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One Health and Engineering: using engineering to further pave the roadmap towards global health security, pandemic preparedness, and personalized medicine

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Abstract
This article delves into the intricate interplay among human, animal, and environmental health, acknowledging the convergence of knowledge across diverse disciplines where traditional boundaries blur, fostering remarkable advancements in engineering, genomics, and medicine. The One Health framework transcends mere disease control, aspiring to enhance the well-being of all life forms on Earth. Positioned uniquely to address global health challenges, pandemics, and personalized medicine, this holistic approach identifies pressing issues such as pandemic preparedness, antimicrobial resistance, zoonotic disease surveillance, vaccine equity, climate change's health impacts, food safety, vector-borne diseases, healthcare access equity, data integration, and public awareness and education. It emphasizes the driving forces behind these challenges, encompassing demographic shifts, urbanization, migration, gender-based violence, poverty, globalization, and climate change. Most notably, we delineate One Health and Engineering (OHE) as a pioneering discipline harmoniously blending engineering, life sciences, and environmental sciences to address multifaceted health challenges. Engineers play a pivotal role in crafting innovative solutions through technology, data-driven methodologies, and sustainable infrastructure. The integration of genomics and data science into personalized medicine represents a transformative approach to disease prevention and healthcare delivery. Insights into One Health and Engineering initiatives in Colombia highlight the profound significance of interdisciplinary collaboration in addressing the intricate web of health, environmental, and societal challenges. We showcase the collaborative efforts between the Universidad Nacional de Colombia and the University of Wisconsin-Madison in the establishment of the One Health Genomic Laboratory in Medellín, a beacon of research into diseases, pathogen discovery, and pandemic preparedness.

1 Introduction

We stand at the threshold of an exciting era marked by an unprecedented convergence of knowledge across diverse domains. In recent years, relentless efforts have been dedicated to dismantling the confines that traditionally segregated disciplines, leading to remarkable innovations in fields like Engineering, Medicine, Chemistry, Physics, Computing, among others. This collaborative endeavor has yielded transformative breakthroughs, shaping the landscape of industries, from mobile technology and advanced instrumentation to revolutionary medicines and groundbreaking treatments, extending even to the domain of transportation and urbanization. An example of this resurgence lies the realm of nanoscale science, often referred to as nanotechnology and molecular engineering, where the forging of unbreakable connections and the establishment of novel paradigms in education, research, and development have blurred the once-distinct boundaries between disciplines.

The concept of One Health [1 - 4] represents a comprehensive and interdisciplinary approach that acknowledges the intricate interdependencies of human, animal, and environmental health. It champions the dismantling of conventional boundaries, fostering collaboration across a spectrum of domains to address health-related challenges comprehensively. This holistic framework aspires not only to prevent and control diseases but also to enhance the overall well-being of all living organisms on our planet, underscoring the inextricable link between the health of one species and that of others. One Health places paramount importance on understanding, monitoring, and effectively managing health risks at the intersection of human, animal, and environmental realms to safeguard public health, preempt pandemics, and

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catalyze the progress of personalized medicine. It is significant to note that a substantial 60% of pathogens capable of causing diseases in humans trace their origins to domestic or wild animals, prompting a global call for strategies aimed at the prevention and control of zoonotic diseases, which include coronaviruses, influenza, rabies, brucellosis, and others.

An all-encompassing definition of One Health transcends the boundaries between animals, humans, and their shared environments, recognizing the interconnectedness of these domains within the context of socioeconomic interests and external pressures. This concept mandates the collective effort of all disciplines to provide innovative methods and tools for research and the implementation of effective services, ultimately contributing to the formulation of norms, regulations, and policies that serve the welfare of humanity, animals, and the environment for current and future generations.

