Transactions of the VSB - Technical University of Ostrava Vol. XIX, No. 1, 2024
Safety Engineering Series, ISSN 1805-3238 pp. 12-29, DOI 10.35182/tses-2024-0002

BIOLOGICAL HAZARDS AND DISASTER RISK: COMPLEXITY OF CAUSES AND SOLUTIONS, AND OVERVIEW OF MANAGEMENT IMPLICATIONS

Crystal May BROWN[1], Rene OOSTHUIZEN[2], Roman TANDLICH[3]

Research article

Abstract: Adaptation and changes to the management of infectious diseases result from human research, knowledge gathering, interpretation and applications. Findings from the current study clearly point to the nature of the policy and disaster risk management response to COVID19, as having characteristics of a super-wicked problem. This provides an explanation for the sometimes diverging strategies in tackling the impacts of the coronavirus pandemic on humans and the surrounding socio-ecological systems. Solutions to the pandemic and its long-term outcomes will have to take into account the disparity of impacts and pre-disaster conditions.

Keywords: Wicked problem, disaster risk, hazards, vulnerability, ethics, governance.

Introduction

Disasters are triggered when hazards interact with human actions, and when vulnerable humans and socio-ecological systems are exposed to the effects of a disaster (Ismail-Zadeh, 2022). Over the course of human history, *Homo sapiens* have learnt to perceive, live and work in proximity to hazards (Arias et al., 2017). Many times risks of a disaster unfolding due to a hazard can be diminished by the human population building capacity to react, to deal with and to prevent disaster impacts of said hazard (Boudreau, 2009). Human population and the socio-ecological/socio-economic systems at risk from disasters can also develop a certain ability to adapt to the hazard disturbance or their future occurrences (Jia et al., 2021). With many disasters, the impacted population returns to the disaster-impacted zones after response phase of the disaster management cycle is over (Yabe et al., 2020). If the returning population is provided with the necessary resources and recovery assistance, then the prompt return to the disaster-affected area can be a sign of adaptation to the post-disaster settings and resilience of the humans and impacted socio-ecological systems to disasters impacts. However, if such a returning of the impacted human population to the disaster zone is driven by the need to recover the limited resources and personal possessions, then the population's return can be a sign of their vulnerability. Considerations like these, and other aspects of disaster risk management, have been summarised by various phenomenological equations. Two examples are shown below, namely the phenomenological equation of Madikizela et al. (2022): Equation 1 and the practical equation of Boudreau (2009): Equation 2.

$$Disaster\ Risk = \frac{DH \cdot PDV \cdot Exposure}{Preparedness} \approx \qquad (1)$$
$$\approx \frac{DH \cdot PDV \cdot Exposure}{Resilience}$$

In Equation (1), *DH* represents disaster hazard that can trigger a disaster event. The term *PDV* is the population's vulnerability to the impacts of a particular hazard, or the socio-ecological system's vulnerability. *Exposure* is the exposure of the population to the hazard, i.e. this term is an expression of the contact between hazard and vulnerability during a particular disaster. This term can also apply to the exposure of critical infrastructure and other components of the socio-

[1] Disaster Management and Ethics Research Group, Faculty of Pharmacy, South Africa, crystal.may.brown@gmail.com

[2] Rhodes University Community Engagement Office (RUCE), South Africa, r.oosthuizen@ru.ac.za

[3] Disaster Management and Ethics Research Group, Faculty of Pharmacy, South Africa, r.tandlich@ru.ac.za; roman.tandlich@gmail.com

economic or socio-ecological systems to disaster hazards. The term *Preparedness* stands for the capacity of the population and the disaster risk management system in the affected area to deal with a disaster from a particular hazard. Finally, *Resilience* is the expression of the population's resilience to the disaster that has been triggered by the *DH*. Resilience is the ability of the impacted population to rebound back to normality from the impacts of said disasters. The phenomenological Equation (1) is presented here in the expanded scope from the original application scope. Same can be said of the socio-ecological system which the disaster-impacted humans are part of. Boudreau (2009) was among many authors to present Equation (2), which is shown to below as:

$$Disaster\ Risk = \frac{DH \cdot PDV}{Capacity} \qquad (2)$$

In Equation (2), *DH* and *PDV* are terms with the same meaning as in Equation (1). At the same time, *Capacity* is the capacity of the disaster risk management system to deal with the impacts of a particular disaster on the humans and the socio-ecological system. This capacity would include resilience of individuals, even if indirectly.

Risks have been classified in various ways and the classifications are generally multi-group or dichotomous (Németh, 2010). Early classifications were divergent, as the term risk was used in multiple fields to describe diverse array of notions, e.g. one-directional or bi-directional risks (Németh, 2010). Dichotomous classifications are simpler, but they often limit a detailed description of the practical implications of risks during disasters (Németh, 2010). Several methods have been developed for risk evaluation, analysis and ranking, e.g. through the semi-quantitave ranking methods which categorise and quantify risk, and their components on a 1-5 scale (Ondrejka and Jánošíková, 2010). Disaster hazards can be divided into manmade, natural, or Natech ones (Cozzani, 2012). Disasters or threats that humans face in proximity to hazards are now often considered complex, but most disasters are viewed as manmade. Complexity is a term that takes into account interplay of various factors. These can be physical parts of societal systems and the difficulty to estimate threat from certain types of risk in such systems (Cox, 2012). Complex systems have parts that undergo dynamic and nonlinear interactions during the normal functioning of the system in question (Schiefloe, 2021; Schultze et al., 2021). Socio-ecological systems are such complex systems where nonlinear interactions can occur between the system's components. This can include humans and environment as parts in the socio-ecological systems. Sometimes disasters can have unpredictable impacts on humanity and socio-ecological/socio-economic systems and cascading impacts can propagate through them (Mignan and Wang, 2020). Such impacts can result from or cause knock-on interactions in such impacted/complex systems. This can in turn create new risks and conditions of novel hazards acting against the stability of socio-economic systems and thus human existence (Mignan and Wang, 2020).

The newly-created risks can be temporary or long-term in nature, and examples can include the long-term and multi-systemic health impacts of the COVID19 pandemic (Joshee et al., 2022). They can also contribute to creating a range of extraordinary situations, from crises to disasters and potentially to catastrophes (Maguire et al., 2023). Such events which have various levels of impact on humanity and the related socio-ecological systems. Adaptive strategies and reallocation of resources, mobilisation of the existing resources across various stakeholder sector have been applied during such disaster such as the recent COVID19 pandemic (Alavinejad et al., 2022). It is critical to understand and describe the potential/effective management and coexistence of the humanity, socio-ecological systems and disaster hazards. This can be exemplified by taking into consideration the pre-disaster considerations which can complicate the in-disaster human existence. The particulars can be demonstrated on the examples of the impacts of erratic electricity supply on various socio-economic in South Africa since 2007/8 (Inglesi-Lotz, 2023). In the current article, a theoretical analysis is performed about the complex and long-lasting impacts from disaster which are triggered by biological hazards. COVID19 and the related considerations are analysed to present a theoretical perspective on the short-term and long-term impacts of disasters due to biological hazards. The balance between the considerations of the disaster and the pre-disaster conditions will be integrated into the analysis.

