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Part II
Presidential Addresses

Sri Lanka Association for the Advancement of Science

Proceedings of the 79th Annual Sessions
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Science Diplomacy as a powerful force for national unity and friendship among nations

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The global order in a state of flux

The international system may be described as a complex system of social, economic, scientific, political, military, and technological systems. This dynamic structure is very difficult to evaluate and it is even more difficult to predict its future. The distribution of power potential in the international system defines the number of major powers and thus the international system's polarity. The system would be multipolar if the great powers are more than two; if they are two it would be bipolar and systems with only one great power are called unipolar. The multipolar world now emerging will not consist of just a couple of significant nations, but rather of multiple nations of varying capabilities. In the limited arena of affairs pertaining to their country, each state with its particular notable qualities will have a decisive say. Therefore, the future multipolar system will not be different from the other multipolar moments that history has seen, resulting in more chaos and unpredictability than in the unipolar world.

Rapid economic and political changes in emerging economies and developing countries have an impact on the existing world order that is gradually moving from a Western-centered international system to a multi-centered one (Ruffini and Krasnyak, 2023). Some lesser powers that were previously on the periphery of international politics now seek to gain more power and build international reputations. They deploy various tools including diplomatic ones that were not available or not applicable before. However, this cannot happen immediately as the traditional great powers continue to maintain their leadership. Therefore, it is crucially important to understand how the rise of emerging and developing countries of the Global South may shape and influence the world order.

With many regional powers emerging on the canvas of international politics, there is growing importance of middle powers, from Turkey and Brazil to South Korea and Australia. Today, the middle powers are significantly more influential than they once were. The resulting multipolar systems are often unbalanced with two or three big powers and several middle powers all jockeying for position. Here, Science Diplomacy becomes a critically important tool for the decision-makers to navigate world politics.

Emergence of alliances and regional groups and game changing initiatives

Since 1945 a proliferation of regional organizations has been one of the most significant developments in the realm of contemporary international relations. This growth of regionalism has been more a pragmatic response to the changing dynamics of international politics than the outcome of a conviction that regionalism is superior to universalism as a form of international cooperation.

Regional organizations could play a significant role in shaping the global political landscape enabling nations to collaborate and address common challenges and issues collectively and effectively. The South Asian Association for Regional Cooperation (SAARC), the Association of Southeast Asian Nations (ASEAN), the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), and the Indian Ocean Rim Association (IORA) are some of the key regional organizations of significance. In addition, BRICS, developing economies, emerging economies, and the Global South are some of the other alliances or groups that will affect the balance of power between global powers. Emerging powers feel that they are insufficiently represented on the global agenda and are demanding a greater voice in international affairs; they have become increasingly assertive in their demands that they should have a place at the table where matters affecting the world are discussed and decisions are made. Their demands are based on their growing economic and political significance and clout at regional, continental, and global levels (Figure 1).

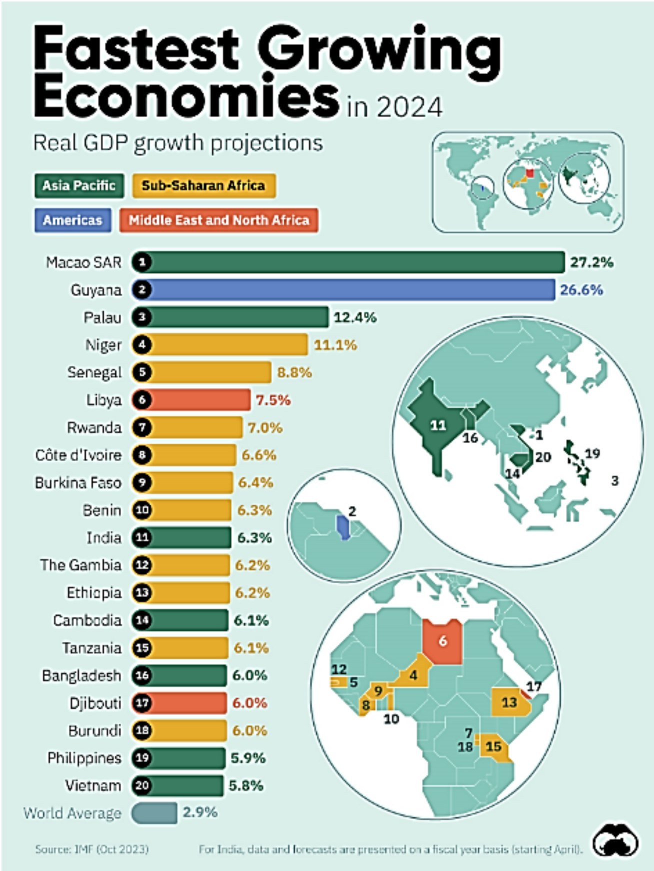

Figure.1 Fastest growing economies in the world (https://www.visualcapitalist.com/ranked-the-fastest-growing-economies-in-2024/)

For an instance, beyond the US, Japan, China, the EU, and India are capable of economic influence due to their advanced technology, increasing economy, and large population base while Iran, Saudi Arabia, Venezuela, African Union countries, and Brazil will also have an impact, owing to their large energy reserves. In addition, the Belt and Road Initiative (BRI) unveiled by China in 2013 is an ambitious effort to deepen regional cooperation and improve connectivity on a trans-continental scale. While the scope of the initiative is still taking shape, the BRI consists primarily of the *Silk Road Economic Belt*, linking China to Central and South Asia and onwards to Europe, and the *New Maritime Silk Road*, linking China to the nations of Southeast Asia, the Gulf Countries, North Africa, and on to Europe. Six other economic corridors have been identified to link other countries to the Belt and the Road. As of August 2023, 155 countries have been listed as having signed up to the BRI. The participating countries include almost 75% of the world's population and account for more than half of the world's GDP, so that the BRI will have far-reaching impacts and ramifications, opening up a host of new opportunities as well as challenges in the global landscape. Amidst these dynamics, the global economic center of gravity is shifting from N. America towards Asia again, and this will also create reverberations across the world (Figure 2).

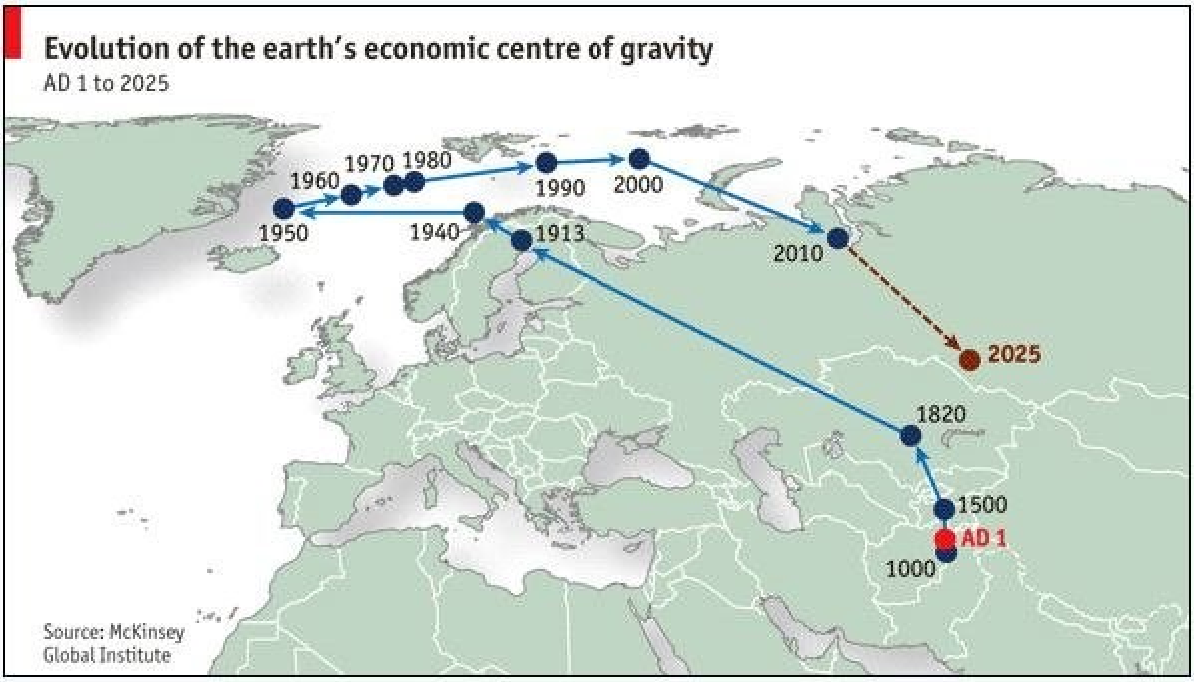

Figure.2: Shift of the economic centre of gravity again to the East

Source: Islam, Mohammad. (2013). China's Look South Policy and Bangladesh's Look East Policy: Convergences and Constraints.

Complex global challenges demand a transdisciplinary and transnational systems approach

Today, the world must come to grips with a myriad of formidable challenges and threats such as climate change, poverty, disaster vulnerability, glaring inequalities, food, water, energy and cyber insecurity, and pollution, to name but a few. They are complex, multi-faceted and multi-dimensional, and thus cannot be addressed effectively through mono-disciplinary interventions. Tackling them demands an interdisciplinary, transdisciplinary, multi-sectoral and transnational systems approach where cooperation between specialists with diverse backgrounds in both the natural and social sciences across territorial boundaries and community engagement are imperative. Besides, there is growing recognition that new approaches and different types of expertise are needed to renew science. Therefore, in a globalized environment, no country can be independent of or insulated from what is happening elsewhere; all countries have become interdependent and interconnected. This is sadly evident from the current conflicts between Russia and Ukraine and Israel and Palestine. They affect not only Europe and West Asia, but the whole world as countries are connected by innumerable supply chains and value chains that account for about 70% of international trade. Hence, the need of the hour is to accept and recognize the oneness of humanity and all nations ought to work in unison to achieve the 17 SDGs by sharing their knowledge, experience, and expertise for the benefit of humanity.

Origin and scope of Science Diplomacy (SD)

Unlike in some other fields, in the case of scientific endeavours, nations must set aside political and other differences and collaborate to advance the best interests of their citizens. Even countries outside the diplomatic mainstream could play new and significant roles in world affairs through the efforts of their scientists even when they come from adversarial nations. This is imperative as the effectiveness of hard, soft, and smart power has been waning in the recent past. Therefore, the time is ripe for science diplomacy as practically every major issue, whether global or national in scale, features Science & Technology (S&T) either as a factor in understanding the underlying cause of the issue or in contributing to its remedy. In addition, the relevance and potential applications of science diplomacy are progressively increasing as the world is becoming multipolar with alliances being formed around specific interests and issues.

Since 2001, the UK Government's Science and Innovation Network has been working in its embassies and high commissions overseas to link science to its foreign policy priorities. The establishment of the Center for Science Diplomacy by the American Association for the Advancement of Science (AAAS) took place in 2008. This now goes by the name of Science Technology and Innovation Diplomacy. The concept of SD was given contemporary emphasis and currency by a meeting held in 2009 at Wilton House, United Kingdom, sponsored by the Royal Society (London) and the AAAS.

Though SD is not new, it has never been more important than now. Many of the defining challenges of the 21st century — from climate change and food security to poverty reduction and nuclear disarmament — have scientific dimensions. No one country will be able to solve these problems on its own. The tools, techniques and tactics of foreign policy need to adapt to a world of increasing scientific and technical complexity.

Definition of SD:

There is no unified definition for SD but it can be defined as a set of policies and practices that combines foreign policy and science, and which provides conditions for transnational cooperation in science and mobilization of resources, bringing scientists from around the world closer together (Echeverria King, 2021). Thus, a SD framework may lead to more equitable and sustainable collaboration between the North and the South but it is no panacea for all the issues encountered in transnational collaboration. Vaughan Turekian, Director of the Centre for Science Diplomacy, American Association for the Advancement of Science, said that science and diplomacy are two terms that may not always mesh coherently. In 1974, Solly Zuckerman, the United Kingdom's first official scientific adviser, said that decision-making rested with government ministers, and that "If scientists want more than this, then they'd better become politicians." This notion was captured by Winston Churchill, who said "scientists should be on tap not on top" (Vallance, 2023). These ideas may be true in a democracy but it does not mean that science will not be ignored or misused by politicians, nor does it mean that what scientists say will be understood.

SD was described at the turn of this millennium as a set of practices by which the work of diplomats and foreign ministries come into contact with that of researchers through various initiatives such as intergovernmental S&T cooperation agreements, the integration of scientific expertise into international negotiations, and the use of S&T achievements to improve the image and positioning of the nations in the world, especially through the use of the soft power of science. Diplomacy and SD can be synergistic and S&T, being the backbone of all developed economies, has a great potential to be used as a smart diplomatic resource, which can open up new diplomatic frontiers.

S&T constitutes the mainstay of bilateral and multilateral agreements and is at the heart of development assistance. Therefore, as in Japan, the Ministry of Foreign Affairs and the Ministry dealing with S&T should have very close cooperation as S&T plays a pivotal role in dealing with global issues including pandemics, cybercrimes, climate change, air and marine pollution, and use of marine resources, and air space.

SD can, therefore, be conceptualized as the set of practices at the intersection of science and foreign policy to advance national interests and address global challenges. It could also be used to promote social cohesion, ethnic harmony, and national unity. It does not exist in a vacuum but is embodied in the foreign policymaking and behaviour of national sovereign states (Ruffini and Krasnyak, 2023). In order for the S&T diplomacy in foreign relations to be effective, it should have the following three basic elements:

i. It should be of mutual benefit leading to a win-win situation for the parties involved,
ii. There should be synergistic effect between diplomacy and science diplomacy,

iii. Where possible, the more powerful partner should support the foundation of S&T through overseas development assistance.

Effective science advice is not possible unless there is a strong independent science base that government advisers can call on. It is not just academics that are needed—often, the expertise lies in industry or in government laboratories. Scientific advice should be published so that the public and the scientific community can provide constructive critiques. This is, ultimately, the very way in which science progresses.

Scientific advice is unlikely to be effective if governments lack scientists. This absence often means that there are no effective mechanisms to absorb recommendations and evaluate policy implications. The lack of scientifically trained individuals in government is striking. Attracting more scientists into government will require new approaches to recruitment and training. Top-notch scientists with roots in the community will be effective in S&T diplomacy. However, many of our overseas missions do not have a science attaché. While sending competent science attachés to relevant foreign missions, it is necessary to interact with the science attachés of other foreign missions in the country. Vaughn Turekian, Director, Center for Science Diplomacy, AAAS (2010) said that SD could serve as the "**pilot light**" of international relationships, a light that would keep burning after all other avenues were extinguished (Wallin, 2010).

Importance and relevance of SD:

From a state's perspective, SD is a subset of national foreign policy and a strategy for advancing its interests and needs. From a global perspective, SD is perceived as a potential solution for tackling common global problems. SD clearly falls within the scope of public policy. It is primarily a lever for action.

Developing economies, mainly in the Southern hemisphere, are home to approximately 80% of the world's population. However, they started introducing SD only relatively recently, *i.e.,* S. Africa in 2012, India in 2018, Pakistan in 2019 and Columbia in 2020 (Karacan and Ruffini, 2023). Researchers in the Global South are under-represented as leading authors in research journals, with the result that research produced and scientific methods and techniques developed in the Global South receive lower visibility and are not fully included and well-integrated into "Global Science". Therefore, SD may provide a framework to acknowledge and address this imbalance in scientific collaboration between regions.

However, unlike countries in the global North, countries in the Global South, barring China and Brazil, find it difficult to post a science attaché in their foreign missions. Hence, the foreign ministry could have a Science Diplomacy Division which liaises between national S&T stakeholders and international partners. It can also call on the services of the diaspora and alumni of foreign universities at home and abroad for advancing the national scientific ecosystem.

SD has the potential to play a role in addressing imbalance and global inequalities, *i.e.,* between North and South, through capacity building in scientifically disadvantaged countries, uniting efforts and infrastructure to address global challenges, promoting more inclusive and socially responsible scientific practices across cultures, and promoting science from the "periphery" to the centre of discussions on policy.