In the recent past, the world has experienced a growing escalation of global concerns related to public health emergencies, triggered by a range of conditions spanning from viral and parasitic diseases to autoimmune and genetic pathologies. Notable among these challenges is the COVID-19 pandemic, along with other high-profile health crises such as bird flu (A (H5N1) and A (H7N9)), swine flu (A (H1N1)), malaria, Ebola virus (EVD), cancer, Parkinson's, Alzheimer's, and the resurgence of arboviruses like Zika (ZIKV), Chikungunya (CHIKV), and dengue (DENV). Many of these conditions have earned the ominous label of "global killers," attributed to their substantial mortality rates in epidemic regions, while others have inflicted significant economic burdens, stemming from recurrent outbreaks and the exorbitant costs associated with treatments, hospitalizations, and lost productivity. Fortunately, strides in public health policies, diagnostic innovations, epidemiological practices, and advancements in telecommunications have unveiled the true dimensions of these pathologies, bringing them out of the shadows that once concealed their impact due to the vast number of affected individuals in remote and non-epidemic regions.

We have emerged from the crucible of the recent COVID-19 pandemic, which has vividly exemplified the severe repercussions of disparities in global health. It is incumbent upon us not only to strive for the prevention of future pandemics but also to make pandemic preparedness a global imperative. This is a compelling example of how the One Health [1 – 4] perspective is uniquely positioned to provide solutions encompassing early diagnostics, pathogen discovery, genomics-for-all, accessible artificial intelligence, and much more. We currently reside in an era where the irresponsible actions of humans within their environment have ushered in unprecedented disruptions to the equilibrium of ecosystems, driving unseen changes in the delicate balance between humans, animals, and the environment. Unrestrained