Materials and methods

Examples from the African continent and in the broader international domain are presented to demonstrate the complicated nature of the impacts of disasters due to the biological hazards on socio-ecological systems. Specific focus is placed on human impacts and the system implications for the disaster risk management are evaluated. The theoretical paper methodology is a combination of evidence synthesis and literature review. Materials that were deemed important for the review part were extracted from PubMed and Google Scholar databases. The review part of this article is not to be considered a systematic review, but rather a use of specific information about the disaster risk management and the evidence synthesis. Specifically, it focuses on theoretical analysis of the complexity of the COVID19 pandemic, and other disasters which are caused by biological hazards. The complexity is aimed at understanding the nature.

Results and discussion

Hazard proximity and partial coexistence with humanity and socio-ecological systems

Hazards and conditions of human existence prior to a disaster, such as COVID19 can contribute to the landscape in which a disaster, and its impacts on humanity will unfold (Du et al., 2015). Capacity of the disaster risk management systems to deal with and adapt to living in the proximity of biological hazards would have developed prior to the coronavirus pandemic. These would include humanity and socio-ecological systems under threat and in proximity to a disaster hazard. This can be demonstrated on examples of infectious diseases such as HIV/AIDS and tuberculosis. Since the early 1990's, South African government has actively introduced policies and interventions to deal with the HIV/AIDS pandemic in the country. The country runs the largest programme for administration of anti-retroviral drugs in the world (Simelela and Venter, 2014). By 2011 alone, 2.3 million people were on retroviral regimens (Simelela and Venter, 2014). Kubjane et al. (2022) showed through mathematical modelling that 8.8 million of South African residents have been clinically diagnosed with tuberculosis between 1990 and 2019. In the same study, the mortality from tuberculosis was equal to 23.8 % of all diagnosed cases (Kubjane et al., 2022). Of the 8.8 million cases, number of people with HIV coinfections ranged from 55 to 69 % (Kubjane et al., 2022). Screening for tuberculosis and the rollout of anti-retroviral medicines contributed to a 28.2 % drop in the incidence of the tuberculosis in South Africa by 2019 (Kubjane et al., 2022). These efforts and campaigns can be seen as examples of adaptive and mitigation measures of the South Africans' public health to deal with the HIV/AIDS pandemic. This is interlinked with concurrent public health problems, and it also demonstrates the adaptive capacity of the whole South Africa society to living in the proximity to biological hazards. Increased resilience and survival in the proximity to the HIV virus and its impacts on socio-ecological systems resulted in the decrease of the deaths from HIV/AIDS from 260000 per annum in 2004-2006 to around 58000 per annum in 2022 (see Figure 1).

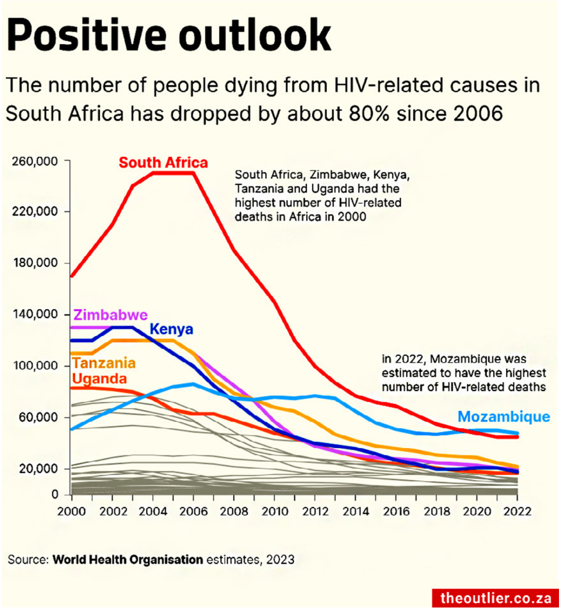

Figure 1. Number of deaths from HIV/AIDS in South Africa based on data from the World Health Organisation (extracted from Theoulier.co.za, 2024a; material is reused under the creative commons licence 4.0)

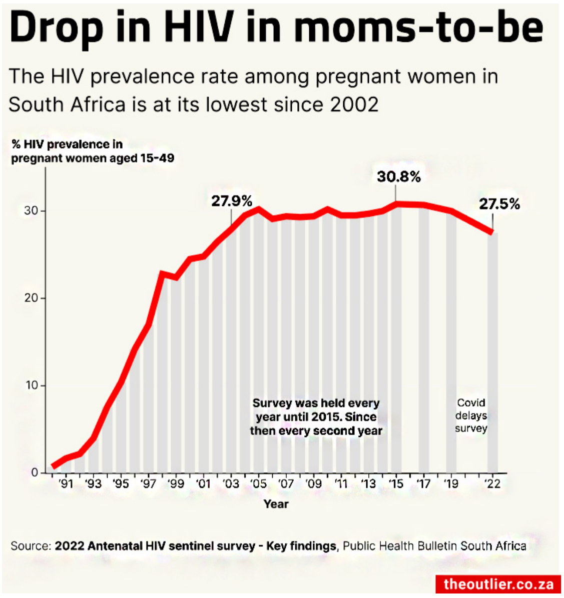

Figure 2. Prevalence of the HIV in pregnant women in South Africa from 1991 until 2022 (extracted from Theoulier.co.za, 2024b; material is reused based under the creative commons licence 4.0)

The rate of transmission of the HIV/AIDS virus from mother to child has stabilised, as the rate of HIV-positive mothers has declined to 27.5 % of all pregnant women in South Africa in 2022 (see Figure 2). Policy changes and honesty about mistakes of the past have been part of the South African government approach since 2009. This fact can be demonstrated by the regular updates of the National Strategic Plan for tackling the HIV/AIDS pandemic (Simelela and Venter, 2014). Being on the African continent, South Africa can potentially suffer due to other biological hazards, which can trigger disasters due to endemicity, migration and intra-continental travel. Malaria is an example of such a natural biological hazard. As shown in Figure 3, there are areas in the central parts of the African continent where up to 10 million cases are recorded annually. This makes Africa the most malaria-impacted continent in the world. At the same time, the population of Africa has been increasing in the last few decades, namely from 724331670 in 1995 to 1393676444 by 2021 (Worldometer, 2024). This indicates that human population and the socio-ecological system in South Africa and on the African continent have adapted to living in proximity of malaria as a biological hazard. Mortality remains high but the population keep growing and mitigation strategies are being implemented.

