating coherent policies and strategies, and for identifying priority areas for intervention. Additionally, it forms the basis for sustainable development and sound human-environmental health outcomes. Thus, the Covid-19-induced shocks, together with the increasing poverty and inequalities on a global scale have highlighted the need to achieve SDGs as a matter of urgency. The focus, therefore, was to reduce the risk posed by socio-ecological changes on both environmental and human health. The premise is to enhance resilience initiatives and inform policy on pro-active interventions through nexus planning towards sustainable socio-ecological systems.

2. Methods

2.1. Conceptual framework

Four thematic areas that are needed to understand novel socio-ecological interactions and how to build human resilience against the risk of social and environmental changes include (i) drivers of change, (ii) risk and exposure to novel pathogens, (iii) recovery and preparedness for future pandemics, and (iv) adaptation and the resilience of communities (Fig. 1). The essence of nexus planning is to simplify human understanding of the complex interrelationships between these thematic areas and how they drive socio-ecological systems (Nhamo et al., 2020). The approach facilitates the comprehension of complex and interlinked socio-ecological processes and interactions (Mabhaudhi et al., 2019). It is a systemic and integrated assessment of distinct but interrelated aspects, a polycentric approach to understand and evaluate the intricately interlinked socio-ecological interactions (Bleischwitz et al., 2018; Nhamo et al., 2020). Each component of the nexus is equally assessed without prioritising one over the other (Hoff, 2011; Nhamo et al., 2018). The process identifies trade-offs and synergies, indicates priority areas for intervention, and reduces the risk of transferring stresses from one sector to the other, or even duplicating activities (Mpandeli et al., 2018; Nhamo et al., 2020).

Closely interlinked components constituting a sustainable and functional socio-ecological system include water, nutrition, environmental and human health, (Folke et al., 2016; Liehr et al., 2017). These components drive the dynamics taking place within a socio-ecological system and have been termed the "WHEN nexus" referring to the intricate relationships between water, health, environment, and nutrition (Fig. 1). Any change or disturbance on any one of the WHEN nexus components triggers a complete evolution or transformation of the whole ecosystem, including species migration, extinction, or invasion by alien species (Bellard et al., 2012; Wong and Candolin, 2015). The WHEN nexus is thus, an essential transformative intervention to understand novel interactions between humans and wildlife and is an important decision support tool for formulating strategies to reduce risk and human vulnerability to novel pathogens from wildlife. The WHEN

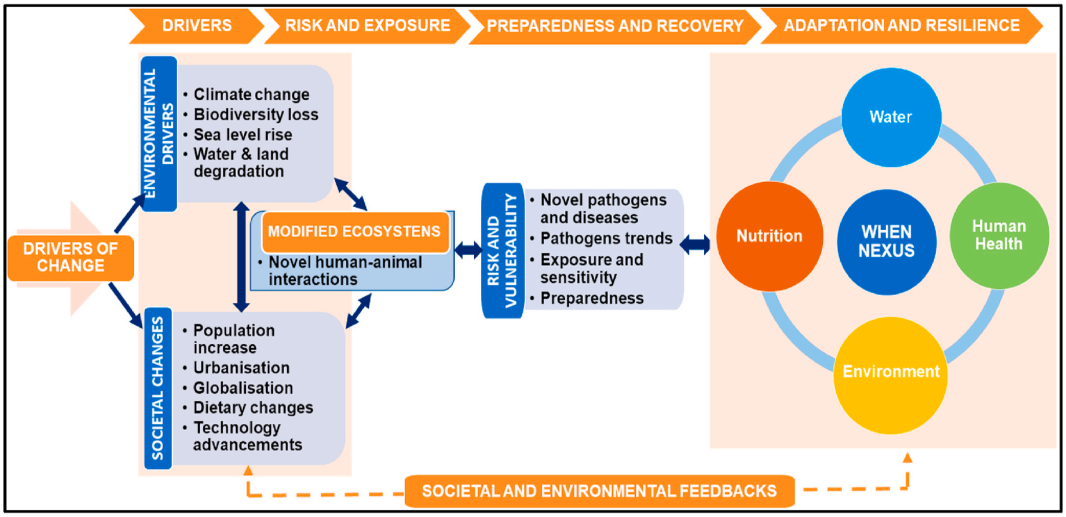

Fig. 1. Transformational and dynamic processes within a socio-ecological system, and the impacts on environmental and human health. Nexus planning simplifies these complex interactions and informs policy on the formulation of coherent strategies geared towards resilience and sustainability.

nexus methodological framework (Fig. 1) illustrates the dynamics and transformational processes resulting from novel human-wildlife interactions.