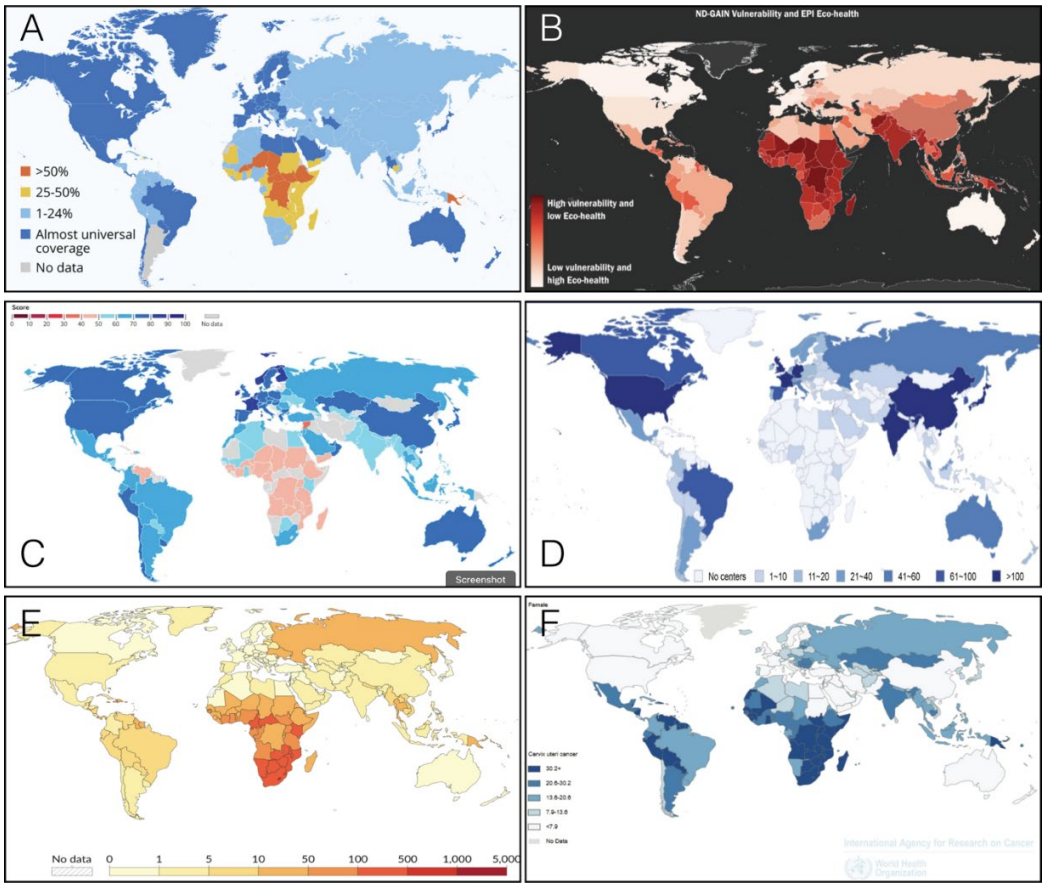

Figure 1. Worldwide distributions that highlight current inequalities that drive exponential difficulties in middle- and low-income countries. (A) People without access to basic drinking water in 2020 [5]; (B) Global distribution of the combined risk of toxic pollution and climate impacts [6]; (C) Food security index [7]; (D) Centers with Genomic capabilities [8]; (E) Dead rate from AIDS/HIV [9]; (F) Incidence of Cervical Cancer – associated with HPV [10,11].

pollution, rampant deforestation, illegal mining, burgeoning overpopulation in metropolitan areas, forced human migration, contamination of rivers and oceans, and illicit trade are among the human-induced processes that fuel climate change and variability, creating precarious conditions that challenge the sustainability of life. Moreover, inherent inequalities within our societies, spanning income disparities, inequitable access to water and food, health security, independence, availability of bio/molecular/genomic technologies, artificial intelligence, and gender disparities, serve to exacerbate the consequences, particularly in low- and middle-income countries. These factors compound the One Health challenges we face, urging us to understand that practical solutions must be both interdisciplinary and incorporate sociological and humanistic dimensions. Behind every health statistic, there lies a human tragedy that must be prevented.

2. Inequality makes things worse

The challenges inherent in the One Health framework necessitate the presentation of contextual examples that illustrate how inequalities interact synergistically to exacerbate existing problems. In Fig. 1, we provide a visual representation of stark realities, encompassing issues of water access (1A) [5], climate change and toxic risk (1B) [6], food security (1C) [7], genomic capabilities (1D) [8], and the prevalence of long-lasting endemics such as HIV [9] (as denoted by the 2019 death rate due to HIV/AIDS, 1E) and HPV (indicated by the incidence of cervical cancer due to HPV, 1F) [10, 11]. Our inclusion of Fig. 1 is intended to encourage readers to delve into the references provided, enabling them to explore the intricacies behind each of these indicators. In broad terms, the utilization of darker colors within the figure serves to denote regions with poorer indices or indicators, except for genomic capabilities, which follow an inverted scale. The sobering portrait that emerges can be deciphered as follows: regions characterized by low water access, inadequate food security, and limited technological capacities are precisely the areas that experience the most pronounced impacts of climate change, elevated toxic risk levels, and heightened prevalence of infectious diseases such as HIV and HPV.

The One Health approach is intrinsically intertwined with the concept of inequalities, as it recognizes that health is not an isolated issue but a complex and interdependent web of human, animal, and environmental well-being. Inequalities manifest across multiple dimensions, and their impact on health is pervasive. Societal disparities in access to healthcare, education, income, and resources directly affect the health of individuals and communities, often leading to inequities in health outcomes. These disparities can be exacerbated in regions where access to clean water, nutritious food, and essential healthcare services is limited. In such contexts, the burden of zoonotic diseases and other health threats is often disproportionately borne by vulnerable populations. The One Health framework seeks to address these disparities by fostering interdisciplinary collaboration and a deeper understanding of the interconnected factors that influence health, aiming to reduce inequalities and promote health equity [12].

Furthermore, One Health underscores the inextricable link between environmental health and human health. Environmental inequalities, such as pollution, deforestation, and climate change, can have profound implications for public health. For instance, marginalized communities often bear the brunt of environmental degradation, facing increased exposure to pollutants and the adverse effects of climate change. These environmental challenges can exacerbate existing health disparities and lead to a higher prevalence of diseases, particularly among those who lack the resources and infrastructure to adapt or mitigate these impacts. By addressing the environmental determinants of health within the One Health framework, we can better understand how inequalities in environmental conditions are closely linked to inequalities in health outcomes. In this context, One Health serves as a powerful tool for both identifying the root causes of health inequalities and developing holistic strategies to address them, aiming for a world where health is truly accessible and equitable for all.