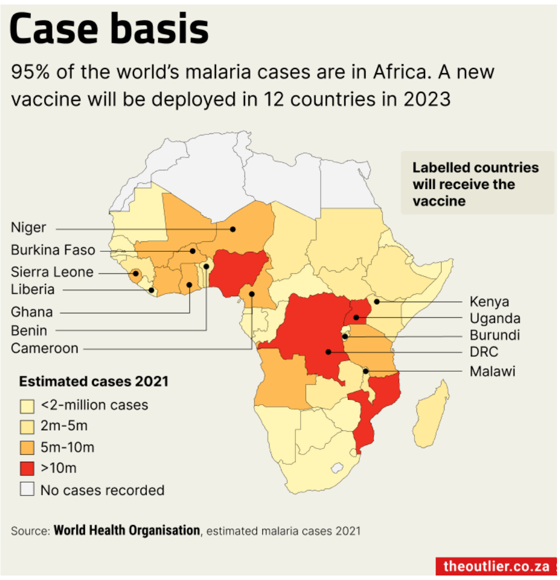

Figure 3. Number of cases of malaria on the African continent in 2021, based on data from the World Health Organisation (extracted from Theoulier.co.za, 2024c; material is reused under the creative commons licence 4.0)

Outside of South Africa, Nzoumbou-Boko et al. (2022) reported that national plan for tackling malaria was being executed, but gaps existed in tracking of all cases in the Central African Republic. For the same country, underreporting of malaria cases is a possibility in the country, as the rate of asymptomatic individuals with malaria could be between 32.4 and 40.6 % of all children tested by Korzeniewski et al. (2021). Mitigation strategies to contain malaria have been implemented, e.g. by vaccination rollout against malaria on the African continent (Harris, 2024). By 2010 alone, up to 300 million of citizens of Africa have been shown to be impacted and handicapped by malaria health outcomes per year (Boutayeb, 2010). Therefore the risk from infectious diseases, and impacts that disasters impacts on the African continent are significant. However, improvements continue to be achieved as the incidence of malaria fell from 26 to 14 % of the African children between the ages of 2 and 10 for the 2000-2013 period (AHS, 2016-2030, page 15). From 2000 until 2015, the person at risk of contracting malaria fell by 42 % across the African continent, even though challenges remain in the Northern African subcontinent (AHS, 2016-2030, page 15). Overall, there are now 66 % fewer fatalities are occurring on the continent when the African Union drafted its 2016-2030 health strategy for the continent (AHS, 2016-2030, page 15). Survival and existence of humanity, as well as the related socio-ecological systems, in the malaria-endemic areas must be seen as a significant achievement from a disaster risk management and public health points of view. Adaptive policies and medicines being rolled out to fight the scourge of the HIV/AIDS pandemic and malaria endemicity in Africa. Such actions clearly demonstrate that human adaptation and living in the proximity to disaster hazards is possible, successful and ongoing. This is stated while being cognisant of the immeasurable suffering that infectious diseases have resulted in on the African continent in mind. Other diseases, which have been detected and where epidemics have occurred recently on the African continent, provide examples about how a healthcare and disaster risk management system can adapt to complex problems which are disasters at a rapid rate.

Novel and recently exacerbated biological hazards on horizon

Listeriosis has been known since the 1980's as a foodborne illness which is caused by bacterial pathogen *Listeria monocytogenes* (Rogalla and Bomar, 2023). This causative agent is a Gram-positive bacterium which is morphologically a rod at the cellular level (Rogalla and Bomar, 2023). The bacterium has three serotypes, namely 1/2a, 1/2b and/or 4a, which can cause human infections in neonatal patients, in the immunocompromised patients or pregnant female patients (Rogalla and Bomar, 2023). Diagnosis can be problematic of listeriosis, as the symptoms of the disease resemble those of other diseases. The symptoms include the flu-like symptoms, diarrhoea, sepsis and/or meningitis (Vhiriri et al., 2020). The sources of infection or biological hazards are foodstuffs which include soft cheeses and meat products. However, it is particularly the ability of the microorganism to grow under the cold storage conditions that can increase the risk of human infections (Rogalla and Bomar, 2023). Growth of the bacterium during ambient temperature storage can also increase the likelihood of a human outbreak and epidemic on the African continent (Sibanda et al., 2023). This is due to the growth, division of the listeria cells and possible exceedance of the infectious dose of the bacterium. The infectious dose for listeriosis was modelled for ice cream sources by Pouillot et al. (2016). Farber et al. (1996) reported that the infectious dose ranged from 0.1 to 100 million colony-forming units. This is the number of cells of *L. monocytogenes* that a human much consume so that they experience clinical symptoms of listeriosis. In other words, the infectious dose is a measure of hazard from this listeriosis pathogen to humans from disaster risk management perspective. Dealing with the hazard in the regulatory environment of a country. This can mitigate the risk to human health from foodborne contamination with *L. monocytogenes* requires that limits be legislated for the listeria concentrations in foodstuffs. Regulatory standards of the concentration of *L. monocytogenes* in meat products vary across the African continent. For example, the Egyptian national standard for seafood and dairy products states that the concentration of *L. monocytogenes* must be below the detection limit in five independent samples of 1 gram each (Sibanda et al., 2023).

Implementation of changes to the regulatory environment is possible, as demonstrated by the recent South African government action. The biggest outbreak in the world and in history, which turned into an epidemic disaster and that was caused by *L. monocytogenes*, occurred in South Africa between 2017 and 2018 (Vhiriri et al., 2023). The contamination of a meat-processing facility in the Limpopo Province of South Africa resulted in the presence of *L. monocytogenes* in a batch of polony (Vhiriri et al., 2023). That batch had later been distributed to retail outlets across South Africa and led to the outbreak of listeriosis. Later, it turned that the polony was consumed by a wide range of age groups of South African residents, leading to the epidemic disaster of listeriosis (Vhiriri et al., 2023). Polony has been a staple in the South African population's diet for a long time. As early as 1978, Prior and Casaleggio (1978) found multiple types of microorganisms in polony samples, e.g. psychrophilic strains of *Pseudomonas spp.* and yeasts. Cells of those microorganisms could grow and multiply on polony as a substrate during cold storage for 12 days or up to 2 months (Prior and Casaleggio, 1978). In the period just preceding the 2017-2018 epidemic disaster or as it had just begun, Asiegbu et al. (2020) found that 46.4 % of the ready-to-eat meat samples, from street vendors in the economic heartland of South Africa, were positive for the causative agent of listeriosis.