2.2. *Drivers of change in socio-ecological systems*

As already alluded to, an important attribute of nexus planning is to integrate distinct but connected components and processes of a socio-ecological system that include the drivers of change, societal and environmental feedbacks, and the multiple outcomes (Fig. 1). The premise is anchored on the understanding that ecosystems are managed (directly or indirectly) for human benefit, however, emphasising on one set of service (e.g. sustainable diets) at the expense of other components (e.g. sanitation and hygiene) usually results in conflict and increases risk and vulnerability (Purvis et al., 2019). Nevertheless, societal, and environmental changes are altering ecosystems and modifying wildlife habitats and human behaviour, increasing the vulnerability and risk of communities to novel infectious diseases originating from wildlife, grossly risking human health (Lindahl and Grace, 2015). As a resilient and adaptive management approach, the WHEN nexus guides informed decisions in the face of uncertainty and unpredictable outcomes. If well applied, it reduces the risk posed by wildlife on human health through informed strategies on readiness and/or timely intervention.

An integrated analysis of socio-ecological processes provides pathways to understand complex interactions and facilitates the comprehension of the critical factors that influence social and environmental outcomes. The processes and components are linked to show the flow and nature of the outcomes at a given point and time or space. Novel zoonotic pathogens that have dominated pandemics in the last 100 years correlate significantly with both population growth and distribution of wildlife biodiversity (Allen et al., 2017). The role of nexus planning is to provide the lens to understand the intricate socio-ecological interactions, simplifying those interactions, and providing guidelines on improving sanitation, waste disposal, and pest control, as a means of reducing risk and vulnerability on human health. These nexus attributes link nexus planning with other transformative approaches such as the circular economy and sustainable food systems.

2.3. *Linking socio-ecological components through nexus planning*

As nexus planning is a ‘‘problem-determined system’’ and not a “system-determined problem‘‘, it is oriented to provide integrated solutions to complex systems through transformative and polycentric processes, other than linear or monocentric processes (Mabhaudhi et al., 2019; Nhamo et al., 2020). Therefore, in developing the WHEN nexus model we considered the complexity of integrating distinct sectors of water, human health, environment, and nutrition components, as well as their heterogeneity over space and time and replete with non-linear societal and environmental feedbacks. Nexus planning is a preferred approach as it unpacks and addresses complex and multi-causal challenges within a system (in the present case, the WHEN components) (Carpenter et al., 2009; Nhamo et al., 2020). The approach provides pathways towards sustainability and reduces the health risks posed by novel pathogens. The WHEN nexus intends to inform policy on strategic pathways that simplify the intricately interconnected relationships within socio-ecological systems, and the drivers of change that result in outcomes (interactions) that reduce specific behaviours and pose risk and vulnerability to human health (Fig. 1).

A set of sustainability indicators related to each WHEN nexus component is given in Table 1. Indicators are essential parameters for establishing a quantitative relationship among interlinked but distinct components or factors of a system (Nhamo et al., 2020). They provide a numerical scale needed to monitor performance, measure achievement, and determine accountability, three elements that form the cornerstone of effective monitoring and evaluation (Warhurst, 2002). Therefore, sustainability indicators are basic decision support tools that simplify the interpretation of complex interrelationships within a system, transforming those relationships into simple formulations for easy monitoring and evaluation (Pavlovskaia, 2014). In nexus planning, sustainability indicators are based on the essence of “nexus thinking”, which is to provide the relevant information that ensures resource security and sustainable development (Hoff, 2011). Sustainable development is meant to balance different and competing necessities against an awareness of the environment, social and economic limitations faced by humankind, and is a pathway towards resilience and adaptation (Meadows et al., 1972). A sustainable system provides for the economy, the ecosystem, and social well-being and equity at all times (Breslow et al., 2017; Shilling et al., 2013).