3. One Health global challenges

Numerous dynamic challenges persist in the field of One Health, continually evolving and charting novel pathways for discovery and innovation. As we emphasize, the attainment of One Health objectives necessitates a collective commitment from governments, organizations, researchers, and communities across the globe. Key concerns, as underscored by authoritative entities such as the World Health Organization (WHO), the World Organization for Animal Health (OIE), and the Centers for Disease Control and Prevention (CDC) [1, 2], encompass the following pivotal topics [12 – 19]:

1. Pandemic Preparedness; our inheritance from the COVID-19 pandemic where the need for improved global pandemic preparedness and rapid response were highlighted. We must ensure early detection, containment, and coordinated responses to emerging infectious diseases.
2. Antimicrobial Resistance; where the global misuse and overuse of antibiotics and other antimicrobial agents continue pose a significant threat to human and animal health.
3. Zoonotic Disease Surveillance; these pathologies are a major global health concern and surveillance systems to detect and monitor these diseases in both animal and human populations is vital.
4. Vaccine Equity; equitable access to vaccines, including those for zoonotic diseases, is a challenge. This item includes vaccine distribution inequalities and vaccine hesitancy.
5. Climate Change and Environmental Health; the degradation of ecosystems impacts human health and animal health.
6. Food Safety: Foodborne illnesses are a major global health issue. Ensuring the safety of the global food supply chain, from production to consumption, remains a challenge.
7. Vector-Borne Diseases; the prevention and control of vector-borne diseases is a critical because there is evidence that they are on the rise and many of the “global killers” are among this category.
8. Equative Access to Healthcare; health services for both humans and animals are limited in many regions.
9. Data Integration and Sharing; data across One Health

sectors should be equative and with universal access. Open data from human health to animal health and environmental monitoring are imperative to generate regional solutions.
10. Public Awareness and Education; it is imperative to rase public awareness about the interconnectedness of human, animal, and environmental health.

Additionally, a set of identified factors and driving forces exerts significant pressure on the dynamics of these critical challenges within the One Health framework. Among these factors, we accentuate the following key influencers [1, 2]:

1. Demographics; the global population continues to expand, leading to increased demands on resources, healthcare systems, and urban infrastructure.
2. Urbanization; the relentless urban sprawl alters the dynamics of human-animal-environment interactions, often intensifying disease transmission and resource consumption.
3. Migration, Displacement, and Armed Conflicts; mass migrations, displacement, and regions affected by armed conflicts create unique health challenges, impacting vulnerable populations and straining healthcare infrastructures.
4. Gender-based violence; it includes domestic violence, sexual violence, and intimate partner violence, it plays a significant role in shaping health outcomes for individuals and communities, especially in risk and unattended regions.
5. Poverty; socioeconomic disparities persist as a formidable determinant of health outcomes, with impoverished communities facing heightened health risks and reduced access to essential services.
6. Trade, Tourism, and the Global Economy; the interconnectedness of the global economy, driven by trade and tourism, accelerates the transmission of diseases and the spread of health-related challenges.
7. Climate Change; ongoing climate change amplifies environmental stressors, leading to the emergence of new health threats and the exacerbation of existing ones.

These multifaceted forces act as influential threads in the intricate core of One Health, shaping the contours of global health challenges and necessitating multifaceted responses that account for their profound impact.

4. The role of engineering

One Health and Engineering (OHE) emerges as a pioneering discipline, seamlessly integrating engineering, life sciences, and environmental sciences to tackle the intricate web of global health challenges. In a world that grows ever more interconnected, OHE seeks to dismantle traditional silos, fostering collaborative efforts that safeguard the health of ecosystems, humans, and animals alike. By harnessing innovative technologies, data-driven methodologies, and multidisciplinary cooperation, OHE goes beyond disease prevention and outbreak mitigation, advancing personalized healthcare solutions that adapt to the unique needs of individuals and communities. It underscores the critical importance of comprehending and managing the tapestry of health interdependencies where human, animal, and environmental systems converge, ultimately striving for an equilibrium in our world.