During the 2017-2018 disaster, listeriosis had impacted the country's economy, health of its population and the healthcare system in South Africa (Vhiriri et al., 2023). One of the consequences was the need to increase the South African public's access to information about listeriosis and about the potential exposure to listeriosis (Louw and van der Merwe, 2020). Accuracy of the information and the need to reach all socio-economic strata of society was paramount in this regard. The public health system improved the monitoring and communication about listeriosis within South Africa's healthcare system (Vhiriri et al., 2020). However, better involvement of all stakeholders and communication to the public was still necessary (Louw and van der Merwe, 2020). Ultimately, all of these efforts are aimed at decreasing the risk of another listeriosis outbreak, epidemic or a disaster occurring in South Africa in the future. Adding listeriosis to the list of notifiable diseases, i.e. infectious and communicable disease which all medical doctors must report to the South African government, was a sign of adaptive planning and risk mitigation (Vhiriri et al., 2020). It was a manifestation of ability of the South African government, and the population to live in the proximity of a biological hazard. Drafting of a code of conduct and placing the focus on the consensus decision-making about the food production and in South Africa were suggested as a way to prevent future listeriosis outbreaks (Vhiriri et al., 2023). In this way, the capacity of the disaster risk management system and the public health will be improved to deal with similar outbreaks or disasters in the future. Capacity and the ability to deal with disaster outcomes will vary among countries and segments of the human population. Such differences in capacity will be examined in the next section of the article.

Safety Engineering Series, ISSN 1805-3238 pp. 12-29, DOI 10.35182/tses-2024-0002

Capacity of the disaster risk management to manage health hazards and related disasters

The COVID19 pandemic hit different parts of the world at different stages of development and pandemic preparedness (GHSI, 2019-2021a). The global health security index was derived recently to evaluate overall and sectoral measures of health preparedness to allow for the ranking of the countries globally. The GHSI values range from 0 to 100, with the country being more health secure the closer the index gets to 100 (GHSI, 2019-2021a). Overall, the highest health security was achieved in the United States in 2021, with the GHSI score of 75.9 (GHSI, 2019-2021a). South Africa ranked 56th out of the total of 195 countries with the GHSI score of 45.8 (GHSI, 2019-2021b). Difference between the global health security index of USA and South Africa was 30.1. That indicated that United States have a higher level of the country health security than South Africa. Therefore, the US system likely had a higher capacity to deal with the COVID19 pandemic, especially if considering the dimensional element of the health security. For South Africa, the dimensional indicators had values with the following scores (GHSI, 2019-2021b): 32.1 for prevent, 50.0 for detect, 62.0 for respond, 29.2 for health, 43.1 for norms and 58.5 for risk (communication). This ranked the country globally between 9th and 118th in terms of individual health security dimension. Comparing the overall ranking and the dimensional rankings, South Africa was in a better position to deal with some aspects of the pandemic compared to other countries. This can be illustrated by the difference of 9-56 which is equal to -47 for the advantage. South Africa had the highest level of the dimensional health security capacity in the deployment of linkages between the public health and the (state) security systems (GHSI, 2019-2021b). In addition, South Africa had strong capacity to conduct risk communication to the population. The security cluster links also led to prompt imposing travel restrictions on the residents and travellers in and out of the country (GHSI, 2019-2021b). There were thus some effective links between the public health system, the security system, and the disaster risk management system in South Africa just before the onset of the COVID19 pandemic disaster.

Diversity of ranking values among the countries in the world, and the divergent preparedness according to the GHSI will be an expression of disparity and inequalities among countries dealing with risk and its components due to biological hazards. This is conceptualized phenomenologically in Equations (1) and (2). These pre-coronavirus inequalities and disparities between different countries would have a strong influence on the way such countries faced the pandemic due to the SARS-CoV-2 hazard between 2020 and present. Several ways and indicators to measure disparities and inequality in healthcare, and indirectly in disaster risk management of infectious diseases, have been published recently. Two articles are mentioned here. Firstly, Pearcy and Keppel (2002) derived and reported a summary and simple measure to determine the disparity/inequality in rates of cardiovascular disease in the United States. Schlotheuber and Hosseinpoor (2022) reviewed the diverse array measures and indicators of health inequality and disparity. They also performed disparity calculations for child and maternal health indicators of health in Indonesia. In the most general plain of consideration, the disparity is measured as the relative or absolute distance between the values of the analysed parameter among two or more groups (Pearcy and Keppel, 2002). Overall, the complex indicators of inequality and disparity have been shown to be multi-dimensional (Schlotheuber and Hosseinpoor, 2022). On the other hand, the single-parameter disparity measures provide a way to track the development of disparities and inequalities over time (Pearcy and Keppel, 2002). The global health security index is an example of a mixture of various measure types of disparity or inequality (GHSI, 2019a,b; Schlotheuber and Hosseinpoor, 2022). Such inequalities and disparities will be characteristics of the pre-disaster settings of the human populations, as well as socio-ecological systems. This might be impacted by a disaster from a specific biological hazard. Calculation of the inequality and disparity criteria can provide a solid foundation in disaster risk management and public health handling of infectious diseases. Those considerations would include the allocation of the necessary resources and other considerations.

Results of the inequality/disparity calculations lead to identification of groups with the highest advantage or highest disadvantage. These need to be interpreted from two angles. The population groups with the highest advantage are likely to have the highest health security and capacity to withstand an impact from an infectious disease on their wellbeing and their lives, their socio-ecological systems (Schlotheuber and Hosseinpoor, 2022). They will likely experience the lowest risk of impact from a disaster that might be caused by a biological hazard, such as the causative agent of an infectious disease. The most advantaged groups will likely have the lowest vulnerability to a hazard and the highest level of resilience. This is a disaster

Safety Engineering Series, ISSN 1805-3238 pp. 12-29, DOI 10.35182/tses-2024-0002

risk management angle of risk considerations. Innate immunity and susceptibility to a disease will also play a role in these considerations. However, the COVID19 pandemic exposed that vulnerability is currently an expression of openness and the need for togetherness of communities of humans and their wider socio-ecological systems (Ten Have and Gordijn, 2021). Considering immunity or lack thereof, incorporating biological susceptibility into disaster risk management is part of the public health angle of managing the COVID19 impacts.