Table 1
Sustainability indicators to establish relationships among the WHEN nexus. The indicators are the same as SDG indicators, and thus, the WHEN nexus can be used to assess progress towards SDGs.

Component	Sub-component	Indicator	Units	SDG indicator
Water	Water security	Proportion of population using safely managed drinking water services	%	6.1.1
		Proportion of bodies of water with good ambient water quality	%	6.3.2
Human health	WASH	Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene	per 100 K of pop	3.9.2
Environment	Functional ecosystem	Forest area as a proportion of total land area	%	15.1.1
		Proportion of land that is degraded over total land area	%	15.3.1
Nutrition	Sustainable diets	Prevalence of moderate or severe food insecurity in the population	%	2.1.2
		Prevalence of malnutrition	%	2.2.2

Therefore, sustainability indicators are an integral part of nexus modelling and are the basic unit of measurement of complex relationships (Glass and Newig, 2019). The WHEN nexus indicators (Table 1) correspond with related Sustainable Development Goals (SDGs) indicators, making the approach relevant for assessing progress towards SDGs (Nhamo et al., 2020). The indicators are the main source of information in determining indices for the WHEN nexus components. The premise is to develop indices for the WHEN components, provide insights into the efficiency of processes and product use and management, and to simplify the intricate relationships of a system (Warhurst, 2002). The process is meant to indicate priority areas needing immediate intervention and reduce human vulnerability to novel pathogens resulting from novel socio-ecological interactions (Milner-Gulland, 2012).

2.4. *Mathematical representation of multi-component complex systems*

We adopted the nexus analytical model developed by Nhamo et al. to establish quantitative relationships between different components (Nhamo et al., 2020). We adapted the model in the context of the WHEN nexus and presented the dynamics between the inputs and outputs taking place within a socio-ecological system. The outcomes include environmental and human health, improved human resilience and immunity, functional ecosystem, and sustainable diets (Chiabai et al., 2018; Martinez-Juarez et al., 2015). The integrated efficiency of these outcomes was determined by computing composite indices for each of the components to reveal susceptibility and risk posed by the incessant socio-ecological changes on human health. The indices are used to classify an area into one of the health hazard risk classification categories (highly or lowly risky) (Nhamo et al., 2020). The composite indices and outcomes are determined by decisions and actions taking place within a system, but also by planetary drivers. The sustainability indicators (Table 1) are the main tools that guide the determination of indices at a given time (Nhamo et al., 2020).

A multi-criteria decision-making (MCDM), method the Analytic Hierarchy Process (AHP), was used to establish the quantitative relationship between the distinct variables of a system within the context of the WHEN nexus. The AHP relates sustainability indicators (Table 1) through a pairwise comparison matrix (PCM) (Saaty, 1990). The indices connect the system components, and they convey relational information regarding the state of preparedness and indicate whether a system is susceptible or resilient to health shocks. The PCM establishes priority weights, in the form of indices, for each indicator as compared to the others. The priority weights of the matrix are denoted as *w* (Saaty, 1990). The overall weight for each indicator is established through a basic input of the matrix, *A*, of *n* criteria, which is of the order (*n x n*) (Rao et al., 1991). *A* is a pattern with elements a_{ij}. The reciprocal matrix is expressed as:

$$a_{ij} = \frac{1}{a_{ij}} \tag{1}$$

Once the matrix is established, it is normalised as pattern *B*, where *B* is the normalised pattern of *A*, with elements b_{ij} and expressed as:

$$b_{ij} = \frac{a_{ij}}{\sum_{j=1} n\, a_{ij}} \tag{2}$$

The weight of each indicator (w_i) is established as:

$$w_i = \frac{\sum_{j=1} n\, b_{ij}}{\sum_{i=1} n \sum_{j=1} n\, b_{ij}},\ i, j = 1, 2, 3\ldots,\ n \tag{3}$$

The composite WHEN nexus index is then calculated as a weighted average of the indices. The indices are visually related to each other through a spider graph that provides an overview of the connectivity of the indicators. The spider graph vividly demonstrates the interconnectedness of different components, the vulnerability, and the risk to human health. The information is used to pick interventional areas needing immediate attention as a resilience strategy (Nhamo et al., 2020). However, the consistency of the comparison matrix is evaluated through a consistency ratio (*CR*), which indicates whether the matrix was consistently and reliably established (Nhamo et al., 2020).