Engineering takes center stage in the quest for One Health solutions, wielding its innovative might to confront multifaceted health challenges encompassing human, animal, and environmental spheres. This versatile discipline acts as a linchpin, propelling cutting-edge technologies and methodologies that elevate healthcare delivery, bolster disease surveillance, and enhance environmental management. In the realm of One Health, engineering wears many hats, from developing sophisticated medical devices and diagnostics to crafting resilient infrastructure capable of withstanding the health-related ramifications of climate change. Engineers play a pivotal role in designing sustainable systems for clean water provision, effective waste management, and sanitation, all vital components for safeguarding public health and averting waterborne disease transmission. Moreover, they have spearheaded the integration of artificial intelligence and big data analytics, revolutionizing disease prediction and epidemiological modeling, thus fortifying our capacity to anticipate and manage health crises. In essence, engineering acts as a propulsive force, propelling the realization of comprehensive health solutions that bridge the gaps separating human, animal, and environmental health domains.

The innate interdisciplinary essence of engineering naturally aligns with the core principles of One Health, fostering connections among diverse sectors and nurturing collaboration between healthcare professionals, veterinarians, environmental scientists, and technologists. This multidisciplinary synergy materializes in the development of telehealth systems that connect remote communities to vital healthcare resources, the creation of biosensors capable of swift disease detection, and the implementation of smart agricultural technologies that mitigate the transmission of zoonotic diseases. Engineering-driven innovations empower healthcare workers with mobile diagnostic tools that transcend geographical boundaries, facilitating early intervention and treatment. By designing resilient, climate-adaptive infrastructure and promoting environmentally sustainable practices, engineering contributes to disease prevention and environmental preservation. Furthermore, engineering plays a pivotal role in ensuring the equitable distribution of health resources, bridging the urban-rural healthcare access divide, and spearheading the development of affordable medical solutions that reach underserved populations. In essence, engineering acts as a unifying force, weaving together the expertise of multiple disciplines in harmonious endeavors that exemplify the holistic spirit of One Health.

One Health and Engineering finds a shining example in the transformative landscape of personalized medicine platforms and predictive medicine initiatives grounded in genomics [19, 20, 21]. Since the 1990s, the realm of medical science has embarked on a genetic and genomic revolution, with the pinnacle being the Human Genome Project's landmark sequencing of the human genome in 2001, an endeavor that entailed a staggering $3.2 billion investment. This pioneering effort led to the identification of over 20,000 genes and their associations with various genetic disorders, autoimmune conditions, cancer, and both transmissible and non-transmissible diseases. The reach of genomic analysis extends

far beyond humans, with over 9,000 genomes from diverse species now cataloged. The genetic industry has spurred remarkable progress in sequencing, bioinformatics, computing, statistics, biology, pharmaceuticals, and medicine. Now, the time has come for genetic and genomic analysis to evolve into an omnipresent research tool for disease identification and the unraveling of biological mysteries. In recent years, a fusion of disciplines, encompassing polymer physics, molecular engineering, genetics, micro- and nano-manufacturing, computing, biostatistics, and medicine, has been dedicated to the development of cost-effective, efficient platforms for genome analysis, a collaborative undertaking requiring interdisciplinary synergy, unwavering teamwork, and an unceasing commitment to innovation and the generation of impactful knowledge.

In the realm of preventive medicine, an extraordinary partnership has arisen between engineering and data science, a continuous evolution that is reshaping healthcare. At its core, this collaboration centers on the transformation of genomics into a potent platform for averting diseases and tailoring healthcare interventions. Engineers, physicists, chemists, biologists, and statisticians have developed cutting-edge DNA sequencing technologies, enabling the rapid, cost-effective decryption of an individual's genetic code. This leap in technology ushers in an era where an individual's unique genetic blueprint serves as a guide for personalized healthcare. Within this domain, data scientists have seamlessly integrated their expertise, skillfully processing, and interpreting vast genomic datasets. Their data-driven methodologies empower healthcare providers to discern genetic variations linked to disease susceptibility, allowing for the customization of preventive strategies based on an individual's unique genetic profile. This union of engineering and data science not only elevates the precision and efficacy of preventive measures but also steers healthcare from a reactive to a proactive model, thereby redefining the future of medicine.