On the flip side of the disaster risk management considerations, calculation of the inequality or disparity indices will further allow for the identification of the most disadvantaged groups in the human population. These segments or subgroups of the human population and the associated socio-ecological system will likely be the most vulnerable to the effects of a disaster from a biological hazard. At the same time, the most disadvantaged groups will be at the highest risk from biological hazards and actions of the disaster risk management systems will have to be targeted most in terms of likely assistance. Now, the interpretation of advantage and disadvantage here is primarily concerned with the access to resources that are needed to deal with the impacts of an infectious disease outbreak as a disaster which can be caused by a biological hazard. Innate and acquired/adaptive immunity will also play a part in this context, merging the disaster risk and public health management angles of the COVID19 pandemic. Individual humans form bonds and relationships with other humans thus vulnerability is an expression of the complicated and precarious reality of the human existence (Ten Have and Gordijn, 2021). Vulnerability is not an accomplishment, nor it is a deficit… rather it is a common binding thread in the human existence in the current reality which is characterised by high degree of uncertainty (Ten Have and Gordijn, 2021). This interpretation of vulnerability must be taken into account, when arranging resource access by the disaster-impacted population. Further considerations will include the contact and communication by the disaster risk managers with the impacted population. Finally, acceptance of assistance by the disaster impacted humans from the disaster risk management professional, will be critically important in protecting human wellbeing. Success of such interventions will be related to the advantage or inequality among the population impacted by disaster risk.

Ethical considerations of the uncertainty of COVID19

The uncertainty of the COVID19 pandemic has led to the potential of humans questioning each individual action they take. Would this particular action contribute to my pain or my suffering? How would I survive this ordeal? Would my immediate family and the people I care about be fine? What is the potential for actions to be correct under such conditions? This is a "puzzle of individual ethics" that a human would and has faced during the COVID19 pandemic? (originally applied to climate change by Rieder, 2024). The puzzle is uncertain in terms of the shape of the pieces, how many pieces exist in total to complete the puzzle, and how they fit together is the big unknown (Rieder, 2024). Interpretation of this puzzle will be personal. It will be driven by the experiences that a particular human would have had during the coronavirus pandemic. Drivers of actions during an unprecedented pandemic are self-preservation, preservation of the wellbeing of one's family and humanity at large. At the same time, assistance to others is also a strong driver for people in the first line of disaster response, e.g. the healthcare workers (Ten Have and Gordijn, 2021). Human conduct and the mutual relationships between humans and the drivers of conduct would ultimately be divisible into two large groups. The negative actions, i.e. not contributing to the exacerbation of the problem and spread of disease, by observing the lockdown regulations (South African Government, 2021). Other hand, positive actions could be taken into consideration as well and they could include the public's support for the track-and-trace programme, and thus accomplishing the COVID19 containment despite some intrusion into the cell phone data privacy (See South Korea example in Baltzersen, 2022). Later in the COVID19 pandemic, getting vaccinated and encouraging others to do so without human rights violations would be a combination of negative or positive reactions, moral actions in relation to COVID19 (based on Riedler, 2024). The uncertainty and the disparity/ advantage of the COVID19-impacted population will require that a balance must be established between the positive and negative actions.

Balancing the negative and positive actions in line with the management of COVID19 as a disaster from a biological hazard was morally and ethically challenging. Iheanetu et al. (2023) and other authors have spoken about and analysed the anthropisation of the Earth's surface as a contributing factor to the contact between humans and the SARS-CoV-2 virus. The expansion of human reach on this planet increased the proximity of humans to the hazard that led to the COVID19 pandemic. Disaster of the coronavirus pandemic occurred because the understanding of the actual biological hazards in the newly and extensively anthropized space was non-existent at worst or was only being discovered during the pandemic at best. Outside of COVID19, the spread of humanity across the globe has had some positive effects on the social and economic conditions of human life, and many people have been lifted out of poverty (WB, 2022). However, anthropisation also led to the development of novel types of disaster situations, e.g. COVID19 (Iheanetu et al., 2023). The expansion and concurrent extractive use of natural resources have resulted in a feedback loop which has caused climate change and other negative outcomes (Riedler, 2024). The COVID19 pandemic and its disaster impact would be outcomes of such feedback mechanism and so dealing with them would raise similar ethical challenges (Iheanetu et al., 2023).

Individual humans are not morally responsible for the coronavirus pandemic, and so the argument could be made that there is no need to act at personal level to mitigate the pandemic (based on Sinnott-Armstrong, 2010 and Riedler, 2024). However, compared to climate change the moral need for human action is needed during the COVID29 pandemic. This is based on the direct and imminent threat to human survival due to human proximity and coexistence with the SARS-CoV-2 virus (Sinnott-Armstrong, 2010). Coexistence and influence of the virus on humanity and vice versa also plays a role here (Iheanetu et al., 2023; Maguire et al., 2023). The openness of the system of humanity to the SARS-CoV-2 virus and the need for global response to the pandemic resolution create or manifest the relationships between of all humanity in terms of COVID19 impacts (Maguire et al., 2023). Risk and the biological hazard, as well as the severity of the likely impact of the coronavirus pandemic, pose ethical challenges and the need to are unpacked further in the next section against the background so far. Vulnerability and resource allocation is important. The unpacking is done in relation to the complexity of the problems that involve biological hazards and the solutions to them. Humans, as part of socio-ecological systems, and the disaster risk management systems must figure out shape and essence of the pieces of the ethical puzzle. The simplicity or complexity of such a puzzle solution search will depend on the in-disaster and pre-disaster settings of the vulnerability being thread. The duty of care that humans must have for one another, and the broader socio-ecological systems must come through and be adjusted to the simplicity or complexity of the settings of common fragility. Simplicity or complexity of the COVID19 and the disaster from biological hazards is outlined in the next part of the article.

Simple and complex practical problems and situations arising due to biological hazards

Situations that describe a departure from the sense of normality, and which are caused by the biological hazards and human proximity to them, will be described in this section of the article. The first example to be discussed is the human infection which occurs upon exposure to the virions of rotavirus, where a patient will mostly get sick after about 48 hours after contact with the pathogen (USCDC, undated). The symptoms include watery diarrhoea, vomiting, dizziness, and malaise (USCDC, undated). The most vulnerable group are children, but severe cases (leading to hospitalisation) can be prevented in 85-98 % of cases if the following vaccines are administered to children between 2 and 6 months of age (USCCD, undated): RotaTeq® and Rotarix®. At the same time, a simple rest period, hydration and electrolyte replacement can lead to recovery from the rotavirus (Dennehy, 2013). It is true that children under 5 years of age constitute a significant cohort of patients at risk from rotavirus, but vaccination and herd immunity can provide sufficient protection (Dennehy, 2013). The rotavirus example presents a disease as an incident, or deviation from the normality of human existence, that can be clearly defined. The pathogen is known, and treatment/mitigation management options are available to the public health officials and disaster risk managers. The incident is easy to solve and even prevented by routine public health measures and resources. Therefore the rotavirus example meets the definition of a simple problem (Klasche, 2021).