3. Results

3.1. Calculating WHEN nexus indices: a case of South Africa

The WHEN nexus comparison matrix developed for South Africa (Table 3), shows the diagonal values as 1 throughout as they represent values of unity, meaning that when an indicator compares against itself the comparison is always 1. The matrix is divided into two symmetrical parts, as the shaded triangle is the section that must be filled, and the bottom unshaded triangle represents reciprocal values of the shaded half. A relational scale ranging between 1/9 and 9 is used to establish the matrix (Table 3) (Saaty, 1990). The weighting of the matrix is based on expert advice and the prevailing status of a country or region under study concerning the relevant indicators for a given period (Table 2). Thus, the indicator values given in Table 2 provide the basis when classifying the indicators.

Table 2
Status of WHEN nexus indicators for South Africa in 2018.

WHEN nexus	Indicator	Status 2018
Water	Proportion of population using safely managed drinking water services (Water accessibility)	74%
	Proportion of bodies of water with good ambient water quality (Water quality)	46.92%
Human Health	Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene (WASH mortality)	13.7/100 K pop
Environment	Forest area as a proportion of total land area (Forested area)	7.6%
	Proportion of land that is degraded over total land area (Degraded area)	60%
Nutrition	Prevalence of moderate or severe food insecurity in the population (Food insecurity)	52%
	Prevalence of malnutrition (Malnutrition)	6.2%

Source: World Bank Indicators (2020).

After establishing the matrix (Table 3), the weights are normalised using Equations (2) and (3). The normalised values (Table 4) indicate that the column sum of the indices is always 1, which is an indication that the indicators are now quantitatively linked, an attribute that allows an integrated numerical analysis of the indicators (Nardo et al., 2005; Saaty, 1990). The *CR* is 0,10, which is within the permissible range. The weighted average of the indices is the integrated composite index and is categorised according to the classification given in Table 5. The 2018 composite index for South Africa stood at 0,170.

3.2. Classifying indices into health risk classification categories

The indices (Table 4) vary between 0 and 1 and are classified into health risk categories as severe, high, moderate, or low (Table 5). The composite index for South Africa (0,170), classifies the country into a high-risk health category. The worst category is a severe risk.

The classification categories also apply to individual indicators and are indicative of the current state of vulnerability of the country to health risks. The classification categories are necessary for interpreting the indices and for formulating coherent strategies to reduce vulnerability and build resilience.

3.3. Interpreting the integrated health indices

The WHEN nexus indices (Table 4) are presented through a spider graph (Fig. 2) which provides a numerical overview of the relational socio-ecological interactions of the different system components. The graph presents how each indicator relates to the others and how each contributes to health sustainability. For example, food insecurity and malnutrition indicators present very high indices of 0,224 and 0,215, respectively, which pose a high risk of disease transmission due to immunity deficiencies. Policy and decision-making should, therefore, prioritise reducing these negative indices which highlight the risk of the most vulnerable people, mainly those residing in informal settlements and rural areas (Satterthwaite et al., 2020). The high-risk health category for South Africa is aggravated by the low indices to important indicators of water accessibility and water quality. Unlike the indices for food insecurity and malnutrition which should be low, the indices for water accessibility and water quality should be higher than what they presently are to ensure good health and wellbeing for all. However, attaining the best possible levels in water-related indices in South Africa is hampered by water scarcity in a country ranked as the thirtieth driest in the world (Sershen et al., 2016). However, despite such challenges, the country has managed to keep water, sanitation, and hygiene (WASH) related deaths very low at 13,7 deaths/100 000 population (Table 2).