Science diplomacy is becoming an important tool by which states can more effectively promote and secure their foreign policy agendas. Recognizing the role science plays at national and international levels and identifying a state's national diplomatic style can help to construct a 'national style' in science diplomacy. SD, therefore, has the potential to influence national audience in ways that traditional public diplomacy cannot. Thus, SD can be deployed for the following purposes:

i. Science diplomacy by the government to advance country's national interests and development
ii. Science diplomacy involving stakeholders to address their real-life issues effectively
iii. Science diplomacy to improve foreign relations and collaborations and to address global challenges
iv. SD to contribute to reducing disparities and inequalities between countries.

SD is neither an all-powerful tool nor a miracle remedy, but it can potentially mitigate conflicts and foster harmony and amity among different communities in a country and promote friendship among nations. While it has its own limitations, its balanced and inclusive use in international relations could usher in a better tomorrow, making the planet a better place to live in. For all this to happen, SD has to be institutionalized and it should also be essentially combined with morality and ethics in order it to be acceptable and effective (The Royal Society, 2010). History is already replete with examples where SD has been deployed effectively to address global challenges. A few striking examples are given below:

1. Despite arch rivalry between North Korea and USA, American and British scientists were able to visit even the remotest villages close to the volcano Mount Paektu in N. Korea, following a catastrophic volcanic eruption in 2011, in order to collect rock samples and deploy seismometers. This led to an unprecedented scientific collaboration resulting in joint publications between North Korean and American and British scientists. It was a real boon, showing the potency and power of SD in bringing even archrivals to work together, making the seemingly impossible happen through S&T. It is an example of how technical collaborations can morph into powerful peace and friendship building initiatives.

Figure 3: American scientist holding discussion with N. Korean scientists following a catastrophic volcanic eruption in N. Korea in 2011

2. Nuclear non-proliferation talks between Iran and USA came to a standstill in 2015 with the atmosphere becoming tense and electrifying. Then Iran nominated Dr. Ali Akbar Salehi, Head, Atomic Energy Organization of Iran, to lead the Iranian team, who in turn requested USA to nominate Ernest J. Moniz, Energy Secretary to President Barack Obama, as his counterpart. Both were alumni of MIT, USA where they studied nuclear physics. When they came to the negotiating table, politics were put behind and they discussed physics instead, which enabled them to make steady progress. The intervention of science made a difference that would otherwise have been next to impossible. Suitably, they were nominated for the Nobel Prize in Peace in 2016.

Figure 4: Ernest J Moniz, Secretary of Energy, USA engaged in a discussion on nuclear non-proliferation with Dr. Ali Akbar Salehi, Head of Atomic Energy Organization of Iran in Lausanne, Switzerland in 2015

3. Eight years after the September 11 attack, President Barack Obama delivered a landmark speech at the Cairo University on 04 June 2009 that marked a strong shift of American policy towards the Arab-Muslim world. He announced the establishment of a separate fund to support technological development and the setting up of centers of excellence in Africa, Middle East and S. Asia related to water, climate, and political science. In addition, he agreed to dispatch a team of high-profile science envoys to facilitate it. This peace-seeking, fence-mending, and constructive speech helped to change the hostile attitude of the Arab-Muslim world towards America in a short spell of time.

4. At the height of the Second World War when fierce fighting was going on between the German troops and British & American troops, German and American scientists and German and British scientists continued to work together not letting the war drive a wedge between them. It shows the profound bonding power of scientific cooperation.

Potential applications of SD to address national issues and regional and global concerns relevant to Sri Lanka

There has been a profound transformation of the Indian Ocean from a mere maritime trade route into a global nexus encompassing security, economic and environmental concerns, social issues, and strategic interests. Moreover, international and regional policy discourses on the Indian Ocean regional order, Indo-Pacific dynamics, and the Belt-Road Initiative are often sensitive and complex, given the intensity of strategic interests and aspirations of some countries in and beyond the region. Here, smaller member-states, particularly when they are economically vulnerable, have no parity when dealing with bigger states that bully them into submission, so that the agenda on cooperation gets submerged by prevailing geopolitical tensions in the Indian Ocean and beyond. Here, SD can be an effective tool to cope with such issues.

Sri Lanka presently occupies the Chair of IORA from 2023 to 2025. Besides, it is a member of BIMSTEC and SAARC. The nature and scope of IORA center around economic cooperation and on achieving sustained growth and balanced development in the region. Economic cooperation extends to areas such as trade facilitation and liberalization, promotion of foreign investment, management of marine resources, maritime security, blue economic opportunities, disaster resilience, scientific and technological exchanges, tourism and movement of natural persons and service providers. Therefore, Sri Lanka's diplomacy needs to rise to the challenge, demonstrating its fullest strength during such discourses in order to navigate the complexities and intricacies involved.

In addition, when bilateral and transborder shared resources such as gas fields, marine resources, fish stocks, rivers and watershed exist, diplomatic efforts without adequate scientific understanding can be ill-directed and counter-productive (Gluckman et al., 2017). This is also applicable to the claimed extended Exclusive Economic Zone of Sri Lanka as per the Convention on the law of the Sea. Therefore, a cogent multilateral vision, underpinned by inclusive, coherent policies and combined with a commendable grasp of science diplomacy and consummate skills will be of paramount importance.

Some major issues and concerns to Sri Lanka are briefly outlined below:

i. Debt restructuring and Climate Change

Sixty one countries in the world face severe debt problems and these debt-distressed countries are unable to make progress towards climate resilience and sustainable development amidst cascading crises and inequalities. "This has not happened because of the bad behavior of one country. This has happened because of systemic shocks that have hit many countries at the same time," said Ms. Rebeca Grynspan, Secretary-General, UNCTAD. With interest rates rising sharply, the debt crisis is putting enormous strain on public finances, especially in developing countries that need to invest in education, health care and their economies, and to adapt to climate change. "To resolve these issues equitably, this needs to be done in a manner that maintains the debtor countries' ability to grow and meet its current and future debt obligations, while also fulfilling its commitments to the SDGs," said Sri Lankan President Ranil Wickremesinghe. Debt cannot and must not become an obstacle for achieving the 2030 Agenda and the climate transition that the world desperately needs.

During the COVID-19 pandemic, "Nobody was safe until everybody was safe." Similarly, unless fair debt relief is provided to debt-distressed countries through interventions such as climate financing, all the countries and peoples in the world, both developed and developing, will be at the receiving end and become victims of climate change. S&T both investigate the underlying causes of climate change and offers remedies for it and other global challenges stemming from human impact. Hence, SD can be applied in an objective and dispassionate manner to address not only climate change but also other global issues such as pandemics, poverty, water, food and energy insecurity, inequalities, conflicts, pollution *etc.* which have far-reaching social, political and economic implications and ramifications on humanity as a whole.

ii. National unity

As a result of protracted internecine conflict, the performance of all sectors of the economy of the Northern and Eastern Provinces, including agriculture, fisheries, tourism, cottage industries, and SMES were drastically affected. Concomitant with this was loss of livelihood and means of sustenance of millions of people in those provinces. Therefore, in order to rebuild and resuscitate the regions, it is imperative to revitalize the key sectors affected so as to restore their livelihoods and raise socio-economic standards.

Jaffna has been a Mecca of culture and scholarship as well as a cradle of intellectuals, scholars, scientists, and professionals who have made an immense contribution to national development. Similarly, the Eastern Province with a lot of natural endowments and cultural heritage sites possesses immense potentialities for economic growth. The Jaffna, Vavuniya, Eastern, and South-Eastern Universities constitute the brains trust and intellectual pulse of the respective

regions. Hence, the universities and R&D institutions in other regions should join forces with them to promote regional development. For instance, with the advent of tsunami in 2004, the University of Ruhuna, with support from CIDA, embarked upon a programme in collaboration with the Eastern University and South-Eastern University in the Eastern Province to rebuild and reconstruct the tsunami-affected villages through livelihood development, by means of S&T interventions, which were quite successful. That led to the development of lasting organic linkages among staff of the three universities, which are still robust and vibrant.
Therefore, identification of critical issues in the North in agriculture, fisheries, tourism, *etc.* and addressing them through such scientific cooperation with the South could contribute to fostering social cohesion, harmony, and national unity in the country.

iii. Claim for extended Exclusive Economic Zone

Sri Lanka possesses a territorial sea of 21,500 km^2 and an Exclusive Economic Zone (EEZ) of up to 200 nautical miles (370 km) from the coastal line with an extent of 517,000 km^2. Sri Lanka has the rights to the resources in the water column, seabed, and subsurface in the EEZ. Under the United Nations Convention on the Law of the Sea (UNCLOS), Sri Lanka is entitled to claim for an extended area of seabed where the thickness of the sediment layer exceeds one km. This claim has been made and, if accepted, Sri Lanka could gain an additional seabed area. Therefore, the EEZ is likely to expand further with the delimitation of the outer edge of the continental margin of the country, which would permit Sri Lanka to own an EEZ equivalent to 23 times (approximately 1,400,000 km^2) its land area (Figure 5). Apart from living resources, this Zone contains a variety of exploitable minerals and hydrocarbons (oil and natural gas).

However, given the geo-political and geo-economic interests in the Indian Ocean, when this arbitration claim is taken up by the UN, other nations could also lodge a claim for part of the area claimed by Sri Lanka. Here, not only a profound scientific knowledge of the sediment dynamics in coastal and marine environments, but also consummate skills in SD are required to succeed in the arbitration process.

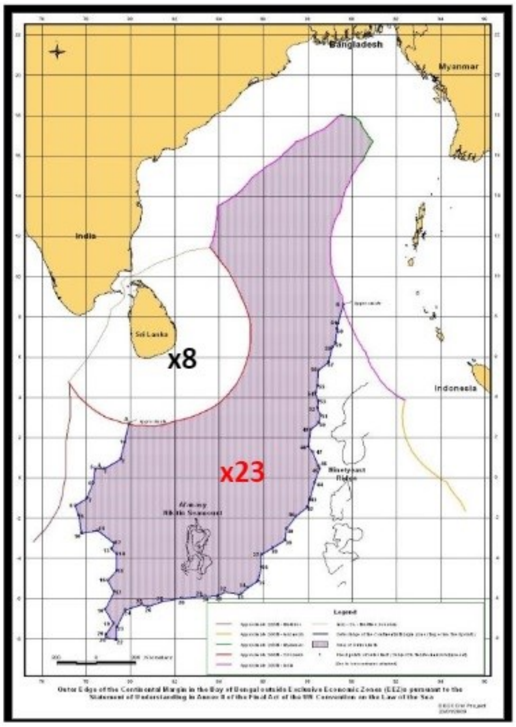

Figure 5: Exclusive Economic Zone and the claimed extended Exclusive Economic Zone of Sri Lanka

iv. ***Potential threats stemming from growing water conflicts in the region***

Climate change and the ever-increasing population, combined with growing economic and social imperatives and needs will create competition for water. This can lead not only to social unrest and regional conflicts but also to hydro-political issues, triggering “water wars” (World Economic Forum, 2018). Water insecurity can be weaponized and exacerbate tension and friction within and between countries. Today water is a growing source of global conflict in nearly 50 countries (World Economic Forum, 2019, 2020). In Asia, while Sri Lanka is blessed with abundant perennial water resources, many countries are already facing moderate to severe water scarcities (Figure 6).

Water being the lifeblood, its scarcities can trigger conflicts not only between but also within countries. The historic Mavil Aru battle in 2006 is a telling case in point. Therefore, SD will be of great relevance in coping with potential conflicts emanating from water scarcities in the region.

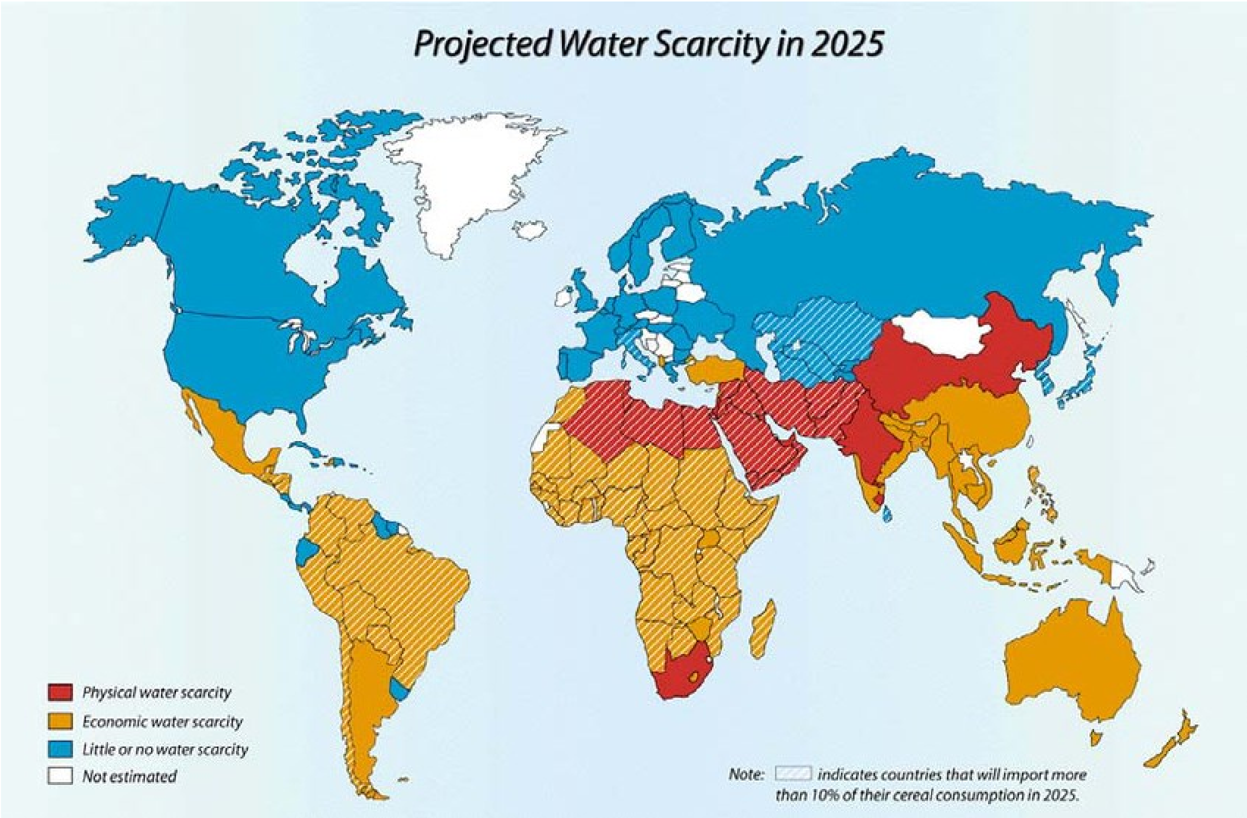

Figure 6: Projected water scarcity in the world in 2025

Source: Mcgranahan, Gordon. (2002). Demand-Side Water Strategies and the Urban Poor.

Issues and challenges for institutionalizing SD and metrics for success

Science diplomacy has attracted remarkable attention in public and foreign policy and academic research in the past 15 years in developed economies. However, this concept is still plagued by a huge talk–action discrepancy in many of those countries. It is a relatively new subject in many countries in the Global South including Sri Lanka. As a matter of fact, there is hardly any discourse on SD either in the Ministry of Foreign Affairs or in the Ministry dealing with S&T in Sri Lanka. Though it has a great relevance and importance in a turbulent, tumultuous, and fractured globalized world rife with manifold issues, challenges and conflicts as enumerated before, SD is still at an incipient stage in Sri Lanka. Therefore, it is opportune to initiate a discourse on this subject at national level with a view to institutionalizing it. Some challenges and constraints encountered in this regard are given below:

1. Though S&T is the prime driver of and key to development, it is still of low priority in the country receiving only about 0.1% of the GDP, which is even below that of Nepal (0.3%).

2. Low number of R&D personnel in the country, which is only about 106 per million of the population as opposed to Israel (8250), Korea (7980), Singapore (6803), Japan (5331), Malaysia (2397), Pakistan (336) and India (253).

3. Dearth of S&T personnel among the cabinet ministers (only 3 out of 22), secretaries to the ministries (2 out of 19), and senior administrative staff in the ministries and state institutions, which is still smaller.

4. Lack of rapport and cooperation between the Ministry of Foreign Affairs and the Ministry responsible for S&T and the absence of a science attaché in the foreign mission of Sri Lanka.