A similar example would be a situation when a human is exposed to drinking water that had been contaminated with faecal matter and which contains a non-zero, but finite concentration of an *Escherichia coli* strain (Luyt et al., 2012). This water is not treated sufficiently, or it has been contaminated by breaks in the distribution systems and so the affected human can suffer from diarrhoea or from interruption in potable water supply (Park et al., 2018). However, the faecal contamination of the drinking water can be eliminated by standard and routinely available disinfection methods, e.g. chlorination (NLOM, 1980) or ozonation (von Gunten, 2003). Pipe breaks can be quickly fixed by digging up the soil, cutting the pipe and replacing it with clamping the new pipe to the remainder of the old reticulation (see Figure 4 below).

Figure 4. A clamp and fix of a broken drinking water pipe outside of the last author's house in Makhanda, Eastern Cape Province, South Africa. Old pipe and a failed clamp are depicted on the right and the new functional fix (clamp with a new pipe interlink) are shown in dug hole on the left

After the pipe is in place the water supply can be restored. A simple problem is at hand again with a clear definition and a simple or standard solution (Klasche, 2021). Depending on the length of the interruption, the impacted humans will have to either boil the water or obtain water from an alternative source (Iheanetu and Tandlich, 2022). This pipe breaks can occur during aging of the drinking water reticulation systems, e.g. due to the environmental parameter changes such as freezing and temperature fluctuations (Gould et al., 2011). During disasters and in disaster risk management, water supply is considered part of critical infrastructure (Víchová and Hromada, 2020). Interruption of water supply due treatment failure or pipe breaks can lead to a minor inconvenience from the viewpoint of normality of human life. Longer outages can lead to a major disruption or an insufficient supply of safe drinking water to the affected population. However, procurement and routine/emergency provision of the necessary materials are possible and so solving the water interruption should normally be considered a simple problem (based on the interpretation by Klasche, 2021). Simple problems covered so far would have definite public health and public administration implications. Disaster risk management will kick in if the pipe breaks or water contamination that are completely preventable would become endemic in an area. Long-term neglect of implementing a standard solution to a simple problem can have disaster risk management implications.

In another example, the exposure and infection scenario could lead to a human infection with a suspected strain of *Aeromonas hydrophila*, which causes a bloody diarrhoea as shown for seven patients in the Port Alfred floods in 2012 (Tandlich et al., 2016). Hospitalisation was required for some of the patients, and they were impacted in the long term (Tandlich et al., 2016). Loss of income followed as the homes and recreation/caravan park that the patient owned was destroyed (NSRI, 2012). A new steady state of the patient's existence after hospitalisation was only achieved after an extended period of time of four years (the unpublished last author's observation from the 2012 Port Alfred flood zone). There was massive destruction of property and infrastructure in the flood zone and disaster recovery took a long time. That was caused by the local government in Port Alfred needing to source external funding to conduct recovery operations (Pyle and Jacobs, 2016; Tandlich et al., 2016). Some houses were destroyed completely, and value of damages was high for the impacted individual residents in the flood zone. The impacts of the flood disaster provided for the complex situation, where the impacted humans had to deal with multiple challenges. There was the impact of a biological hazard on the immediate human wellbeing by hospitalisation and the following recovery of the diarrhoea-suffering patients. However, there were also knock-on effects of the flood disaster on their socio-ecological system. These included the loss of work and income for the staff in the caravan park, the post-flood contamination of the flood zone and the potential for theft of damaged property. There was also widespread damage to the environment due to the flooding. Non-governmental and governmental measures had to be put in place to re-establish a new steady state of human existence after the flood disaster and after the impact of a biological hazard on individual residents. The problem of the post-flood existence was not simple but complex (based on the short definition by Klasche, 2021). Multiple stakeholders with different mandates had to come together to deliver reconstruction of the housing units, insurance claims payouts. They provided relief to the impacted human population in the recovery

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stage of the disaster management cycle. Complexity of the challenge and the solution required collective action by multiple stakeholders and mistakes were made (Pyle and Jacobs, 2016; Tandlich et al., 2016). However, the existing biomedical treatment protocols, policy and legislation tools were ultimately sufficient to solve the complex problem.

Another example of a complex problem and a potential disaster due to biological hazards includes water quality challenges and insufficient treatment. Contrary to the simple problem example from the previous section, here we are talking about a situation where the water contamination in the drinking water supply system persists for a long time. If a person is continuously exposed to contaminated water or infectious particles that caused diarrhoeal diseases, then there will be complex and lasting impacts on human life. These impacts include chronic diarrhoea (Parsonnet et al., 1989), gut damage during childhood development and inflammation related to the gastro-intestinal system (Prendergast and Kelly, 2016). In addition, oral vaccine efficacy, stunting and malnutrition might occur in children that are exposed to such conditions (Prendergast and Kelly, 2016). If a patient is co-infected with the HIV virus, then immune response can also be compromised, and opportunistic infectious diseases can impact the health of the patient (Prendergast and Kelly, 2016). Learning disabilities can develop if insufficient water supply is available to a human population. The need to provision water for potable uses in a household can lead to disabilities such as the sustained spinal axial compression in the cervical region due carrying of heavy loads over long distances (Geere et al., 2018).

In the above example, water provision to the population is affected by systemic problems such as corruption in service delivery (Corruption Watch, 2020). Lack of technical capacity at the local government level is also a contributing factor (South African Government, 2015). Solution to this problem is a complex one, and the problem requires the collaboration of multiple stakeholders. These include the higher education sector and further technical education stakeholders for skills development (based on the findings of Afrosearch & Hlathi Development Services, 2007). At the same time, there is a requirement for consequence management of responsibility for non-performance in service delivery at local government (PMG, 2023). All actions are implementable and even though they might take time, routine procedures and collaboration by multiple stakeholders can help solve this problem. This is a complex problem. Looking at COVID19, what kind of a problem was it from a policy and systems point of view? The problem also transcends the complexity consideration, as some impacts of this problem could be irreversible. The problem is no longer complex but rather wicked. The wicked problem characteristics, and possible solutions are analysed in the next section of the article. Links are made to the COVID19 pandemic.