An area of concern is the low environmental indices related to the proportion of forested area and land degradation. Over 60% of South Africa's land area is degraded and only 7,6% of its total land area is forested (Niedertscheider et al., 2012). These numbers indicate an alarming rate at which the environment is degrading and altering wildlife habitats. These environmental changes are driven, in part, by rapid urbanisation, increasing population, and expanding agricultural land (Satterthwaite et al., 2010). Habitat loss is driving wildlife to invade human settlements, particularly in urban areas where food is readily available (Nava et al., 2017; Wong and Candolin, 2015). These novel socio-ecological interactions risk human health from zoonotic

Table 3
Pairwise comparison matrix for WHEN indicators.

Indicator	Pairwise comparison matrix						
	Water accessibility	Water quality	WASH mortality	Forested area	Degraded area	Food insecurity	Mal-nutrition
Water accessibility	1	1	1	1/4	1/2	1/3	1/2
Water quality	1	1	1	1/3	1/3	1/2	1
WASH mortality	1	1	1	1/2	1/3	1	1/2
Forested area	4	3	2	1	1	1/3	1/3
Degraded area	2	3	3	1	1	1/3	1/3
Food insecurity 1	3	2	1	3	3	1	1
Malnutrition	2	1	2	3	3	1	1

Table 4
The WHEN nexus normalised pairwise comparison matrix and the composite indices.

Indicator	Normalised pairwise comparison matrix							
	Water accessibility	Water quality	WASH mortality	Forested area	Degraded area	Food insecurity	Mal-nutrition	Indices
WASH mortality	0,071	0083	0,091	0028	0,055	0074	0,107	0073
Water quality	0,071	0083	0,091	0037	0,036	0111	0,214	0092
WASH mortality	0,071	0083	0,091	0055	0,036	0222	0,107	0095
Forested area	0,286	0250	0,182	0110	0,109	0074	0,071	0155
Degraded area	0,143	0250	0,273	0110	0,109	0074	0,071	0147
Food insecurity	0,214	0167	0,091	0330	0,327	0222	0,214	0224
Malnutrition	0,143	0083	0,182	0330	0,327	0222	0,214	0215
Consistency Ratio (CR) = 0.10								$\sum = 1$
Composite WEF nexus index (weighted average)								0.170

Table 5
Health risk classification categories for WHEN nexus indicators.

	Severe risk	High risk	Moderate risk	Low risk
Category	0–09	0.1–0.2	0.3–0.6	0.7–1

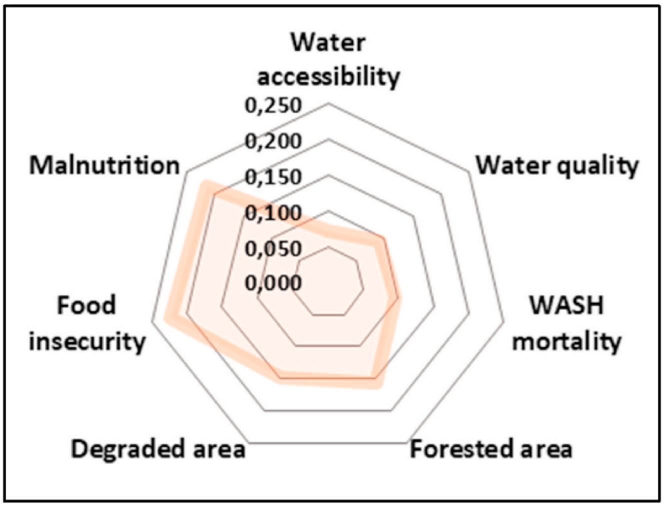

Fig. 2. Quantitative relationship among WHEN nexus indicators in South Africa.

threats (Jones et al., 2008; WHO, 2018).