5. Lack of integration of the scientific and foreign policy communities into a cohesive nexus

6. Absence of a dedicated in-house scientific advisory mechanism and a Chief Science Advisor (CSA) who can link the Ministry of Foreign Affairs to the International Network for Government Science Advice (INGSA)

7. Limited dialogue between policy makers, academics, and researchers working in the realm of foreign policy

8. Imposition of new rules and regulations causing inordinate delays on international scientific cooperation and collaboration

Therefore, it is imperative to address the above as a matter of utmost importance and urgency given the momentous role Sri Lanka has to play as the Chairman of the IORA from 2023 to 2025 and the geo-political and geo-economic significance of the Indian Ocean which has become a cynosure in world politics with USA, China, and India already viewing it through their own geo-strategic lenses.

Way forward

Today we are living in a complex, multipolar world rife with geopolitical rivalries and undercurrents where national security goes beyond the physical securing of one's own borders. Moreover, in this era of internet and cyberspace, the actual location of individuals hardly matters as ideas and ideologies travel at the click of a mouse beyond borders on a real time basis. Swami Vivekananda described the world as a "gymnasium" where nations come to make themselves strong. It is against this backdrop that the world must come to grips with a myriad of formidable challenges and threats such as climate change, poverty, disaster vulnerability, glaring inequalities, food, water, energy and cyber insecurity and pollution, to name, but a few. They are complex, multi-faceted and multi-dimensional, and demand an interdisciplinary, transdisciplinary, multi-sectoral and transnational systems approach where cooperation between specialists with diverse backgrounds in both the natural and social sciences across territorial boundaries and community engagement are imperative.

In this context, SD has a great relevance and value in view of its profound unifying, bonding, levelling and healing power, and its ability to transcend cultural, national, and religious boundaries—for science, as we know, provides a neutral environment for the free and friendly exchange of ideas between people. It could also be a powerful and effective tool in addressing complex and intractable issues such as poaching in Sri Lankan waters by fishermen from a neighboring country, debt restructuring, and promoting foreign direct investment and international trade.

However, this formidable tool still remains untapped and underexploited for fostering social cohesion and ethnic harmony in our country, promoting international relations, mitigating regional and global conflicts and addressing SDGs. In order for SD to be credible, acceptable and effective, it has to be combined with morality and ethics and should be free from political interference. Here, it is important to cultivate a climate in which subjects will not be influenced by extraneous considerations such as military prowess, economic might, or the size of the country, but instead will act on merit and substance in an objective and dispassionate manner free from prejudices, biases and preconceived notions.

Sri Lanka is strategically located in the Indian Ocean, which has outstanding geo-political and geo-economic interests. Alfred Thayer Mahan, an Admiral in the US Navy, said in 1897, "Whoever controls the Indian Ocean will dominate Asia. This ocean will be the key to the seven seas in the 21st Century. The destiny of the world will be decided on its waters". The Indian Ocean which has become a cynosure in world politics, and the USA, China and India already viewing it through their own geo-strategic lenses. It is under such circumstances that Sri Lanka serves as the Chairman of the IORA from 2023 to 2025 and also as a member of the SAARC and BIMSTEC.

In Sri Lanka, there are several challenges and constraints on institutionalizing SD including the low national priority given to S&T, dearth of scientists conversant with SD, lack of discourse between the Ministry of Foreign Affairs and the Ministry dealing with S&T. Therefore, addressing the constraints and limitations on institutionalizing SD and creating a vibrant framework for systematic use of science diplomacy constitute high-priority concerns in Sri Lanka at this crucial juncture. Their urgent necessity cannot be overemphasized. Sri Lanka's diplomacy needs to rise to challenges and to demonstrate great strength to navigate the complexities and intricacies involved in the region while also safeguarding her sovereignty and territorial integrity.

Sri Lanka has produced several outstanding sons of global repute such as Dr. Lakshman Kadirgamar, Shirley Amarasinghe, and Dr. Neville Kanakaratne who have made an indelible impression in the arena of international relations. There are still able and competent Sri Lankans at home and abroad with a commendable grasp of intricacies involved in international relations in a multipolar world. They need to be identified and mobilized to complement the national endeavours, discourses, and deliberations in the realm of international relations through SD. Sri Lanka can make diplomatic gains in any forum that matters to it most, provided there is a cogent multilateral vision, underpinned by inclusive, coherent policies, science diplomacy combined with moral and ethical values, and consummate communication skills.

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Section A

Medical Tourism as a Growing Industry for a Sustainable Economy: New approach through Science Diplomacy

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Introduction

Understanding the Scope of the Medical and Wellness Tourism and Science Diplomacy

Sri Lanka has a huge market potential in developing Medical Tourism as a profitable industry. The better fraction is wellness tourism which has the most favorable demand of the customers and a large influx of foreign currency and is also a reasonable solution for the debt recovery. Sri Lanka has to reintegrate the tourism industry with more user-friendly measures, while utilizing digital technology and artificial intelligence. A focus on introducing more customized services to the different social segments and giving priority to the target markets may attract more people from more countries than now. Customizing the pricing strategies will open more opportunities to travelers to increase their purchasing power. The Sri Lanka Tourism Development Authority (SLTDA) has developed an action plan considering the potential areas of earning (for the years 2022 to 2025) (CBSL, 2021). This needs to be taken forward with more stakeholder involvement, including the education of the service providers, as the world is moving towards the low-cost high convenience strategies for Health and Wellness tourism, along with the global economic crisis. Inflation and USD rate fluctuation changed the demand of the tourists. Most tourists select South Asia as their travel destination, especially the people who seek medical care for a comparatively lower cost. There is a different market trend for those who need natural or herbal based medical care.
Science diplomacy is a new trending buzzword, which explains how science could make the world the best possible place for all the living beings, connected through 3 defined areas. **Science in diplomacy** explains how science could lead the decision-making process in policy development. **Diplomacy for science** covers vast areas across countries, where it facilitates large scale research opportunities. **Science for diplomacy** promotes a more peaceful world through scientific cooperation.

Science diplomacy has the power of negotiations, collaboration, and cooperation across countries. This will enable trade, tourism, and opportunities in all the sectors, to improve their domestic economy and GDP. Therefore, through science organizations such connections could be built across nations considering the following objectives:

1. Enhance the knowledge base of the professionals in each country, about the potential areas of interest.
2. Disseminate scientific evidence and promote related businesses at all levels of society.
3. Promote the wellbeing of all the living beings and educate the public.
4. Connect with the communities and address their issues making the country a better place for all the living beings.
5. Improve the economy of the country considering all above actions.

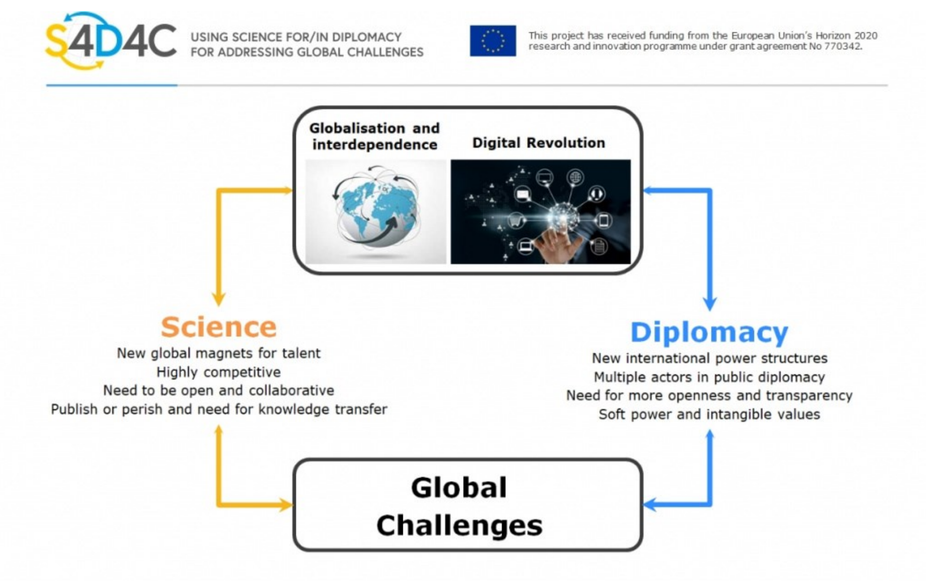

Figure 1: Interconnection of Science Diplomacy in Global challenges (Melchor, 2023)

The interactive space of science diplomacy has a number of benefits for the medical / wellness tourism industry. Science diplomacy has the ability to address global challenges in a competitive manner. Strengthening the Science – Diplomacy interface as an instrument will support achieving the sustainable development goals (Sevilla, 2021).

The brain drain across borders may also open another spectrum of business trends, giving the opportunity of getting local treatment overseas at a competitive price. Combining these

phenomena, it is indeed a trending business to open a tourism destination offering the opportunity of getting wellness experience and medical treatments.
Operation of Medical / Wellness tourism is not a single business; it could lead to initiating many avenues in local as well as international businesses. The traveler, who seeks care, is the decision maker and the decisions will be taken based on personal experience about the attributes of the host country, including value for money, standards of the health care provision, hospitality, and the quality of the service delivery. This has a number of considerations including demand, affordability, accessibility, and availability of better communication. Safe environment, weather, and the culture of the people also have an impact on the selection of the destination by travelers. Also, lateral services such as transport, security, and freedom of access to information may play an important role.

The efficiency of the health workforce is another driving force for the client. Availability of well-trained staff is one of the key success factors for client attraction. Efficiency of the universal languages, easy travel opportunities with user-friendly regulations, 24 x 7 access for credit and banking, flexible laws, cost effective standard services, and service-oriented citizens are the other factors affecting the highest penetration of the countries which have succeeded in medical tourism. Recognition of this sector is very relevant for the recovery from the economic crisis, as it is one of the key sources of generating foreign currency.

Medical tourism is not a new venture for Sri Lanka. Since ancient times it was recorded that this country was one of the best hubs for medical tourism. It was known at the time that the Sacred Tooth Relic was brought to Sri Lanka (325-377 AD), that this country was reputed as a medical hub and people used to seek care for various illnesses.

Health tourism has a number of fractions

Health tourism could be categorized in a number of ways reflecting the need and the demand. It is more towards the multidisciplinary approach rather than simple service management.

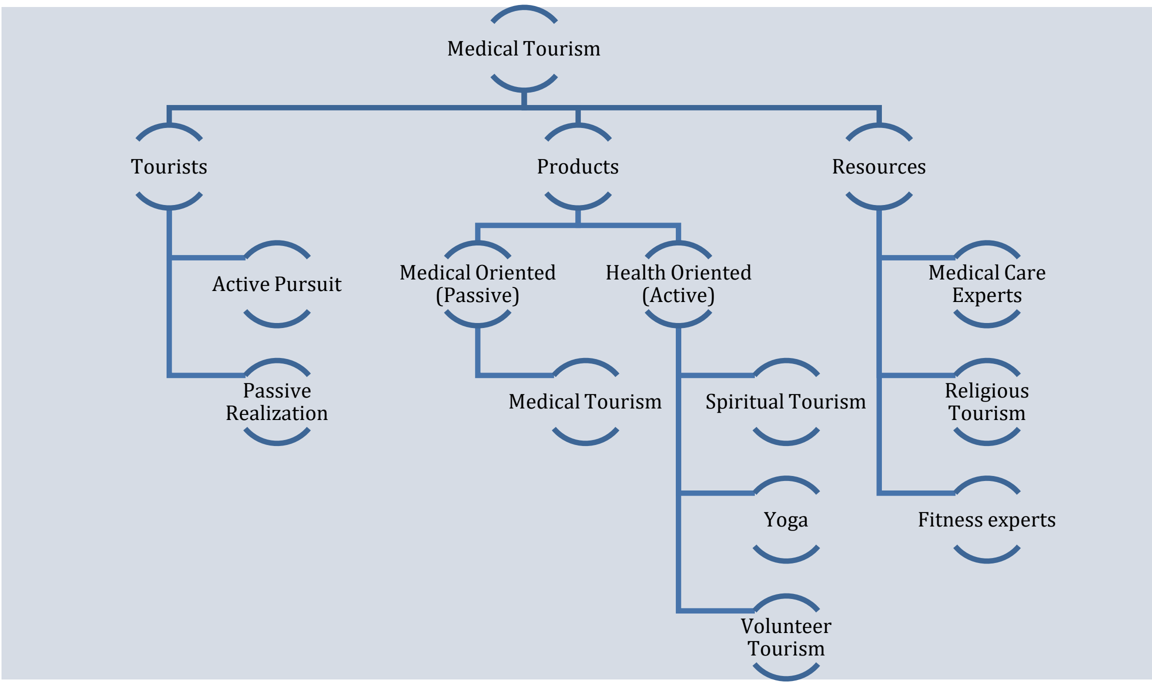

Figure 2: Fractions of Health Tourism Industry (Sunny Sun, 2022)

People travel overseas not only to get treatments, but also to shop for medical products, especially wellness products and cosmetics of herbal origin. Few of the people travel for medical opinion and investigation rather than getting active treatments. Short-term education with hands-on experience may also be another avenue of interest under medical tourism, as participants get lifelong experience on the medicinal practices of the host country. Cultural values embedded with the therapies, which are combined with rituals, have more attraction to travelers. Therefore, to get more visibility of clients towards medical tourism, it has to offer more customized and personalized treatments to the seekers. The development of alternative medical practices and practitioners also needs attention, as there was no proper training or recognition for them.

Key Stakeholders and their contribution to Value Co-Creation

The key stakeholders are the decision makers of the development of the medical tourism industry. Tourists, healthcare providers in the public and the private sector, government agencies such as the Foreign Ministry, Sri Lanka Tourism Development Board (SLTDB), facilitators, accreditation and credentialing bodies, healthcare marketers, insurance agencies, infrastructure developers and designers are the responsible key players who have the dominant role (Kamassi, 2020).

Intergovernmental science organizations such as SLAAS can also address many challenges faced when operating medical tourism as an industry. Almost all the countries have their own or internationally connected Science organizations such as Organization of Women in Science for the Developing World (OWSD) or Women in Science and Engineering (WISE). Conventional collaborations in policy decision making, policy adaptation and operational research will give a stronger impact for the development of the industry in a sustainable manner (Roland *et al.*, 2023).

Nationally and internationally, certain businesses are changing their view from an institutional perspective to a person centric approach. The primary objective of the provider and the consumer is continuous creation of value and value extraction. Sustainable dialogue between the two parties, access, transparency, and risk understanding are the key considerations of value creation. Co-creation needs the combined effect to get a synergetic impact. Intergovernmental science organizations have a major role in this value creation.
In health tourism, value co-creation could be done in different levels of the service provision:

1. Micro system level - Individuals
2. Meso system - Healthcare Organizations
3. Macro system - Health system and Government Policies

The co-creation has both monetary and non-monetary aspects of the development. As a whole the performance of the health care institutions will improve with multiple involvement and supervision with different angles of the service delivery. The client is expected to have a positive attitude towards the public sector services. They may be shifted from the private sector to get more accurate, timely and standard services. When the service quality and responsiveness is improved, it will ensure the brand loyalty. Altogether it is expected to attract more tourists and more penetration into different service segments such as curative, preventive (including screening services at competitive prices), rehabilitation, and counseling services covering all the age groups.