Wicked problem and the COVID19 pandemic

During the COVID19 pandemic, many articles focused on the provision of biomedical resources, such as vaccines, personal protective equipment, and medicines. Novel therapies and reuse of existing therapeutic agents, i.e. off-label use of drugs such as ivermectin (O'Higgins et al., 2021), were the order of the day. Bull et al. (2021) proposed that challenge trials to study the natural history of COVID19 be launched. In such trials, healthy volunteers are infected with the SARS-CoV-2 virus and the progression of the disease is studied under quarantine in a designated facility (Bull et al., 2021). Strict monitoring would be performed, and continuous, uninterrupted medical oversight of the patients' conditions would be in place. Sampling of the tissues of the participants and collection of medical data would be conducted (Bull et al., 2021). In theory, such an approach would speed up the development of the vaccines. Such challenge trials have so far only been performed in animal models. For example, Biering et al. (2016) studied the optimisation of the experimental protocol for intraperitoneal injection of 107 colony-forming units of bacteria in 0.1 mL of sodium chloride suspension. The wrasse fish was assessed for infection by two bacterial strains, namely atypical *Aeromonas salmonicida* and *Vibrio anguillarum* (Biering et al., 2016). The efficacy of the tested vaccine was proven, but some protocol issues arose with respect to the cohabitation experiments (Biering et al., 2016). In another study, the therapeutic efficacy was tested for the recombinant protein vaccine of the rainbow trout (*Oncorhynchus mykiss*) against *Aeromonas salmonicida* (Marana et al., 2017). Results showed that 3 weeks into a challenge trial, the vaccinated group of fish experienced a mortality of 17-30 % against the 48-56 % mortality in the unvaccinated control group (Marana et al., 2017). Ethical limitations on animal research exist, and experiments are still possible to conduct even if the animals experience some suffering. Procedures in animal research, where biomedical interventions are tested, occur under strict ethical and animal welfare regulations. Challenge trial means that an active infectious agent, a biological hazard is introduced into the body of the animal. Infecting humans in challenge trials has been prohibited due to unethical and highly discriminatory/abusive relationship among oppressors and the oppressed in the past. Uncertainty about the ethics of challenge trials in humans and so let's review the ethical concerns.

Where does the ethical challenges lie with human trials has been documented by many authors. Firstly, the experiments on humans during World War II led to massive deaths, human suffering and highly criminal and unethical conduct (Weindling et al., 2016). Such genocide and killing of innocent civilians are inexcusable and cannot be sanctioned under any circumstances. Secondly, free will and equality of all human lives is sacrosanct and enshrined in international treaties, with some rights not limited under any circumstances (Thielbörger, 2019). Therefore, any medical and other decision must be made by human beings freely and of their own volition, including participating in a trial where a potentially deadly biological hazard exposure occurs. Strict procedures are in place to examine and limit any violations of human free choice in relation to their body and their medical decisions. They also prevent human rights abuses, human suffering and ultimately human deaths. After rigorous ethical scrutiny and lengthy approvals/public debate, the challenge trial with SARS-CoV-2 went ahead. The results showed that the COVID19 vaccination works immunologically, and the participants only experienced mild symptoms (Jackson et al., 2024). One of the reasons why the challenge trials were proposed was the lack of the SARS-CoV-2 vaccines until late 2020 and early 2021. Any person participating in challenge trials would be signed up only after being given full information about the nature of the procedures to be used, the monitoring and the consent of participants was voluntary (Jackson et al., 2024). At the same time, full-time medical care and monitoring would be provided to the challenge trials. Therefore, COVID19 brought on conditions and created an environment which has been termed VUCA. This meant that COVID19 and provision of assistance to the affected population unfolded under the conditions of 'volatility, uncertainty, complexity, and ambiguity' (Schulze et al., 2021). Flexibility and coordination were essential in the provision of mitigation and intervention measures, e.g. the vaccination campaigns in Germany (Schulze et al., 2021). Networks that existed or that formed during the pandemic were crucial to success of the campaigns and communication across them was vital to sharing latest information and for coordination purposes (Schulze et al., 2021).

Decisions made in the VUCA environment must be understood as being made in a 'Catch 22' situation, i.e. not all impacts of a decision made during COVID19 across human society can be predicted (Schiefloe, 2021). The temporal fluidity of the VUCA environment of COVID19 led to the adoption of flexible measures and adaptive management of the critical infrastructure, namely the public health systems management of the pandemic (Schulze et al., 2021). On the ethical and practice front, diverging views of the lockdown vs. vaccination vs. the acquired immunity were suggested during the COVID19 pandemic. On one hand, there was the push by some academics and public healthcare practitioners that the less vulnerable groups of humans should have been allowed to leave the lockdown to prevent the psychological, broader social and negative impacts of the COVID19 pandemic (Great Barrington Declaration, 2020-present). This approach would be relying on the acquired immunity of the population due to exposure to the virions of SARS-CoV-2 (Great Barrington Declaration, 2020-present). On the opposite end of the debate, the John Snow Memorandum was rejected letting people out of lockdowns before vaccinations are covering sufficient portions of the population to achieve herd immunity (Alwan et al., 2020). Diverging and contradicting approaches are an expression of the 'Catch 22' type problem that the COVID19 pandemic was. This problem in its every essence went beyond the complex problem nature, as no trial or error approaches are possible to solve the problem (Schiefloe, 2021). Existing approaches, not even through multiple stakeholder engagement, were enough to solve the problem. Both the Great Barrington Declaration and the John Snow Memorandum do carry some inherent value and do correspond to some of the experiences that humanity has experienced since 2020 and the onset of the coronavirus pandemic. The Great Barrington Declaration and the John Snow Memorandum are manifestations of the time-sensitive nature of the COVID19 pandemic as a disaster, and a need to find a solution to protect humans and their socio-ecological systems. The best solution to the problem was the network-based and network-driven push for addressing the immediate, medium-term and long-term impacts of the COVID19 pandemic by adoption of the vaccines-plus strategy (Greenhalgh et al., 2022).

In the vaccine-plus strategy, lockdowns, and acquired immunity and socio-economic assistance are combined in dealing with the impacts of the coronavirus pandemic onto the human population affected by it. Financial and socio-economic protections are provided to the human population, which had been exposed to the hazard of the SARS-CoV-2 virions. The population and its socio-ecological/economic systems have been impacted by the displacement from pre-COVID19 existence during the coronavirus pandemic (Maguire et al., 2023). The vaccine-plus strategy provides those resources and assistance needed (Greenhalgh et al., 2022). Financial assistance was provided to populations by the United Kingdom government through the furlough programme (Stuart et al., 2021). After the completion such programmes, job security, worker voice and related human-resource questions/ issues should be addressed to achieve long-term benefits and to provide some protection during future pandemics, or disasters. These elements of the vaccine-plus strategy must be complemented by the redistribution of the vaccines according to need and regardless of the geographical location around the world (Steinert et al., 2022). Vaccine production redistribution must be based on the international consensus and some deviations from certain provisions of international economic order, e.g. intellectual property rights must be changed (Singh et al., 2023). At the same time, the World Health Organisation has proposed a new pandemic accord to fight and prepare for the next pandemics (WHO, 2024). Summary of the COVID19 characteristics indicate a type of problem which go beyond the complex problem. It is a problem that is referred to in literature as a wicked problem, and it will be described in the next section of the article.