This socio-ecological relational information is critical for formulating strategies that build resilience, especially when linked and associated with the epidemic preparedness index (EPI) (Madhav et al., 2017; Oppenheim et al., 2019). Unlike in sustainability studies where the spider graph has to be circular to attain sustainable resources management, in health preparedness and risk reduction strategies the weights of negative indicators like food insecurity and malnutrition have to be drastically reduced (Nhamo et al., 2020). This should happen as indices for water quality and accessibility are improving and those for land degradation and deforestation are reduced.

4. Discussion

The overall health risk index for South Africa (0,170) places the country in a high-risk category, making the country highly susceptible to health risks. This is worsened by globalisation and easy means of international travel, which often accelerates the rate and risk of transmission on a global scale (Kilpatrick and Randolph, 2012). The risk is high, requiring urgent international cooperation to curb and ring-fence zoonoses hotspots (Morse et al., 2012). Societal changes (population increase, rapid urbanisation, and globalisation), together with environmental degradation and climatic change (biodiversity loss, sea-level rise, and water and land degradation) are altering ecological, biological, and social conditions, and giving rise to the risk of novel wildlife pathogens on human health. These drivers of change are aiding the prevalence, transmission, geographical range, and control of pathogens, especially those transmitted by vectors (Saker et al., 2004).

Both the drivers of change and the risks to human health are intricately interconnected in such a way that focusing on a single part of the challenge will only expose the other components of the system (Preiser et al., 2018). The adoption of nexus planning and other transformative approaches such as circular economy, sustainable food systems, and scenario planning is critical in achieving the global agenda on sustainable development (Nhamo et al., 2020). Nexus planning facilitated the identification of priority areas needing intervention as a pathway towards water security and availability of safe drinking water to all, at the same time curbing deforestation, land degradation, malnutrition, and food insecurity (Fig. 2). However, the success of nexus planning as a decision support tool for formulating coherent policies is reliant on data availability and the adoption of digital technologies. Data availability and digital technologies are important for improving global health outcomes beyond the Covid-19 pandemic. The use of ICT to provide healthcare has the potential to improve health services and it holds transformational capability for health care services during the 4IR (Zonneveld et al., 2019).

The intricately interconnected socio-ecological changes are a risk to human health through exposure to novel pathogens. Preparedness and readiness are dependent on the adoption of interdisciplinary and transformative approaches to inform strategies on the prevention and control of novel infectious diseases. The challenges are non-linear nor monocentric as they involve complex systemic relationships that should be considered by both research and decision-making (UNEP and ILRI, 2020). Nexus planning is one transformative approach that has gained prominence as it can address multi-faceted, multi-connected, and complex challenges (Nhamo et al., 2020).

With the increasing risk on human health posed by environmental changes, poor communities are the most vulnerable as they lack resources to adapt. Decision-making should prioritise on providing clean, safe, and reliable water supplies, provide good sanitation and hygiene (WASH) in poor communities. Health risk reduction initiatives should include curbing air pollution and unsanitary conditions that generally prevail in informal settlements.

5. Conclusions

Understanding the complex interlinkages and interdependencies between climate change, ecosystems, and human health is essential to effectively plan adaptation responses against novel pathogens. As a transformative approach, nexus planning is ideally suited to understanding intricate interrelationships within socio-ecological systems. A WHEN nexus assessment has facilitated a better understanding of complex socio-ecological interactions and the processes that drive them. The assessment allowed the identification of priority areas for intervention to ensure mutual socio-ecological co-benefits and reduce the risk of novel pathogens on human health. The use of nexus planning in epidemiology research facilitates the simulation of novel pathogens and move from anecdotal through analytical to potentially predictive modelling. The challenge at hand requires substantial investments directed towards risk reduction initiatives, as socio-ecological changes are occurring at an alarming rate, increasing the risk of disease transmission from wildlife to humans. The challenge requires evidence-based policies, global collaboration and coordinated actions, and investments in goal-oriented basic and applied research at a global level. Nexus planning forms an important part of building resilience as it informs the formulation of coherent strategies towards resilient communities.

Credit author contribution statement

Luxon Nhamo: Conceptualization, Formal analysis, Methodology, Formal analysis, Project administration, Writing - original draft. Bekithemba Ndlela: Conceptualization, Formal analysis, Methodology, Writing - review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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