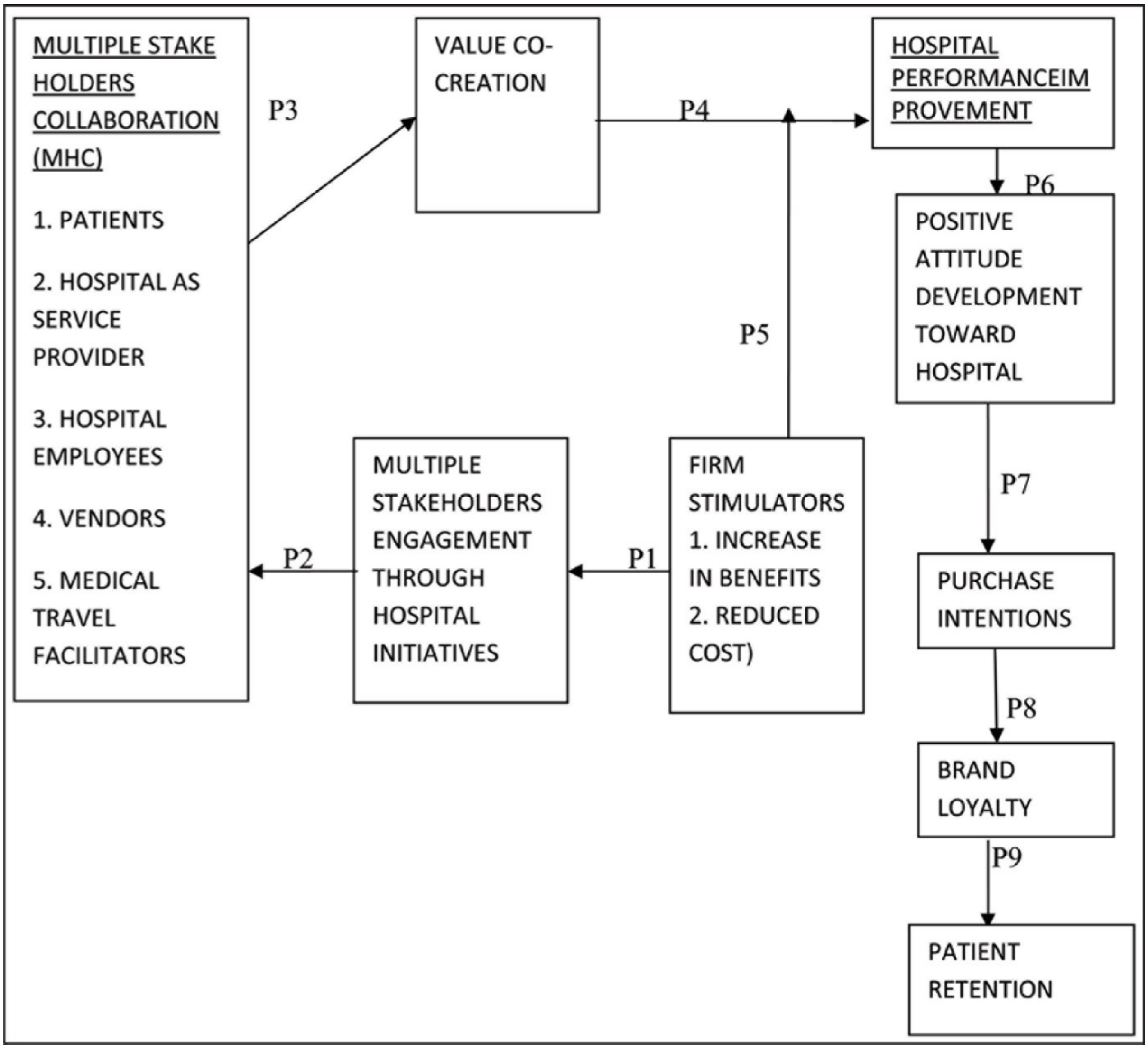

Figure 3 : Value Co -Creation with multiple stakeholders (Chakraborty, 2020)

Value co-creation is not a simple entity as it involves multiple stakeholders of different aspects. This includes the service seekers as well as the service provider categories.

Controversy of Health Tourism

Health Tourism can be domestic or international and provide facilities to improve people's health. Also, the clients could be in two major fractions:

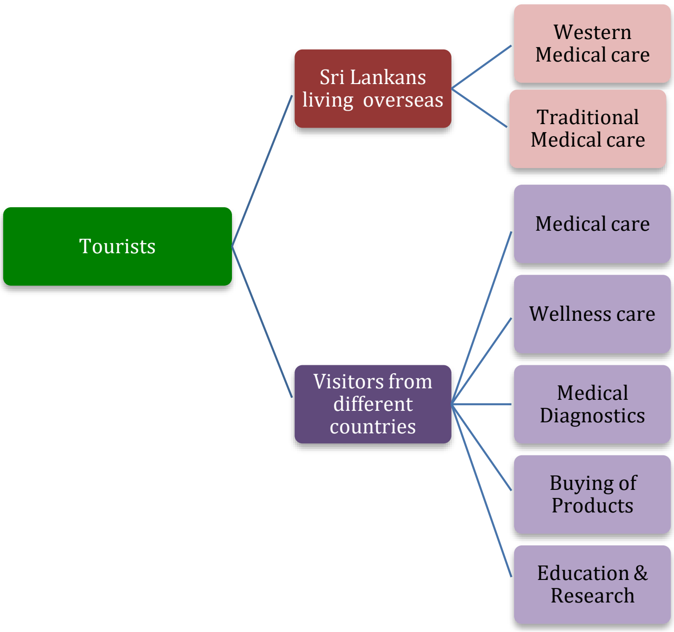

Figure 4: Types of tourists expected (Author generated)

Though we categorize the entire scope as medical tourism, a number of fractions could be observed depending on the needs and demands of the consumers. All these categories might be differentiated according to the gender, age, economic status, and the country of origin. People who cross borders have a number of purposes. Therefore, the practice of targeted care tourism is having success in a number of countries where they target the customer needs as per this segmentation. Therefore, market segmentation has another wide scope in opening the opportunities for various levels of care. This could be an opening of the services at a different cost and service quality. It also could be changed with the level of the pricing. As a government, or responsible ministry, categorization of the hospital care according to these standard prices would obtain a better yield than fixing a standard price for all the care providing hospitals. Then the high-end customers, those who could afford comparatively higher prices, may enjoy the premium level of care.

Sri Lanka has a more unique reputation in wellness tourism for the traditional and complementary practices, as it is the market trend of the current context (Arachchi, 2019). Therefore, services such as combined or integrated care will have more attraction for travelers, when they are delivered to the customer considering the holistic approach. This could be offered together with the treatment, mental wellbeing with relaxation therapies, Yoga, meditation, food therapies, pet therapies, and music therapies with lifestyle modification. Most of the aspects are underdeveloped and some do not have standard protocols either.

Government policies are needed for training in these areas, especially focusing at least as a solution for the unemployment of the school leavers.

Risk of Medical Tourism

Commonly the risk due to the long flying hours, such as deep vein thrombosis, pulmonary embolism, and risk of infection due to the procedures are the main areas of concern. The risk of infection is associated with the competency of the health services in the host country. At the point of entry there should be a well-planned mechanism to screen the passengers for communicable and non-communicable diseases and allergies, which need medical management. Following admission, inadequate screening before surgical procedures and short pre-medication time may have an impact on the outcome of these services. This also could be minimized with the digitalized and networked data system at the point of entry.

There are problems with the accreditation certificates of certain institutions and laboratories, as they may have certificates not issued by the competent standard licensing authorities (Crooks, 2013). The government should strengthen the accreditation process, which needs prompt attention of the leaders in evaluating those areas, as the current mechanism is not developed to track the expected results.

Also, the outcome indicators of the treatment or procedures could not be assessed, as there is no mechanism to do the regular follow up of the managed patients. The public sector is not at all ready to provide these services, as there is no updated mechanism at the Ministry of Health for the adequate charging. The existing policies also do not provide much support for this novel opportunity of income generation in the government institutions. Therefore, a number of areas need to be invented to initiate medical tourism in the public sector, including the ethical behavior of the employees and the readiness of care in the service organizations.

Industry drivers and Factors affecting the Growth of the Medical Tourism

Medical tourism is a vast industry, which is commercially driven and operated on demand of the clients. This is operating in a more autonomous, client oriented, and economically beneficial manner. Availability of care for the need and trust of the receivers are the main factors that decide the destination tourism. If Sri Lanka is planning to become a health tourism hub, a number of factors needs attention (Lokupathirage, 2011), including the regulations and availability of other services such as visa approval, currency conversion facilities, affordable transport facilities, language efficiency of the service providers, information security and accessibility, and safety and reliability of the offered services.

Market drivers of the medical tourism industry are cost factors such as cost saving, quality of service delivery, accessibility including transport and travel infrastructure, responsiveness, insurance schemes, and timely information through the web. Cost factors were the greatest concern of the European travelers, as they could receive better care at a lower cost than in their native countries. The cost difference between the selected country and the native country improves the willingness of selection. Therefore, competitive market prices may enhance the number of travelers who are seeking medical care (Pasadilla, 2013). The availability of world-class health care facilities may also attract clients over other subsidies. Making partnerships with private sector and foreign investors, and technology transfer from world renowned hospitals need to be incorporated to obtain a competitive advantage. State-of-the-art facilities may improve client satisfaction in a number of ways including the trust of the receiving party.

Longer waiting hours in the hospitals are negative factors for medical tourists, as they need quicker attention and care. Therefore faster, cheaper, and reliable alternatives should be planned. Accessibility to the services such as transport and travel infrastructure plays an important role in this Industry. Budget airlines and budget taxis, and pricing them need to be regulated by the government. Improvement of the information flow and the real-time data is one of the key considerations of the clients as their counterparts are residing outside the host country. One of the main limitations is the lack of insurance schemes networked within their respective countries, for them to adopt. Government policies need to be focused on such issues, which is limiting the draining of the clients from various developed countries.
Other than the availability of sub-specialties and a well-trained workforce at the centers with service readiness, a wider choice of treatments within close proximity and affordability, with paying options, may encourage the vast majority of travelers across the borders.

Need of a Medical Tourism Policy

This segment of tourism became popular 15 to 20 years ago, as an industry, and gave tremendous opportunities for earning foreign currency. However, it has a number of risk areas, as there is no solid legal and ethical security with the established governing mechanism. A number of countries have initiated the practice of relaxed visa approval policies for patients who seek medical care. The safety of the travelers also has to be ensured, offering them the complete benefits and privileges, which normal tourists are entitled to. The insurance sector has already begun to incorporate medical tourism as an option, charging unexpected amounts from people, referring to the issues of the tourism policies of other countries. Because countries have very rigid laws on acceptance of the insurance policies of certain countries, clients may have to face problems with their payments. All these need to be regulated with global agreement of one policy for all countries. Otherwise, this sector may not adequately serve the client's expectations.

Key Players

Currently in Sri Lanka, the main players are within the private sector, because of the inefficiency of the service management of the government sector, with a lower standard of facilities and delays. Private players have greater remuneration than the public sector and a quick response to the growing trends of the client's requirements. Lengthy procedures, rules, and regulations of the public sector may create an unpopular reputation, even though they maintain the required standards in the medical treatments (Cloutier, 2020).

Medical Tourism needs a more systematic approach to succeed as an industry. There are a number of agencies that give synergic impact to the growth of this industry. Key stakeholders responsible for the development of this industry are the Government, companies which are involved with the travel and needy segments, hospitals, hospital staff and suppliers, the transport industry both private and public, and service providers in the ancillary services (Gupte, 2014).

There are a number of concerns in the service sector for the sustainability of Medical Tourism as an industry. Financing, continuous quality service delivery, health work force, medical technology, health insurance facilities, and health information are contributing to the sustainability of Medical Tourism.

Future of Medical Tourism

Business activities within the tourism industry are highly competitive as a growing industry for customized service delivery. The front-runners are not always within the public sector. Public-private partnerships in offering market driven competitive services are highly recommended, expecting improvement of the reputation of the country. Also, a number of countries have business opportunities in other countries for their popular hospital brands. Therefore, opening such opportunities to other countries may improve tourism in the hosting country.

Optimum diagnostic services with accredited laboratory chains are very important for medical tourists, as they may have to travel from one hospital to another. Also, the availability of reputed brands of drugs and other devices may enhance the trust of the consumers.

Insurance providers may have to consider alternative options to satisfy their clients, who require facilities for medical tourism. More coverage through insurance policies and flexible regulations of payment needs to be introduced to minimize the countrywide disparities of currency and financial restrictions.

Managing the risk of travel related illnesses adequately, in between the host country and the residence is another issue that needs to be addressed. The need of secure and safe services, considering the risk applying to both countries, should be considered with every traveler. This will enable the travelers to understand the risk of cross transferring communicable diseases, especially in an epidemic or pandemic situation.

Government Role in the Medical Tourism Industry

The Government has a bimodal involvement in the medical tourism industry. It has to safeguard its own citizens' health and similarly ensure the safety of the clients (Labonte, 2018). The government has to ensure the standards of the medical education of physicians and other professionals in the health services. There are countries which have substandard medical training in their Medical Colleges. The accreditation of institutions should be up to internationally recognized standards. Service delivery and facilities also need to be accredited in a government-accepted manner. Intermediary services such as brokering agencies and supportive agencies need to be regulated by the government. Procedures that are illegal in the home country should be banned in the host country, unless under life threatening circumstances. The gaps in the laws against medical malpractice should be addressed, and a monitoring team should be appointed to take care of it.

Laws regarding the confidentiality of information need attention when the client is requesting medical records. There should be at least a provider agreement in issuing the records while maintaining the confidentiality. Countries should agree upon a global governance mechanism for medical tourism to address those issues in a diplomatic manner.

Concluding Remarks

The country should identify the services that could possibly be delivered to tourists with the opinion of the key stakeholders and key industry players. Segmentation of the Services should be done depending on the age, sex, ethnic differences, purchasing parity and social status of the client. Safety measures should be taken as a priority, and standardization should be in place.

All the stakeholders need close communication, with regard to the supply chain and continuation of the services. Language proficiency, trust, and the attitude of the staff should be developed to create a better service environment. Positive marketing strategies should be incorporated into all government strategies.

Education should focus on more country specific businesses. Necessary reform in each field should be gradually adopted to minimize the resistance of the institutions.

Science organizations should contribute to the development of the country through collaborations to build international recognition and trust, and support to achieve the sustainable development goals through science diplomacy.

Government should identify the legal governance mechanism in sorting the problems and issues. Infrastructure and other logistics need to be developed to continue the services. There should be a wellness tourism policy for the system. The Ministry of Health could coordinate training and development of staff. Lateral / supportive services need reassessment to improve the capacity. Transparency and accountability need to be assured. The marketing of the services should be done ensuring the ethical and cultural values of the country.

Monitoring and evaluation should be done regularly to identify the gaps and to improve the service delivery. In order to regulate all these aspects, it is proposed to have an agency to observe and act against breaches of transparency and governance.

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Section B

Algae in Food and Agriculture Industry: Recent Advances and Future Prospects

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Introduction

Eliminating hunger, poverty, and food insecurity while ensuring sustainable use of natural resources for agriculture, as highlighted in the United Nations Sustainable Development Goals (SDG 2: Zero hunger), is paramount since the world is facing a myriad of economic, social, political, and environmental challenges. As estimated by the Food and Agricultural Organization (FAO) between 690 and 783 million people in the world faced hunger in the year 2022. It is interesting to note that, compared to the COVID-19 pandemic era, this accounts for 122 million more people suffering from hunger. Furthermore, as estimated by FAO, about 2.4 billion people have faced moderate to severe food insecurity in 2022. These values indicate the lack of access to adequate nourishment worldwide. When it comes to the Sri Lankan context, as estimated by the FAO and the World Food Programme (WFP) 6.3 million people faced moderate to severe acute food insecurity in 2022 and the situation is expected to be worsen in the future if adequate life-saving assistance and livelihood support is not provided. By 2030, the world population is expected to have reached a total of 8.4 billion and rise further to 9.5 billion in 2050 and 10.4 billion by 2100. This increase in population will also lead to a higher demand for food products and highlights the necessity of increasing agricultural products. However, with the increasing global population, the reduction of arable lands for food crops, water scarcity, and soil quality degradation could create another challenge for food production. To meet those challenges, improvement of crop productivity and sustainable agricultural practices is needed.

Moreover, according to FAO estimates, up to 40 percent of global crop production is lost annually due to pest and pathogen attacks. Each year, plant diseases cost the global economy over $ 220 billion. This is another factor that limits regular access to safe, nutritious, and sufficient food aggravating hunger and malnutrition among people worldwide. With this background, it is obvious that achieving the Sustainable Development Goals' Zero Hunger target by 2030 will be a difficult task. In fact, it is estimated that in 2030 nearly 600 million people will still be at risk of hunger. Therefore, it is essential to take actions to increase crop production, start using novel and more sustainable food sources, and minimize crop losses. Such measures will be able to eradicate hunger, poverty, and food insecurity while promoting sustainable agriculture.

Algae

Algae are photosynthetic, eukaryotic organisms that have recently gained interest in different industries (Figure 1) due to the high content of compounds with different biological activities including both primary and secondary metabolites. Algae can be divided into two major groups as microalgae and macroalgae based on their morphology and cellular arrangement. Microalgae are microscopic organisms and comprise diatoms (Bacillariophyta), dinoflagellates (Dinophyta), and green and yellow-brown flagellates (Chlorophyta, Prasinophyta, Prymnesiophyta, Cryptophyta, Chrysophyta, Rhaphidiophyta). Macroalgae are macroscopic, multicellular organisms and include green algae, brown algae, and red algae. According to the global algal database (AlgaeBase: http://www.algaebase.org) 173 129 algal species have been reported worldwide. Sri Lankan coastal waters are rich with marine flora and a variety of seaweeds have been identified. According to Silva et al. (1996) 455 macroalgal taxa belong to 410 species and 161 genera were identified from the Sri Lankan coast. Furthermore, there are several rivers and lakes in the inland, which are rich with microalgal species. This diversity of algae is one of the reasons to select them as a suitable candidate for addressing current issues in the food and agriculture sectors of the world; especially, for island nations including Sri Lanka.