In this dynamic landscape, engineering and data science synergistically propel genomics into a preventive medicine platform, providing the essential tools and methodologies to navigate the complexities of an individual's genetic code. These advancements facilitate the early identification of disease predispositions, enabling timely and precise interventions to minimize health risks. Moreover, the integration of artificial intelligence and machine learning amplifies genomics' predictive capabilities, allowing healthcare providers to anticipate an individual's susceptibility to a wide spectrum of health conditions. Engineering and data science have not only deepened our understanding of the genetic foundations of diseases but also granted individuals the knowledge to proactively manage their health. As this collaborative spirit continues to flourish, genomics as a preventive medicine platform stands as a testament to the transformative power of interdisciplinary teamwork in shaping a healthier future for all.

However, amid the rapid advancement of genomics and the exponential growth of genomic data, data science and data storage have emerged as formidable challenges. Genomic research generates vast datasets, everyone’s DNA sequence comprising billions of data points, creating an enormous need for robust data management and analysis. The intricate nature of genomics necessitates sophisticated algorithms and computational tools to decipher the genetic code and unveil its secrets. Furthermore, as genomic studies expand to include diverse populations, track genetic variations, and delve into rare diseases, the volume of data escalates dramatically, straining computational infrastructure and storage capacities. Therefore, harnessing the full potential of genomics in healthcare relies on surmounting the data science and data storage obstacles to ensure the secure, efficient, and accurate processing of genomic information, paving the way for more personalized and effective medical interventions.

5. One Health Colombia and the Global Health Institute (GHI) initiatives

In 2018, a partnership emerged between the Universidad Nacional de Colombia and the University of Wisconsin-Madison, driven by a shared vision of leveraging scientific and technological expertise to enhance healthcare within the framework of "One Health." This approach transcended traditional disciplinary boundaries, uniting various scientific domains, including the natural sciences, engineering, medicine, and social sciences, to address healthcare comprehensively.

This collaboration gave rise to the One Health Genomic Laboratory, located in Medellín, Colombia. This state-of-the-art facility operates with an open-door philosophy and has attracted a diverse community of researchers dedicated to human, animal, and environmental health. The laboratory's core mission is to facilitate research and technological advancement in support of healthcare. It boasts cutting-edge technology and a highly skilled workforce committed to upholding the most rigorous laboratory standards. The laboratory functions as a valuable resource, providing research services and healthcare technologies to the academic, scientific, and broader communities. Its primary research focuses include arboviruses (such as dengue, Zika, and chikungunya), respiratory viruses, cancer, OMICs, pathogen discovery, and pandemic awareness. These areas encompass diverse aspects, from disease detection and epidemiological surveillance to the application of mathematical tools for disease modeling.

Under the GHI One Health Colombian program, fever clinics, and disease monitoring sites have been established in multiple regions across the country, including the eastern plains (Cúcuta, Villavicencio, and Acacías), the Pacific coast (Cali), the central mountains (Medellin and several municipalities of Antioquia), the Urabá zone (Apartado and Necoli) and the Amazon River (Leticia and Puerto Nariño). The One-Health Center's infectious disease portfolio includes SARS-CoV-2, arboviruses, influenza, and blood-dwelling parasites. Leveraging state-of-the-art next and 4th generation sequencing platforms, the One Health Genomic lab's capabilities span from analyzing simple viruses to whole human genomes. During the COVID-19 pandemic, the lab played an active role in advising the Gobernación de Antioquia, providing support to the National Institute of Health [22], and collaborating with the Ministero de Salud y Protección Social de Colombia. Their involvement extended to the COVID-19 diagnostic network, genomic surveillance network, COVID-19 crisis committee, and safe economic reactivation committee. The lab secured funding to serve high-risk communities, offering over 100 thousand free PCR diagnostic tests and administering more than

70 thousand vaccines in remote areas. Notably, the GHI One Health program's pathogen discovery platform led to the identification and characterization of the SARS-CoV-2 mu variant [23, 24 - 26] and the detection and study of the Oropouche virus [27], Dengue 2 Cosmopolitan [28], and Mansonella blood parasite in Colombia [29]. It's worth mentioning that these capacities were amplified through the Abbott Pandemic Awareness Coalition Program [30].