Wicked problem of COVID19 and its characteristics

Uncertainty was created during the COVID19 pandemic in terms of various layers of socio-ecological systems that humans are an integral part of. Firstly, the uncertainty about the nature of the threat from SARS-CoV-2 as a hazard and the impacts of the coronavirus pandemic were not easy to predict accurately in the early stages of the pandemic (Recchia et al., 2021). Secondly, the holistic estimates of disruption of the individual human lives were not so easy to predict in the early stage of the pandemic. Thirdly, the actual level of risk kept evolving throughout the pandemic (Siegel, 2021). COVID19 was thus a manifestation of the dynamic nature of (disaster) risk (ISO, 2018-present) and so humans were forced to continuously evaluate the nature of the actual risk they faced during the pandemic and how they should adapt to it (Maguire et al., 2023). For this, the evaluation of the pandemic-related data was needed continuously, and this led to decisions about the best risk management and treatment options. An example of this was the re-issuing of disaster regulations during various stages of lockdown in South Africa (South African Government, 2021). Pre-coronavirus vulnerabilities are exacerbated, and new vulnerabilities are added on, new risks and problems to resolve were created against the background of the pandemic and concurrent extraordinary situations/challenges (Sultana, 2021). Complexity of the problem from the solution point, i.e. from the angle of the disaster risk management system, gradates and ranges from simple, through complex to wicked (see next section for details). This made COIVD19 a wicked problem is a new situation and solutions, even analysis, were complicated and often must be developed on the go throughout a disaster (Klasche, 2021; Schiefloe, 2021). Klasche (2021) summarised the characteristics, which are based on the original wicked problem definition by Rittel and Webber (1973):

"1. No definite formulation of the problem;

2. They have no stopping rule;

3. Solutions are not true-or-false but good-or-bad;

4. There is no immediate and no ultimate test of a solution;

5. Every solution is a "one-shot operation"; there is no opportunity to learn by trial-and-error; every attempt counts significantly;

6. They do not have an enumerable set of potential solutions, nor is there a well-described set of permissible operations;

7. They are essentially unique;

8. They can be considered to be a symptom of another problem;

9. The choice of explanation determines the nature of the problem's resolution;

10. The planner has no right to be wrong (Rittel & Webber, 1973, pp. 161-167)".

Schiefloe (2021) suggested the 'Catch 22' comment nature of decision-making and living through the situations of the pandemic. The author then goes onto state that the standard analytical approaches and methods are not able to provide a complete and distinct formulation of the problem of the nature of the hazard and impacts of the COVID19 pandemic as a disaster (Schiefloe, 2021). Next, situations and the environment, the progression of the COVID19 pandemic across humanity's ontological realm of existence was unique (Schiefloe, 2021). No previous extraordinary situation could be compared to the coronavirus pandemic, even though similarities might have existed (Schiefloe, 2021; Maguire et al., 2023). Thirdly, decisions are made in a state of flux where information about the new pandemic occurs in novel situation and in real time there are constant changes in the parameters of the response and management of the COVID19 pandemic as extraordinary situations. Fourth and distinctly persistent implication of the COVID19 pandemic as a problem is the fact that no true or false decisions can be made (Schiefloe, 2021). Solutions to the hazard of the SARS-CoV-2 virus and disaster of the COVID19 pandemic was not simple or clear cut. Four characteristics of the super-wicked problem make the COVID19 pandemic a unique disaster. Firstly, the time to respond comprehensively to the coronavirus pandemic has always been very short with high urgency for action ever present (Schiefloe, 2021). Adoption of the vaccine justice and the pandemic accord will require the rationality of decision-making by politicians beyond the elected mandate terms. Both these elements of policy response are in response to the two other aspects of super-wicked problems. The solutions and accomplishment of vaccines justice and pandemic accord will require to 'bypass' the usual lack of political rationality, where response to extraordinary situation is normally driven by the next election considerations (Schiefloe, 2021). The last characteristic of the COVID19 problem is the fact that humans are impacted by the COVID19 pandemic, but they have also largely contributed to the development of the pandemic (Schiefloe, 2021). To summarise this paragraph, COVID19 is a super-wicked problem based on the discussion here and the ways it stretches across socio-ecological and socio-economical systems.

Super-wicked problems will be related, at least in part, to the influence humans have over the Earth's surface through anthropisation (as summarised and analysed by Iheanetu et al., 2023). At least some of the policies that were drafted, operationalised adopted in the coronavirus management but the solution to the COVID19 pandemic must be structured with the long-term view. Human actions and interactions with the hazards, which trigger disasters and other extraordinary situations, must be understood in more detail. Extensive efforts have been put into understanding of the genetic information (ACDC, 2024) and the transmission of the SARS-CoV-2 (Liu et al., 2021). The outbreak of the Wuhan original strains of SARS-CoV-2 was investigated by the WHO and the Chinese authorities (WHO, 2021, Summary). Circumstantial evidence pointed to the significance of the Huanan Seafood market, where 73 % of the samples taken were positive for the SARS-CoV-2 virus but the actual origin of the virus was not identified (WHO, 2021, Summary). The super-wicked problem therefore indicates that the speed of action can lead to several decisions which can cause further harm to humans under pandemic impacts. Only long-term commitment and effective management of human actions can lead to management of extraordinary situations such as the COVID19 pandemic. Solutions must be based on networking and comprehensive governance of complex problems, e.g. as suggested for climate change by Klasche (2021).

Conclusions

Findings from the current study clearly point to the nature of the policy and disaster risk management response to COVID19, as having characteristics of a super-wicked problem. This provides an explanation for the sometimes diverging strategies in tackling the impacts of the coronavirus pandemic on humans and the surrounding socio-ecological systems. Solutions to the pandemic and its long-term outcomes will have to take into account the disparity of impacts and pre-disaster conditions. Local specifics and regional/national, as well as international cooperation and management of future pandemics will need to be formalised through agreements and similar mechanisms.

Acknowledgements

The authors would like to thank Rhodes University for supporting the study in the following ways. Firstly, online resources were accessed through the institution, and these were used in the study. Secondly, the student was provided with a partial scholarship for the study in order to complete her Master of Science in Pharmacy degree. No structures or representatives of Rhodes University have reviewed, commented on or approved/endorsed the study, any of its findings/methods or conclusions. Therefore the readers should not imply that Rhodes University endorses its study.

Safety Engineering Series, ISSN 1805-3238 pp. 12-29, DOI 10.35182/tses-2024-0002

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