Algae have been cultivated as a food source for many years even though it is not popular among many countries. Algae have evolved to be highly efficient at resource utilization and have proven to be a viable source of nutritious biomass that could address many of the current food production issues in the world. Nowadays, there is a clear need to develop new, efficient, and environmentally safe methods for combating plant diseases caused by pests and pathogens because they contribute to a considerable loss of economically important food crops. This loss directly affects hunger and malnutrition among people around the world. Algae have the potential to become a new generation of bio-products suitable for use in sustainable agriculture. This choice is beneficial for sustainable production due to several reasons such as low toxicity to humans and the environment, enhanced resistance of cultivated plants to biotic and abiotic stress, increased yield, quality of crops, as well as the reduction in the use of mineral fertilizers and pesticides.

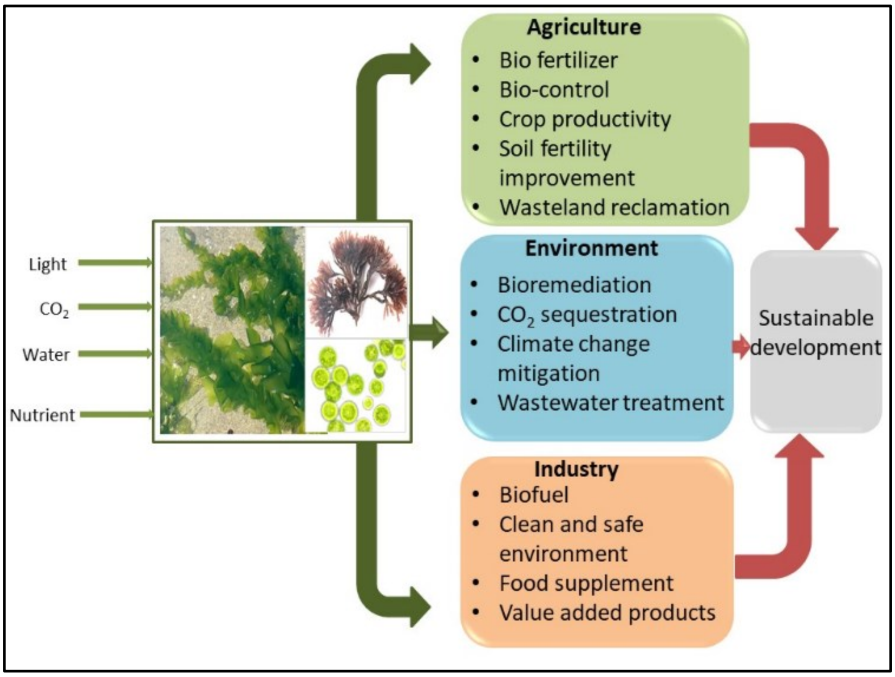

Figure 1: Industrial applications of algae

Role of algae in the agriculture industry

Algae play a major role in sustainable agriculture since they contain essential nutrients and metabolites with known activity in crop nutrition, growth stimulation, and protection.

Algae as a source of biofertilizers and biostimulants

Biofertilizers are live microorganisms that enhance the chemical and biological properties of soils, replenish soil fertility (providing essential nutrients including nitrogen, phosphorus, and potassium), and promote plant growth and development. Algal-based biofertilizers provide several advantages in agriculture, such as increased yield per unit area, maintenance of adequate soil properties and fertility, lower risk for soil and water contamination, and crop protection against pathogenic organisms. Algal-based biostimulants are compounds that in minute quantities can increase plant growth, crop productivity, nutrient uptake efficiency, and tolerance to a large number of abiotic stressors. They are directly involved in improving respiration, photosynthetic activity, nucleic acid synthesis, and ion uptake in plants. A wide range of compounds has been identified from algae including polysaccharides, phenolic compounds, hormone-like compounds, vitamins, etc. and these compounds can be considered as biostimulants for crop plants.

Some microalgal species are recognized as biofertilizers because of their positive effect on soil quality improvements. Moreover, due to their photosynthetic nature, they can recover nutrients from different sources, thereby reducing the use of chemical fertilizers in agricultural lands. Grzesik and Romanowska-Duda (2014) showed that monocultures of *Microcystis aeruginosa* MKR 0105 (Cyanobacteria), *Anabaena* sp. PCC 7120 (Cyanobacteria), and *Chlorella* sp. (Microalgae) could significantly enhance the germination of seeds and the growth of corn seedlings. Additionally, the applied monocultures improved the chlorophyll content of leaves, transpiration, stomatal conductance, and enzyme activity of dehydrogenases, RNases, and acid/alkaline phosphatases. Further, this study confirmed the application of microalgae cultures on grains before sowing was more economically desirable, compared to continuous application to roots *via* a substrate. Another study demonstrated that photosynthetic and N-fixing microbial consortiums could significantly increase the growth of wheat plants (*Triticum aestivum* L.) and enhance soil fertility (Ramírez-López et al., 2019). The findings suggested that 75% of chemical fertilization applied to wheat plants can be reduced by applying photosynthetic and N-fixing microbial consortium. Further, the results showed that the application of biofertilizers significantly improved the grain weight and grain yield compared to when applied chemical fertilizers. Dineshkumar et al. (2018) also showed that it was possible to reduce N-fertilizer application by 50 to 75% for rice plants (*Oryza sativa*) by applying *Chlorella vulgaris* and *Arthrospira platensis* (cyanobacteria) -based biofertilizers. Further, this study demonstrated that the use of biofertilizer made by the combination of both organisms significantly enhances the rice yield in contrast to chemical fertilizers.

Marine macroalgae have been used in agriculture for thousands of years. Farmers in coastal parts of Europe used harvested algae for their crops, either directly or after composting, and observed good impacts on soil fertility. Recent research have found extensive applications of marine macroalgal extracts from *Macrocystis pyrifera*, *Gelidium robustum* and *Sargassum* species as eco-friendly fertilizers in modern agricultural and horticultural crops. Briceño-Domínguez et al. (2014), showed that alkaline seaweed liquid extract from *M. pyrifera* with high polysaccharide content can enhance the adventitious root formation in mung beans. This result was comparable with the application of indole-3-butyric acid (IBA) and suggested that the seaweed extract could be a promising alternative. Further, this extract can enhance the growth of tomato seedlings. A study conducted in the eastern Himalayas region of India showed higher rates of seed germination, increased shoot and root length, and improved seedling vigour index after soaking rice seeds in *Kappaphycus alvarezii* or *Gracilaria edulis* sap (Layek et al., 2017). The presence of growth-promoting substances such as auxin, gibberellins, phenylacetic acid, and micro-nutrients in the algal extract may contribute to these observations.

Even though Sri Lanka is endowed with high algal diversity, there are only a few published reports on utilizing algae as biofertilizers or biostimulants in agricultural crops. Liquid fertilizers prepared from seaweeds; namely, *Ulva lactuca*, *Sargussum wightti*, *Gracilaria verrucosa,* and *K. alvarezii* collected from the Sri Lankan coast were able to enhance the growth and yield of *Capsicum annum* plants (Jayasinghe et al., 2016). Therefore, the utilization of seaweed as organic fertilizers could be beneficial for farming communities as an eco-friendly approach.

Biopesticides

The use of conventional pesticides in controlling insects, nematodes, bacteria, and fungi in crop fields is related to several negative impacts including the degradation of natural ecosystems and causing insect resistance. Microbial biopesticides, biochemical biopesticides, and plant-incorporated protectants (PIPs) are the most well-known types of biopesticides, accounting for 5% of the worldwide pesticide industry with microbial biopesticides leading the way. However, the use of biopesticides as the sole agent is hampered due to several factors including the low supply of the products, the high cost of refined products, and the slow action that they often exhibit.

Ranglová et al. (2021) showed that extracts of *C. vulgaris* were active against the phytopathogenic bacterial isolate *C. michiganensis* and three fungal isolates, *Fusarium oxysporum f. sp. melonis*, *Rhizoctonia solani* and *Phytopthora capsici*. Further, their study confirmed significantly higher antibacterial and antifungal activity against the above isolates when algae were grown in wastewater. Another study showed that the microalga *Chlorella fusca* CHK0059 is an efficient biological agent for improving strawberry plant growth and suppressing Fusarium wilt disease in organic strawberries (Kim et al., 2020). Also, they confirmed the reduction in population density of *F. oxysporum f. sp. fragariae* (Fusarium wilt disease-causing fungi) approximately by 86.8% in the treated plants compared to the untreated control after 70 days of application.

Although a lot of literature is available on the antibacterial capacity of marine macroalgae against human pathogens, reports on their bioactive potential against bacterial plant pathogens are relatively low. Studies that have been conducted on bacterial pathogens including *Xanthomonas* sp. (O'Keeffe et al., 2019), *Clavibacter michiganensis subsp. sepedonicus* (Cai et al., 2014) and *Pseudomonas syringe* (Kumar et al., 2008) showed promising results against tested algal extracts. The antifungal activity of various macroalgal extracts against plant pathogenic fungi has been well documented in many countries. Pourakbar et al. (2021) showed mycelial inhibition of *Botrytis cinerea*, *Aspergillus niger*, *Penicillium expansum*, and *Pyricularia oryzae* using *Gracilariopsis persica* collected from its natural habitat in Suru of Bandar Abbas, Iran. Further, they identified phenolic compounds, *e.g.,* rosmarinic acid and quercetin, as well as palmitic acid and oleic acid in the algal extract using Gas Chromatography-Mass Spectrometry (GC-MS) analysis whose antifungal effects have already been confirmed. Also, Selim et al. (2015) showed promising activity of *U. lactuca* extracts against the mycelial growth of *Fusarium solani*, *R. solani*, *Sclerotinia sclerotiorum*, *Alternaria solani*, *Phytophthora infestanse* and *B. cinerea*. A study carried out in Egypt revealed *Gracilaria confervoides* extracts show significant antifungal activity against soil-borne pathogenic fungi of cucumber; namely, *R. solani*, *F. solani* and *Macrophomina phaseolina* (Soliman et al., 2018). Our recent research findings also suggest that methanol extracts of *Ulva fasciata* show promising effect against *Pseudopestalotiopsis theae,* which causes leaf yellowing in *Solanum melongena* plants (Balasooriya et al., 2023). Further, this study confirmed the presence of 17-octadecenal and palmitic acid as potential antifungal compounds in the algal extract using GC-MS analysis.

A few important and interesting research findings regarding biofertilizers, biostimulants and biopesticides derived from algae are summarized in Table 1.

Table 1: Impacts of algae and their metabolites on agricultural crops

Algae/ Algal extracts	**Country/ Region**	**Target crop**	**Impact on crop**	**References**
Biofertilizers/ biostimulants/ composting				
Macrocystis pyrifera aqueous extract	Argentina	*Lactuca sativa*	Germination and establishment of seedlings; Adaptation to water deficit environment	Julia, 2020
Chlorella, *Scenedesmus*, *Chlorococcum*	-	*Triticum aestivum*	Increase in nitrogen availability in the soil; Increase grain yield	Renuka et al., 2016
Ulva lactuca and *Jania rubens* aqueous extract	Egypt	*Spinacia oleracea*	Increase plant yield; Improve nutritional value of plant	El-din, 2016

Chlorella vulgaris, *Spirulina platensis* (Cyanobacterium)	India	*Zea mays*	Increase seed germination rate, growth, and yield	Dineshkumar et al., 2019
Biopesticides				
Sargassum swartzii methanolic extract	Tamil Nadu	*Oryza sativa*	Inhibit the growth of *Xanthomonas oryzae* pv. *oryzae* (Bacterial blight causing agent of rice)	Arun Kumar et al., 2005
Cystoseira myriophylloides, *Fucus spiralis* aqueous extracts	Moroccan, Atlantic coast	*Solanum lycopersicum*	Reduction of crown gall diseases caused by *Agrobacterium tumefaciens*	Esserti et al., 2017
Laminaria digitata	-	*Vitis vinifera*	Reduction of growth of the pathogens *Botrytis cinerea* and *Plasmopara viticola*	Aziz et al., 2003
Spatoglossum variabile, *Melanothamnus afaqhusainii*, *Halimeda tuna*	Buleji Beach, Karachi	Tomato and sunflower	Show the antifungal effect on *Fusarium* spp., *Rhizoctonia solani* and *Macrophomina phaseolina*; Nematacidal activity against *Meloidogyne* spp.	Sultana et al., 2011
Padina gymnospora, *Sargassum latifolium*, *Hydroclathrus clathratus*	Safaga coastline, Egypt	*Solanum melongena* L.	Reduce the percentage of root rotting disease caused by *Fusarium solani*; Increase plant growth	Ibraheem et al., 2017

Role of algae in the food industry

Global demand for algal food is growing as they exhibit rapid growth and cost-efficient photosynthesis. These features make them attractive candidates as a food source for human consumption. A study conducted by Ullah et al. (2014) showed that algae can annually produce a higher amount of useful biomass (in the form of oil or carbohydrates) than corn when using the same area of land. Therefore, algae can make an important contribution to the food security of the increasing population, especially in regions where the arable croplands are limited. Further, algae are an ideal source of nutrients since they are rich in carbohydrates/fiber, protein, lipids, vitamins, minerals, and other bioactive phytonutrients such as polyphenols and carotenoids. This superb nutrient composition makes algae an ideal candidate to include in the human diet paving ways to eliminate malnutrition among people.

Nutritional value of algae

Algae proteins contain the entire spectrum of essential amino acids needed for the human body. In contrast to major agricultural crops including corn, rice, cassava, and other grains, algae are rich in proteins that are highly digestible and nutritionally well-balanced. Table 2 shows the comparison of amino acid content between human dietary requirements, algae, and other major agricultural crops (Diaz et al., 2023). The highest protein content was reported in red alga *Porphyra* species, which was estimated to be 30.6% of the dry weight (Wahlström et al., 2018). Some microalgal species are also rich in proteins. Reportedly, *Chlorella* species and *Dunaliella salina* have been widely consumed as they have a high protein content of 38 to 70% of the dry weight.

Table 2: Comparison of amino acid content between human dietary requirements, algae, and major agricultural crops (Diaz et al., 2023)

Amino acid	**Human requirement**	***Dunaliella bardawil***	***Chlorella vulgaris***	**Soybean**	**Chickpea**	**Wheat**	**Rice (Japonica)**
Histidine	10	1.8	2	2.6	0.214	1.8	0.9
Isoleucine	20	4.2	3.8	5.3	0.379	3	0.8
Leucine	39	11	8.8	7.7	0.635	6.8	1.9
Lysine	30	7	8.4	6.4	0.521	2.8	0.4
Methionine	10.4	2.3	2.2	1.3	0.087	1.9	0.6
Phenylalanine	25	5.8	5	5	0.476	4.4	0.7
Threonine	15	5.4	4.8	4	0.364	2.6	0.5
Tryptophan	4	0.7	2.1	1.4	0.037	1.3	0.9
Valine	26	5.8	5.5	5.3	0.379	4.5	1.9

Due to their photosynthetic nature, algae are rich in carbohydrates. This carbohydrate portion consists of dietary fibers, soluble fibers, alginates, sulfated heteroglycans, sulfated galactans, *etc.* There is an unusually large amount of dietary fibers in edible macroalgae, ranging from 23.5% in *Codium reediae* to 55.8% in *Gracilaria* spp. of dry weight basis and those values exceed the normal value for wheat bran (McDermid et al., 2005). Those fibers are considered as prebiotics, which promote peristalsis, satiety, and slow gastric emptying. Further, green and red macroalgae consist of soluble fiber and its content ranges from 52-56 % while brown algae have 85% of total fiber content. Such a high amount of fiber content could help to nourish the epithelia of the large intestine and regulate the immune function of the host. Among the microalgal species, *Chlorella pyrenoidosa* was identified to be rich in acidic polysaccharides and is a potential candidate for anti-tumor and immunostimulant supplements (Kralovec et al., 2005).