In 2022, the One Health Colombian program served as the catalyst for the GHI One Health Centers initiative. Under this initiative, both universities are pooling their scientific capabilities and resources to identify critical knowledge gaps in infectious disease ecology. They are dedicated to promoting scientific training, building capacities, fostering multicultural and geographically diverse representation, and advocating for racial and gender equality in the field of science. These endeavors are poised to alleviate the burdens posed by disease, climate change, and social disparities. By bridging scientific knowledge, community insights, and indigenous wisdom, the GHI OH Colombian Center offers a framework for translating research from the laboratory into real-world settings. The initial focus includes five vital areas:

1. Emerging infectious diseases
2. Human, animal, and plant health
3. Climate change and land use
4. Sustainable and adequate food, water, and energy
5. Social, cultural, and economic equity.

In Colombia, the intersection of One Health and a complex web of socio-environmental challenges underscores the imperative for holistic approaches to address pressing issues. As the nation grapples with the far-reaching consequences of violence and migration, it becomes evident that these challenges are intrinsically linked to the environment and public health. Forced displacement due to armed conflicts often drives populations into ecologically sensitive regions, leading to heightened vulnerabilities. In this context, illegal mining emerges as a significant driver of environmental degradation, deforestation, and water pollution, with implications for both human and animal health. It amplifies the risk of exposure to tropical diseases as well as zoonotic diseases, which can have devastating impacts on communities in these already marginalized areas. Hence, Colombia faces a twofold burden: the re-emergence of diseases once thought to be under control and the emergence of new threats, often exacerbated by unsustainable practices tied to illegal mining, population displacement, and the degradation of critical ecosystems.

The One Health framework in Colombia offers a pivotal strategy to navigate this complex landscape. By acknowledging the intricate interdependencies between human, animal, and environmental health, it can serve as a catalyst for innovative solutions. Efforts to mitigate the consequences of violence and displacement could be paired with initiatives to combat illegal mining, thereby safeguarding the environment, and minimizing the risk of zoonotic and tropical diseases. Promoting sustainable mining practices and reforestation, while also enhancing healthcare access and surveillance in affected regions, represents a multidisciplinary approach to tackle these intertwined challenges. This synergistic approach could not only prevent the resurgence of diseases but also foster environmental conservation and social well-being, reflecting the core principles of One Health in action.

The establishment of a One Health program within the new Faculty of Medicine and Life Sciences, at the Universidad Nacional de Colombia-Medellin, reflects a forward-looking approach to address the intricate challenges of the 21st century. As the boundaries between human, animal, and environmental health continue to blur, the need for interdisciplinary collaboration is more pressing than ever. By connecting the vast knowledge reservoir of medical and life sciences with the principles of One Health, we create a fertile ground for innovation and progress. This integration not only paves the way for a comprehensive understanding of health and disease but also instills a culture of collaboration and holistic problem-solving in the next generation of healthcare professionals and scientists.

The overarching goal of this union is to foster a generation of experts who can tackle global challenges such as emerging infectious diseases, climate change, food security, and health equity with a multifaceted perspective. The future health of our planet, its inhabitants, and the myriad species that share it depends on our ability to transcend disciplinary boundaries. In this context, a new Faculty of Medicine, and Life Sciences, coupled with a robust One Health program, becomes an exemplar of how academia can serve as a hub for innovation and transformation. By embracing this paradigm shift, we open doors to unprecedented research opportunities, education models that nurture well-rounded professionals, and the prospect of building a healthier, more sustainable future for all.

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