Alginates are a major class of polysaccharides found in brown algae and are widely used in the food industry. Recent studies are more focused on the applications of alginates rather than the consumption of alginate-containing brown seaweeds. Commercially available alginates are mainly produced by *Laminaria hyperborea, Laminaria digitata, M. pyrifera* and *Sargassum* species. Several studies have shown that an alginate coating can increase the storage time of different food products including tomatoes, mushrooms, shrimp, turkey fillets, chicken thigh meat, and low fat-cut cheese. Also, its thickening and gelling properties could be utilized in the production of sauces, jam, marmalade, syrups, and ice cream toppings. Algae that are belong to the orders Gelidiales, Gigartinales, and Gracilariales are rich in carrageenan, a type of polysaccharide which is used as an agent for gelling, thickening, emulsifying, and stabilizing of food products. However, due to some health concerns including inflammation, glucose intolerance, insulin resistance, and gastrointestinal ulcerations, carrageenan has limited use in the food industry.

Algal lipids also have promising applications in nutraceuticals and pharmaceuticals. Macroalgae typically contain 2-4.5% of dry weight as lipids, while some microalgae species contain 40-60% of lipid content in their dry weight. Microalgae can provide essential fatty acids, such as alpha-linolenic acid (ALA), which can be metabolized in mammals to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The well-known algal taxa capable of producing EPA belong to diatoms and eustigmatophytes, while DHA producers belong to the taxa of dinophytes, haptophytes, and thraustochytrids (Conde et al., 2021).

Algae are also considered as superfoods because they are rich in different vitamins including provitamin A, vitamins B1, B2, B6, B12, C, and E, as well as folic acid, niacin, and pantothenic acid. For instance, some seaweeds including *Porphyra umbilicalis*, *Himanthalia elongate,* and

Gracilaria changii contain vitamin C equivalent to common vegetables such as tomatoes and lettuce. Also, macroalgal species like *M. pyrifera* contains α-tocopherol, which is the most biologically active form of vitamin E while *Codium fragile* and *Gracilaria chilensis* contain β-carotene (pro-vitamin A). Additionally, microalgae are also rich in vitamins, particularly *Chlorella stigmatophora* contains vitamin A, E, B1, B2, B6 and B12.

Apart from the above-mentioned nutrients, carotenoids and phenolic compounds can be identified as co-nutrients present in microalgae and seaweeds. Green microalga *D. salina* accumulates β-carotene to about 8% of its dry weight, which has been marketed as a functional food in several countries. In addition, phenolic compounds such as flavonoids and phenolic acids show potent antioxidant activities and anti-inflammatory activities. Several microalgae including *Scenedesmus* sp., *D. salina,* and *Chlorella minutissima* produce considerable amounts of phenolic compounds at different phases of their growth curve. Based on all the above-mentioned examples, it is clear that algae can be an excellent source of a wide range of essential nutrients and micronutrients. Therefore, algae could play a vital role in the elimination of malnutrition from the growing world population.

Edible algae

Archaeological evidence shows that the consumption of algae dates back to 14,000 years in Chile. Some microalgal species have achieved “Generally Recognized as Safe” (GRAS) status by the U. S. Food and Drug Administration (FDA) indicating those algae are safe for human consumption. The species obtained GRAS include *Chlamydomonas reinhardtii*, *Auxenochlorella protothecoides*, *Chlorella vulgaris*, *Dunaliella bardawil*, *Euglena gracilis*, *Haematococcus pluvialis,* and *Schizochytrium* sp. Various countries consume many edible seaweeds including Japanese kelp (*Laminaria japonica*), Kombu (*Sacharinna* spp.), *Gracilaria* spp., Nori Nei (*Porphyra* spp.), Eucheuma seaweeds nei (*Eucheuma* spp.), Laver or Nori (*Porphyra tenera*), Wakame (*Undaria pinnatifida*), Elkhorn Sea moss (*Kappaphycus alvarezii*), Hijiko or Hiziki (*Sargassum fusiforme*), Umudggasari (*Gelidium amansii*), and Gamtae (*Eckonia cava*) (Rogel-Castillo et al., 2023). Edible seaweeds are consumed directly, as an ingredient for sushi wraps or in salads and soups. Most of the edible seaweeds are harvested from natural seaweed beds in many countries including Chili, Mexico, the United States, Peru, and Canada. It is interesting to note that about 80% of the seaweed in Africa is received from seaweed farming.

Conclusion

The utilization of algae as biofertilizers and biopesticides has exhibited promising outcomes in facilitating nutrient recycling, augmenting nitrogen accessibility, and enhancing plant development; hence, diminishing the reliance on synthetic fertilizers. Consequently, this approach has a significant promise for the advancement of sustainable agricultural practices. From a nutritional point of view, algae contain a variety of nutrients including polysaccharides (dietary fibers, soluble fibers), proteins, fats, minerals, and vitamins. Therefore, the potential of algae as a novel food source to meet the global demand for food in the twenty-first century is enormous.

Recommendations

Large-scale production of algae is essential with respect to utilizing them in sustainable agriculture or food industry without over-exploiting naturally available resources. An aggregate of 35.8 million tons of global algae production (both seaweed and microalgae) in 2019 was shared by 54 countries, and cultivation accounted only for 97% of this production. It shows that 100% attention has not yet been given to the large-scale cultivation of algae to exploit its full potential. Further, fluctuations in environmental factors such as salinity, water current, tides, and available nutrients of the surrounding water would affect the growth performance, bioactive constituents, and nutrient content of algae. Therefore, it is necessary to find suitable culture media (low-cost media) and conditions for culturing algae to maintain their properties. The social acceptance of algae as a food source is still poor in many countries in the world. Therefore, it is important to educate the public about the well-documented health benefits of algae as a food. Although seaweed consumption offers several health benefits, it is important to note that it can also lead to the accumulation of harmful substances including pathogenic microorganisms and heavy metals, which may have varying degrees of adverse effects on human health. In order to guarantee the quality of seaweed for human consumption, each nation should establish protocols and standards for the effective cultivation, harvesting, processing, and management of seaweeds.

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Section C

Recognising the value of non-perennial (ephemeral) streams

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1. Introduction

Non-perennial streams, commonly known as ephemeral streams, form temporarily during or immediately after precipitation events and comprise of over 50% of the length of the world's surface flow network (Figure 1 shows the flowing and dry phases of an ephemeral stream). Certain streams run as perennial streams for years, and then suddenly dry up, forming ephemeral streams (Datry et al., 2017). Their extent is currently increasing because of climate change, water abstraction and land use changes. Despite the seasonal flow of ephemerals, they should be considered an important source which supplies water, seeds, nutrients, sediments and organic matter to downstream perennials (Amaiz et al., 2011; Brown et al., 2017). Ephemerals provide ecological benefits such as harboring high biodiversity by provision of habitat to diverse fauna and flora, due to the existence of both wet and dry phases of the stream (Corti and &, 2012). Also, provision of fertile soils for agriculture during the dry phase of the stream, maintaining riparian vegetation, and supplying food and water for wildlife proves the ecological importance of ephemerals. Moreover, ephemerals offer hydrological importance to the ecosystem by provision of hydrological connectivity and conveyance of water, nutrients, and organisms across the terrain (von Schiller et al, 2017). Also, high nutrient processing rates, interception of contaminants, replenishment of aquifers and suspended sediment removal of water have been identified as benefits provided by ephemerals (Datry et al., 2017).

Figure 1: An ephemeral stream that flows to Minneriya reservoir, Sri Lanka showing flowing and dry phases.

Ephemeral streams provide a wide variety of ecosystem goods and services. Ecosystem goods refer to directly harvestable or usable components, while ecosystem services refer to environmental processes influenced or regulated by the ecosystem under consideration (Porras, 2012). Ecosystem goods and services are directly associated with the well-being of humans since they are critical resources for sustaining life (Porras, 2012). In the Sri Lankan context, ephemeral streams are acknowledged for being one major part of the cascade irrigation network of ancient Sri Lanka and still plays a significant role (Bandara, 1985). Despite the provision of a wide variety of ecosystem goods and services beneficial for human livelihoods, ephemeral streams are being degraded as a result of unsustainable human activities. One major reason for this could be that some services are not direct, and the negative impacts of impaired ephemerals may take some time to emerge (Sheldon et al., 2002). The rapid growth of population along with high demand for goods and services has increased, thus resulting in deprivation of ecosystems. In general, developing countries show less interest in environment and ecosystem goods and services provided by ecosystems, as the priority is development – develop now clean up later is the maxim of any developing country (Costanza et al., 1997). This is obviously the case for ephemerals and is much worse than for perennials. Therefore, economic valuation of the ecosystem goods and services provided by ephemerals could be considered a productive approach in conveying the true value.

Economic value of ecosystems conveys the income generated from ecosystem goods and services and other benefits. Some disapprove of the concept of valuation of ecosystems for being too abstract and overlooking the real value of the ecosystems which are more complex and priceless (Mangi, 2016). But it is argued that even marginal or approximate valuation of these ecosystem goods and services could be a key element which could convey an impression of the significance and would influence the survival of these ecosystems and protect them from unsustainable human activities. The concept of total economic value is widely used to quantify the value of ecosystems in terms of both monetary and non-monetary aspects. The total economic value considers the direct use value, indirect use value, and non-use value of the ecosystems (Brown et al., 2007).

This paper/presentation will be done in three parts. Firstly, the ecosystem goods and services of ephemeral streams will be discussed with especial emphasis on the dry zone of Sri Lanka. The dry zone has the highest density of ephemeral streams compared to other climatic zones of Sri Lanka. The wet zone that hosts most of the population in Sri Lanka anyway has lost most of its ephemeral streams, some even without a trace, a long time ago. Secondly, a conservative economic value estimation of these streams will be done referring to their major hydrological services, again referring dry zone of Sri Lanka. The third and final part is dedicated to discussing the legislative protection related factors of ephemeral streams, including challenges.

2. Ecosystem goods and services of ephemeral streams

Ecosystem services are benefits offered by the environments in which we live, that are strongly tied to human well-being. Provisioning, regulating, cultural, and supporting ecosystem services are the four categories identified by many ecosystem assessors (Brown et al., 2007). Some of these ecosystem services are well-known, such as food, fiber, and fuel provisions, as well as cultural services such as recreation. Ecosystems also provide services that are less widely understood (Turner et al., 2012)). Climate regulation, air and water purification, protection against flood, formation of soil, and nutrient cycling are among them. Table 1 shows end uses, ecosystem services, and functions of ephemeral streams, referring to the dry zone of Sri Lanka. It should be noted that ephemeral streams play a key role in cascade type irrigation systems in the dry zone of Sri Lanka, something that has been acknowledged and protected since ancient times (Bandara, 1985).

Table 1: End uses, ecosystem services and functions of ephemeral streams

End use, Ecosystem services and functions	**Description**	**Relevance to the dry zone, Sri Lanka**
Direct uses (by humans)		
Drinking water	Water from ephemerals is directly or indirectly used as a drinking water source	Not observed
Recreational activities and aesthetic information	Ephemeral streams are widely used for activities such as fishing, swimming, skin diving, water skiing, wind surfing boating, wading and mussel harvesting and for aesthetic pleasure.	Activities such as fishing, and swimming could be observed in rare occasions at reaches close to the perennial. The nature of ephemerals is visually appealing especially during flow season.
Firewood and timber	Collection and logging of trees and branches in the terrestrial region, to be used as fuelwood.	Can be observed on a small scale, and in some cases are illegal since many reaches are inside forest reserves. A dense population of commercially important timber plants such as Kumbuk was observed.
Medicinal Plants	Collection of riparian herbs could be observed in many ephemeral streams due to the species richness of the terrestrial region as a result of varying flow conditions.	Observed but not common enough to show quantifiable monetary value.
Water for agricultural purposes	In some countries floodwater farming could be observed where runoff from ephemerals is diverted	Ephemerals play a key role in water conveyance to

	to cultivation lands through systems of ditches or to perennial rivers/tanks and subsequently distributed to farmers.	reservoirs such as Minneriya tank.
Livestock grazing	Since water is limited in arid environments, cattle and wildlife tend to linger near water sources and feed on riparian vegetation.	Can be observed on a small scale.
Sand Extraction	Sand mining from ephemeral streams could be observed in many areas which causes erosion and loss of riparian land.	Small scale illegal sand mining was a possibility.
Indirect uses (physical and biological functions)		
Conveyance of water	Ephemeral streams are major contributors which direct water to perennials during flow season.	Ephemeral streams constitute a large part of water inflows to the irrigation reservoirs
Ground water recharge/replenishment of aquifers	Ephemeral channels, with their sandy and coarse-grained soils, provide a much more rapid infiltration of water.	Can be observed prominently and infiltration from ephemeral streams is an important source of ground water.
Flood control or direct runoff control	Floodplains create a connected system of floodwater transmission channels. Ephemeral streams help reduce the risks from overland flooding in urban areas and agricultural lands.	Can be observed, yet due to less urbanisation in most areas, not a critical factor.
Sediment regulation	In non-perennial streams, regulation of sediments occurs as a response to runoff generated within	Can be observed and probably play a major role of sedimentation of irrigation reservoirs

	a short duration mainly due to precipitation events.	
Water quality maintenance through nitrogen removal	Freshwater microbial communities perform processes such as nutrient cycling and thus support maintaining the quality of the runoff water through ephemerals.	Yes, similar to other lotic systems
Leaf litter processing	Leaf litter processing is an important source of energy for high secondary production and an efficient energy source in freshwater ecosystems.	Yes, similar to other lotic systems
Erosion control	During floods and periods of stream flow, the roots and stems of riparian trees and vegetation capture sediment, build up stream banks, and reduce erosion.	Yes, and related to sediment regulation

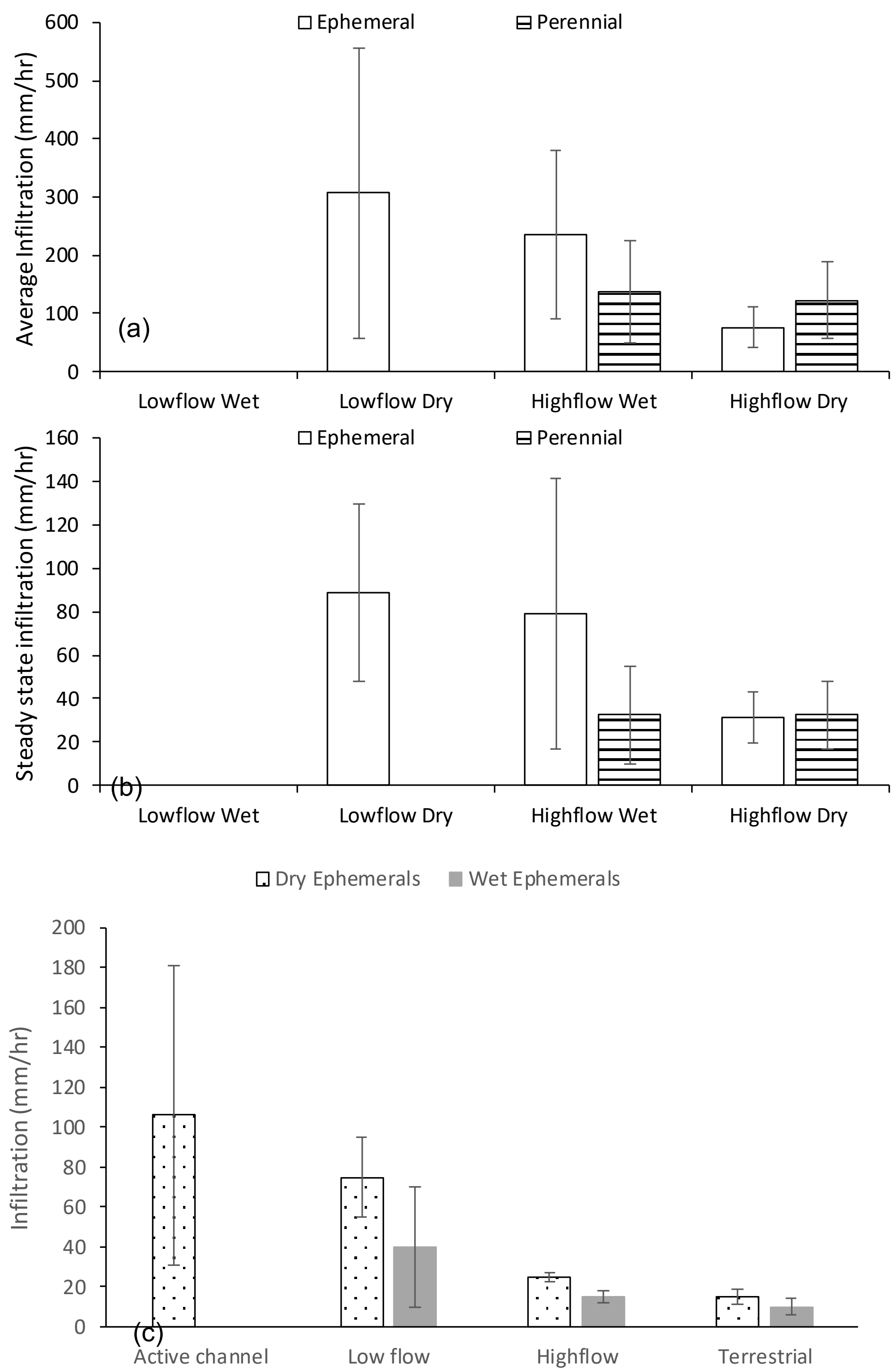

Figure 2: Variation of (a) average infiltration and (b) steady state infiltration rates of intermediate zone, and (c) steady state infiltration in dry zone

Figure 2 shows infiltration test results done in ephemeral streams in the intermediate and dry zones of Sri Lanka. It was clear the low flow areas as well as high flow areas in wet season of ephemeral streams showing high infiltration rates, and the rates are similar to man-made infiltration trenches. Figure 3 shows the unit discharges of comparable ephemeral and perennial streams of the intermediate zone, and it is obvious the unit discharges are low in ephemeral streams, thus more holding capacity, an important factor in flood control in downstream areas. It should be noted that the observations of infiltration and discharge were similar in dry zone and wet zone ephemerals. However, the statistical significance and power of results were not as strong as that of the intermediate zone, due to unavailability of many comparable perennials in the dry zone, and the fact that in the wet zone, not many ephemerals were found and also all streams were subject to regulation.

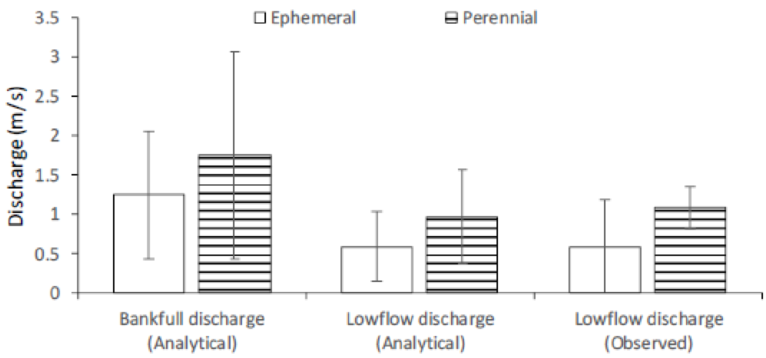

Figure 3: Specific discharges of ephemeral and perennial streams (intermediate zone)

3. Monetary value of ephemeral stream referring key hydrological functions

3.1 Regulation of runoff

The contribution of ephemeral streams in this regard was quantified as the difference between the runoff generation of a catchment with ephemerals (actual scenario) and without ephemerals using HEC-HMS 4.7 (Hydrologic 301 Engineering Centre-Hydrologic Modelling system, U.S. Army corps of Engineers). Part of the stream network flowing into the Minneriya reservoir was isolated for this task so that it was inclusive of ephemeral headwater streams and perennial streams that flow directly into the reservoir. The identification of the stream network was done by HEC-HMS using a digital elevation model (DEM) with terrain data and verified with field investigations. The sub-catchment and reach characteristics were calculated using the software itself which was then in turn used to assign parameters for the Mod-Clark transform method. The loss method was taken to be initial and constant, where the constant infiltration is defined to be the infiltration rate after initial loss into soil has been satisfied and can be equated to hydraulic conductivity (HEC-HMS User Manuals). These values were entered manually using field data collected for different laterally defined hydrologic zones of streams and terrestrial areas. Base flow was negligible as modelling was used for direct runoff generation since it was what needed for the comparison. The modelling was done for separate events of 3 months during the dry (October-December) and the wet (May-July) seasons. A meteorological model was created, along with a control specification and a time series model with a daily precipitation interval.

Figure 4 (a) and (b) shows the hydrographs and the average discharges vs. the apparent catchment area of wet season for the existing scenario (*i.e.*, presence of both stream types) and assuming the entire stream network is perennial. The reduction in discharge volume because of the presence of ephemeral streams was the area between the two hydrographs. The reduced water volumes were 241,920 and 138,240 m^3 for wet season and dry season, respectively (dry season data not shown); and in an annual cycle this corresponds to 85,161 m^3/km^2 of catchment. Also, it should be noted the peak wet season discharge with ephemerals was 10.7 m^3/s, whereas without those it was about 4.3% more (data not shown). Assuming that this additional volume causes flooding and that the water has to be pumped to the Minneriya reservoir using a pumping station of 0.55 m^3/s capacity, which would cost about Rs. 28.9 million/year (Rs. 1524/m^2 year), this was the monetary value of having ephemeral streams.

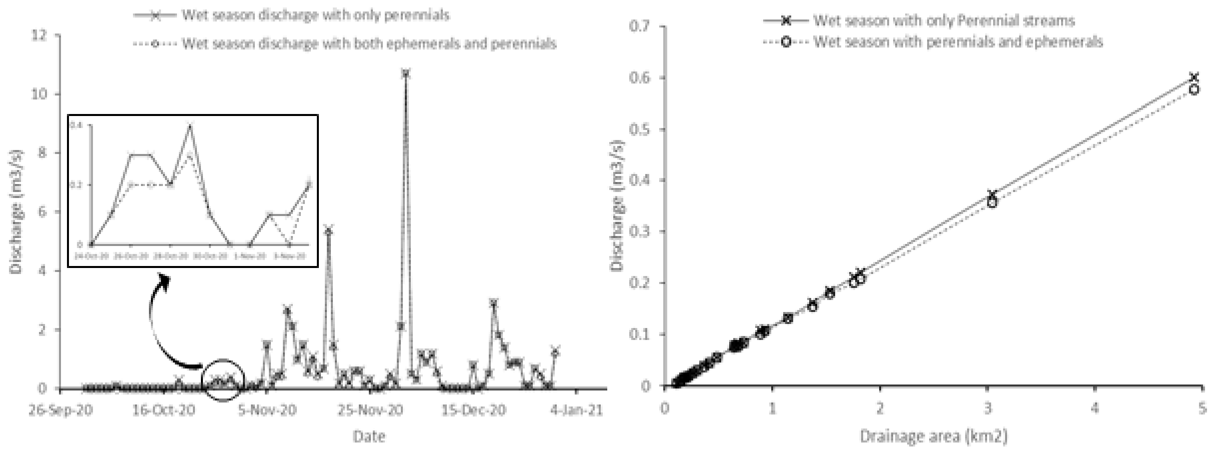

Figure 4 (a) Hydrographs (b) average discharge against apparent catchment area in wet season

3.2 Groundwater recharge

The groundwater recharge was derived based on the infiltration method. In this method the weighted averaged of infiltration over an area (catchment) was derived using the different infiltration rates of different lithological configurations. Then the infiltrated amount of each region was aggregated to get the total ground water recharge for two scenarios, with and without ephemerals (Lite et al., 2005).

The analysis of groundwater recharge with the effect of ephemeral streams and without them has indicated as 1.16×10^7 m^3/year and 1.18×10^5 m^3/year, respectively. Therefore, the presence of ephemeral streams has resulted in additional groundwater recharging around 1.15×10^7 m^3/year. Assuming that this water would be used for potable consumptions, the monetary value of groundwater recharge was calculated using the water bill calculation method listed in the National Water Supply and Drainage Board of Sri Lanka. According to the National Water Supply and Drainage Board considering the average water consumption of a family of four, the price of water is Rs. 0.02/L. Consequently, the monetary value of groundwater recharge has been valued to be Rs. 12,127 /m^2/year; this is the monetary benefit of having an ephemeral stream network.

3.3 Sediment transport regulation

Sediment transport is a key function of streams and rivers. Streams are the conduits of sediment that come from the catchment and help maintain a delicate balancing between different components (Amaiz et al., 2011). The sediment mobilization, be it bedload or suspended load, depends on 3-D physical characteristics of a reach, friction from the wetted perimeter, channel slope, and so forth. Stabilization of bed and banks is one of the main regulations that can happen to an ephemeral stream. This is done mainly to stop lateral channel migration (which anyway is a natural process) and to reclaim the land by straightening the channel. Channel straightening was considered in our evaluation relative to a natural stream. To be specific it was assumed the channel is concrete lined and regulated to be with a rectangular cross section, with the channel width being two times the depth of the channel. A width to depth ratio of 2 to 1 corresponds to the most efficient channel with respect to maximum discharge and is one of the preferred design options for small drainages. The probability distribution of flow determines the sediment transport in streams, and is often represented by a dominant flow, such as the high flow. It should be noted in the ephemerals investigated, the high flow levels and bankfull levels were very close, such that the corresponding wetted areas did not have more than 10% difference. The study channels in total had 50-70 days of high flow situations observed during the past two years. Thus, the period of high flow is considered as 60 days, which was the median duration.

The suspended load was taken proportional to the average velocity of the channel, and the average velocity of a cross section was obtained by the Mannings equation (equation 1). V is the velocity of the stream (m^3/s), n is the Manning's roughness co-efficient, R is the hydraulic radius of the cross-section considered (m), and S is the Slope of the reach portion considered. Bed load transport was determined via Shield's bedload equation (equation 2). Here, q_b is the discharge per unit channel width (m^3/s), q is the water discharge per unit channel width (m^3/s), d is the sediment particle diameter, ρ_s is the sediment density in kg/m^3, ρ is the water density in kg/m^3 and τ_0 (equation 3) and τ_c (equation 4) are bed and critical shear stress in Nm^{-2} respectively. The bed material on weight basis 90% sand, therefore only sand bed transport was considered. Sediment density was taken as 2650 kg/m^3. Suspended load concentration was determined with the aid of a calibration curve derived for total solids under suspension and the velocity of the study area streams, since suspended load is proportional to the velocity.

$$V = \frac{1}{n} R^{\frac{2}{3}} \sqrt{S} \quad .... (1)$$

$$\frac{q_b}{q} = \frac{10\, S_0\, \rho^2}{\rho_S} \frac{\tau_0 - \tau_c}{(\rho_S - \rho)^2\, gd} \quad .... (2)$$

$$\tau_c = 0.056\, (\rho_s - \rho) gd \quad .... (3)$$

$$\tau_0 = \rho g R S_0 \quad .... (4)$$

During the dry season, flow conditions would not trigger quantifiable bedload movement even in concrete lined scenarios, since the tractive force does not exceed the critical tractive force (data not shown). Therefore, sediment load during high flow season was evaluated in the realization of the monetary value. High flows of unregulated ephemerals on average hold 80 mg/L total sediments in its water column, and the regulated stream will have 166 mg/L, which is 51.8% more. During the high flow a representative ephemeral reach would mobilize 1.64 m^3/s, which is 50.6 % less than a reach that is subject to concrete lining. Therefore, within the high flow period of 20 days, 2.8×10^6 m^3 of sediment will get mobilized downstream, ultimately ending in the Minneriya reservoir. Considering the discharges of 1.64 and 3.32 m^3/s in natural and regulated reaches, each high flow day would supply a suspended sediment load of

131,200 and 551,120 mg/s respectively. Consequently, the sediment load regulated by the ephemerals per year was estimated to be 1643 m^3 considering the difference between the regulated and natural cases. The bed load discharge by the ephemerals per unit channel width per year was estimated to be 9313 m^3 by assessing the regulated and natural cases. Thus, total sediment load (suspended and bed loads) regulated by the ephemeral per year was obtained as 10,956 m^3.

To economically evaluate sediment regulation, costs associated with sediment dredging could be considered. The direct cost of dredging is about Rs. 404/m^3. Hence, the monetary value of sediment regulation of ephemerals in the study area was valued as Rs. 4.43 million /year (Rs. 233/m^2 year).

3.4 Total value of hydrological functions

Pertaining to the study area considered in the research the ecosystem services runoff regulation, groundwater recharge and sediment regulation were observed to be most prominent. The total costs associated with these ecosystems services if no ephemerals were present is 13,884 Rs/m^2 of the catchment or 41.65 million Rs/km of ephemeral stream.

4. Legal aspects related to ephemeral streams and their protection

Figure 5 shows key laws related to streams and rivers. The oldest of all, the Roman law (507 BC to 27 AD), actually did not recognise ephemeral streams as a public property in contrast to its perennial counterpart. However, this changed to a certain extent after about 200 years. In France (similar situations in many European countries) until 1910 (from 11th century) only navigable and floatable rivers were considered public, excluding ephemeral streams from the protection that their perennial counterpart received. This was the case until 1992, where all waters, surface, or ground irrespective of its permanency was given legal protection and is the case in many European countries.

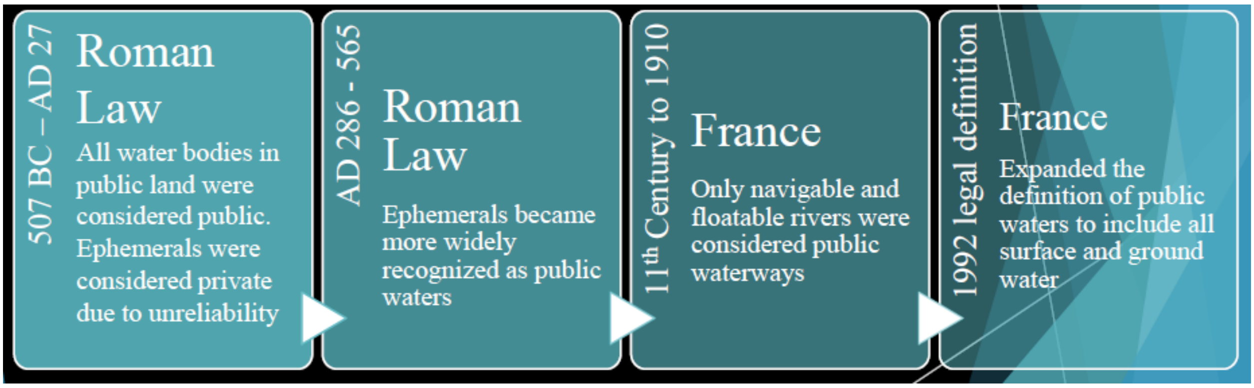

Figure 5: Progression of rules and regulations

Some of the Sri Lankan legislative protections that may cover ephemeral streams are summarised in Table 2. It should be noted only two rules have directly mentioned ephemeral streams. The Crown ordinance (1949) used the word intermittent streams, which in a practical sense are the same as ephemerals, and included them in the public inventory list, unless the entire course is on a piece of private land. Perhaps, this is one of the few rules in Sri Lanka that can be used to protect ephemeral streams. However, the Crown ordinance also deals with management of the streams mainly for flood conveyance. Many flood control methods such as vegetation removal are against the natural processes in a stream and would directly impact the ecosystem services (Costanza et al., 1997). The Agrarian Development act (2000 and amended in 2011) also mentions intermittent streams. But this act solely deals with maximising the yield of water resources for agriculture purposes, perhaps, this too would compromise the ecosystem services of ephemeral streams.

Table 2: Laws and ordinances that may cover ephemeral streams in Sri Lanka

Law/ordinance	Description
Forest Ordinance (1907 amended 1979):	Deals with sustainable forests and the felling and transport of timber. Here, river definition is broad, and does not specially mention ephemeral/intermittent, and states should not obstruct rivers
Crown land Ordinance (1949)	Deals with management of lands, reservoirs, streams (section IX, Regulation and control of the use of the water of lakes and

	public streams; any stream, whether perennial or intermittent). A stream is private if the entire course is in private land
Irrigation Ordinance (1946)	Deals with protection of irrigation works and conservation of water (see: PART VI "The prevention of any encroachment upon any such ela, channel")
Mahaweli Authority Act (1979, amended 1993)	Covers land and water resources of areas under the Act
National Environmental Act 1980	Broad and also with deals protection of water bodies from pollution
Flora and fauna protection Ordinance (1938/38 amended 1970)	As the life cycle of some flora and fauna is related to ephemerals, ephemerals may have an indirect protection
Agrarian development Act (2000 amended in 2011)	Maximum utilization of lands for agriculture purposes.

There are challenges in providing legislative protection to ephemeral streams. The first challenge is the fact that ephemerals are without water for a considerable period of time (Datry, 2012). Most legislation focuses on water quality and suitability for public health and biota, and due to the fact that ephemerals are without water at certain periods, they by default get excluded based on the principle of maintaining water quality and biota (Magand et al., 2020). The worst is not that, but the fact that perennial streams are not only valued (as should be the case), but at a cost of regulating ephemeral streams that often leads to loss of natural characteristics. The second challenge is the difficulty of predicting when water and aquatic life is present in ephemerals. Therefore, evaluating water quality and aquatic life is a difficulty (Perman et al., 2003). The third challenge is an inherent principle in rules, that is separation of private and public properties. Under most governance systems, the legal definition of a waterway includes some way to distinguish a public waterway from the adjacent private land. Documenting the legal boundaries between public waterways and adjacent land can be complex (extended long-term monitoring is needed) for ephemerals, due to the dry phases.

5. Concluding remarks

In general ecosystems are not represented or used in quantifiable economic indicators, and they are often disregarded in decision making. Most ecosystems services are regarded as free and in addition certain ecosystems are not deemed important at least on a relative basis; ephemeral stream ecosystems are one such example. One reason is difficulties in expressing the value in monetary terms. The other reason is the limited knowledge of ecosystem services provided by ephemeral streams, and this is obviously the case in Sri Lanka, and an indication where future studies should focus. Perhaps due to this reason, the legislative protection of ephemeral streams is rather indirect and/or coverage is due to existing in a protected area (*e.g.*, forest reserve). This is why we hardly see ephemerals in urban areas, and this could be one of the reasons for flood hazards in urban areas. Considering primary and secondary data and findings, it is time that these streams should be given solid legal protection followed by dedicated management.

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Section D

Coping Drought Stress: Plant Adaptive Responses and Approaches to Alleviate the Adverse Effects

"Drought has been established as the single greatest culprit of agricultural production loss". (FAO)

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Introduction

Water is one of the vital resources that determines the global distribution of terrestrial plants. Rain-fed agricultural systems sustain about 60% of global food production and are vulnerable to erratic rainfall and periodic droughts. A drought generally refers to as an extended period of unusually low precipitation that produces a shortage of water for people, animals and plants. Agricultural drought occurs when soil moisture availability to plants drops to a level that it adversely affects the crop yield and consequently agricultural profitability (Falkenmark, 2013). Drought or water stress is a common environmental constrain often faced by plants in their life cycles. Water stress impairs normal plant functionality and causes morphological, physiological, and biochemical changes to compensate for water limitations. Water deficit-mediated plant growth retardation and crop yield failures lead to disrupted agriculture and drought has been established as the single greatest culprit of agricultural production loss in many parts of the world. According to the recent data, droughts affect around 23 million hectares of rainfed rice, reducing global production by 18 million tons per year and global yields of wheat and maize by 21% and 40% respectively (Daryanto et al., 2016). Climate change accelerates the problem of water stress highlighting the emerging challenge for crop production in the future.

As sessile organisms, plants are naturally equipped with efficient mechanisms to safeguard themselves against the detrimental effects of environmental stresses including drought stress. A plethora of sequential events occur initiating from sensing water deficit conditions in the soil, transmitting the signal from the roots to the leaves and initiation of adoptive responses at transcriptional, translational, and post-translational levels (Griffiths and Parry, 2002). Plants' response to drought significantly depends on the species, extent and duration of water stress. Deep understanding of the mechanisms of responses by plants to water stress is pivotal to predict plant functionality and explore the holistic practices to mitigate the effects of water stress and ensure food safety.

Effect of water stress on plant life

Plants are affected differently under mild, moderate, or severe water deficit. The impacts of water stress on plants are highly variable depending on length of stress imposition, stage of plant development, species, and efficiency of stress tolerance mechanisms. Morphological, physiological, biochemical, and molecular traits of the plants are affected under water stress conditions. The most conspicuous morphological characteristic observed in water deficit conditions is the retardation of plant growth often noted by reduced plant height, smaller leaf sizes, reduced leaf numbers, reduced yield/ biomass, and high root to shoot ratio (Jaleel et al., 2009).

Photosynthesis is one of the main processes affected by water stress. Other conspicuous physiological changes manifested by plants under water stress are reduction in leaf water potential and transpiration rate, stomatal closure, declined stomatal conductance and change in cell wall integrity.

Several biochemical changes take place in the plants depending on the severity of the water deficit stress. Decrease in chlorophyll content, biosynthesis and accumulation of abscisic (ABA) acid, proline and polyamines, increased cellular production of reactive oxygen species and nitric oxide and modification in nitrogen metabolism are some of the changes among others (Sah et al., 2016)

Coping with water stress

Plant responses to water deficiency are complex involving a stress avoidance and tolerance strategies that vary with genotype and the severity of the stress. Plants respond to water stress and adapt to water shortage by modulating their drought response mechanisms at the molecular, biochemical, physiological and anatomical levels. Mechanisms associated with water-stress tolerance of plants have been extensively studied. Morphological and structural changes, changes in phytohormones, expression of drought-resistant genes and synthesis of osmotic regulatory substances are a few examples. Early responses help plants immediate survival and complex combination of regulatory strategies helps to improve plant performance over periods under stress (Griffiths and Parry, 2002; Bandurska, 2022).

Sensing the water stress signal and transmission of the signal

Root cells are the first to sense that plants are under water stress and this signal is transmitted to other organs and tissues of plants. Membrane receptor proteins of root cells percept the water stress signal (hydraulic signal) as decrease in turgor pressure, caused by cell water loss. The osmotic stress signal is then converted into an intracellular chemical signal and triggers the production of second messengers to transduce the signal in different organs and cells in plants (Kuromori et al., 2022).

The well-described second messengers in signal transduction are Ca^{2+}, hydrolytic products of phospholipids such as inositol-3-phosphate (IP_3) and phosphatidic acid, nitric oxide (NO), reactive oxygen species (ROS), and variety of protein kinases especially Mitogen-activated protein kinases (MAPKs). Plant hormones, for instance indole -3-acetic acid (IAA), ABA, and ethylene act as chemical signals to transmit stress signal (Wimalasekera et al., 2011a; Gupta et al., 2020; Kuromori et al., 2022). Signal transduction events including signalling cross talks result in activating a plethora of drought stress response genes including both functional genes and regulatory genes.

Plant responses

Sensing and signalling of water stress conditions lead to trigger mechanisms to reduce water loss from plants, reduce consumption of resources, and adjust the growth to adapt to the condition.

Water saving - Stomatal regulation

About 90% of water loss from plants occur through opened stomata *via* transpiration. Stomatal regulation has a vital impact on the plant's water status and ability to withstand water deficit conditions. Reducing water loss through transpiration by stomatal closure is the first reaction to water stress in most plants. Stomata can be closed in response to declined leaf water status, low-humid atmosphere, and low soil moisture content. Decline in the number of stomata is another strategy to response to prolonged water stress (Hetherington and Woodward, 2003; Yang et al., 2021). ABA is a crucial hormone that regulate stomatal movement. Redistribution of ABA through transpiration stream and higher rate of ABA synthesis during leaf cell dehydration are important for stomatal closure. Besides ABA, signalling molecules, NO and ROS and pH gradients are also important regulators of stomatal closure (Wimalasekera et al., 2011b; Yang et al., 2021).

Water retention - Osmotic adjustment

Osmotic adjustment or net increase in solute content of leaf cells develops slowly in response to tissue dehydration. Accumulation of a variety of common solutes such as sugars, proline, glycine betaine, amino acids, and inorganic ions helps to reduce the osmotic potential of the cell to sustain cell turgor and maintain water balance. Proline is the most common compatible osmolyte in plants and plays an important role in increasing the adaptation of plants to drought. Compatible solutes protect proteins and membranes from the injury caused by high concentrations of inorganic ions and oxidative damage under water deficit (Blum, 2017). The importance of proline metabolism and turnover is well studied for the role of buffering cellular redox status in water stress resistance.

Protection from oxidative damage

Water stress results in increased oxidative stress and cellular damages due to increased production of ROS. As a defence mechanism against oxidative damage, several antioxidant enzymes, non-enzymatic antioxidants, and osmotic substances are synthesized in excess which scavenge the ROS and protect cells (Kar, 2011; Wimalasekera et al., 2011b). Peroxidases play a key role in enhanced lignin production and contribute to increased rigidity of cells.

Enhanced signalling function – An important gaseous molecule nitric oxide (NO)

Nitric oxide is considered as a key signalling molecule mediating its action in concerted with other signalling molecules. Biosynthesis of NO is enhanced in water stressed tissues and plays a key signalling role in ABA-induced stomatal closure and it also enables the scavenging of ROS by induction of antioxidant defence mechanisms. Further, NO induces the expression of stress-related genes in response to drought stress (Wimalasekera et al., 2011a; Lau et al., 2021).

Reduced food production - Limits photosynthesis

Closure of stomata in response to water stress leads to limitation in intracellular CO_2 and reduced photosynthetic metabolism resulting a reduction in leaf photosynthetic capacity. ROS scavengers, expression of several drought stress tolerance genes that code for different metabolite signals are used to regulate chloroplast functions (Chavers et al., 2009; Zargar et al., 2017). These cellular functions are finally involved in protecting the photosynthetic reactions from the injury during water stress.

Alterations in growth

Plants under water stress can adapt to the condition through phenotypic plasticity. Slow growth rate during water limited growth conditions controls several energy consuming cellular processes (Falkenmark, 2013). Reduced leaf area that results in less transpiration of water is an early adaptive response to water deficit. Deposition of wax layers on leaf surfaces is another adaptation to control rate of water loss. Stimulation of leaf abscission is a long-term change that improves the tolerance to water deficit (Falkenmark, 2013; Zargar et al., 2017). Enhanced root growth into moist soil is another important growth response to enhance water absorption.

Gene and epigenetic regulation

Among the multiple mechanisms of water stress responses, gene regulation is one of the key mechanisms. A large number of drought responsive transcription factor (TF) families are expressed depending on the responsive mechanisms in action. For example, TFs involved in signal transduction cascades, many genes of ABA-dependent pathway, ABA-independent pathways, ethylene pathway, WRKY and NAC (Eulgem et al., 2000; Nakashima et al., 2012) are involved in the defence responses. Plants impose effective epigenetic regulations, including DNA methylation, histone modifications, chromatin remodelling, and small RNA to respond water stress.

Approaches to ameliorate the adverse effects

With the advent of the advanced knowledge and modern technologies in molecular genetics, transcriptomics, metabolomics and systems biology, scientists have made remarkable progress in elucidating physiological, biochemical, genetic, and signalling processes in plant water stress responses. The knowledge has been successfully utilized to screen the plants in water deficit, develop biosensors, and breeding for drought tolerance (Griffiths and Parry, 2002; Bandurska, 2022). However, due to the complex nature of the water stress tolerance, approaches of improving water stress tolerance particularly in crop species are not completely known. The description below outlines a few approaches to improve plants' ability to improve water stress tolerance and enhance plant growth and productivity.

Screening plants

Identification and validation of traits for tolerance to water deficit is an important phenomenon. Some physiological and biochemical parameters such as water potential, relative water content, stomatal conductance, photosynthetic rate, osmotic concentration stress related metabolites such as antioxidant enzyme activity and proline content are good indicators to screen plant responses to water stress. Morphological variables *e.g*., leaf area and yield are common stress indicators. Fluorescence imaging of chlorophyll a is one of the widely used methods to evaluate spatiotemporal leaf changes and monitor plant physiological status. To effectively screen and select water stress tolerance, it is important to identify several key indicators as biomarkers. Profiling the primary and secondary metabolites, amino acids, and polyamines as tolerance indicators and signal molecules is important (Hoyos-Villegas et al., 2017; Tiwari et al., 2023) Plant metabolite screening can also be done with image-based screening methods. Quantification of signalling molecule nitric oxide provides a clue on stress tolerance.

Inducing water stress tolerance

Foliar application of proline and glycinebetaine is a strategy to induce water stress tolerance in some of the plants (Ashraf and Foolad, 2007). Studies have proven that foliar application of trace elements such as Zn, Mn, Se, Mo and B can increase the growth and yield of some crops under water stress. These elements are capable of decreasing the production of ROS and inducing antioxidant enzyme activities. Application of silicon to plants is also shown to be beneficial to improve growth and yield of plants under drought stress conditions (Wang et al., 2021). Entry of silicon into plants alleviates the damaging effects of oxidative stress by increasing the activity of antioxidant enzymes. Further, priming of seeds with NO donors and polyamines enhances their germination ability and seedling establishment under water deficient conditions (Wimalasekera et al., 2011)

Biosensors

Development of biosensors for early detection of plant cells under water stress is a promising technique. ABA is a drought stress signalling molecule and detecting its levels by biosensors is a novel concept. Förster resonance energy transfer (FRET)-based biosensors are capable of monitoring ABA. The emission output of the sensor correlates with the ABA content present in a plant, which indirectly predict the stress response (Jones et al., 2014; Rowe et al., 2023).

Breeding for drought resistance

Conventional breeding, molecular marker-assisted breeding, genetic engineering in combination with breeding are employed to produce drought tolerant crops. The ultimate target of any crop breeding program for improving drought tolerance is to obtain high yield potential under drought stress. Identification of important traits for drought resistance is an important process in plant breeding. Root system architecture is the most promising trait used in breeding.

Development of marker genes is the initiative for selection criteria used in crop breeding. Marker assisted selection has the advantage over conventional breeding by facilitating the improvement of traits that cannot be improved easily by conventional methods. Identification of drought-resistance quantitative trait loci (QTL) is essential to provide valuable targets in crop breeding. Drought related traits are under the influence of several genetic loci and controlled by a large number of QTLs. QTLs for yield under drought, morphophysiological traits, root characteristics, leaf ABA, relative water content have been identified in some crop species (Dixit et al., 2014; Wimalasekera, 2016; Luo et al., 2019).

Transgenic methods are used to improve drought resistance and an array of pathways have been engineered. ABA receptor proteins, ABA biosynthesis enzymes, and ABA inducible transcription factors have been engineered to enhance the drought responses (Liang, 2016). In addition to this pathway, a variety of genes coding for signal perception, signal transduction and downstream responses have been manipulated to improve drought tolerance.

Future perspectives

Although noteworthy progress has been made in elucidating the genetic mechanisms underlying drought tolerance, a considerable number of challenges remain. Advanced knowledge including the identification of new key genes and QTL related to drought stress responsive mechanisms, genome editing, transgenic approaches, next-generation breeding techniques and other novel technologies will facilitate the development of plants with improved stress tolerance while maintaining productivity. Hence, it is believed that recent advances made towards improving drought stress in crop plants by combining a variety of traditional and modern biotechnological approaches will bring new insight into sustainable crop production under drought conditions.

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Section E1

Astronomy and Space Science in Sri Lanka: Reinventing the Future from the Past & Present

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Introduction

The statement "Astronomy is the mother of all sciences" is a historical perspective that highlights the significant role astronomy has played in the development of scientific knowledge throughout human history. While it's a somewhat poetic or metaphorical way to express the idea, it carries some truth. Astronomy is often considered one of the oldest sciences, with roots that go back thousands of years to early civilizations such as the Babylonians, Egyptians, and Greeks. These ancient cultures used astronomy to track celestial objects and develop calendars, which were essential for agriculture, navigation, and understanding the passage of time.

While it is essential to recognize astronomy's historical importance, it's also important to acknowledge that modern science encompasses many diverse disciplines, each with its own unique contributions and significance. While astronomy played a foundational role in the development of the scientific method and mathematical modeling, other fields such as Physics, Chemistry, and Biology have evolved independently and made substantial contributions to our understanding of the natural world. In the recent past, Artificial Intelligence (AI), Data Science, Planetary Geology and Space Technology (Figure 1) have also been nourished by Astronomy (Baron, D., 2019; Zhang, Y. and Zhao, Y., 2015). Therefore, Astronomy can be considered an early cornerstone of science; it is not the only parent, and all sciences have their own distinct contributions to human knowledge.

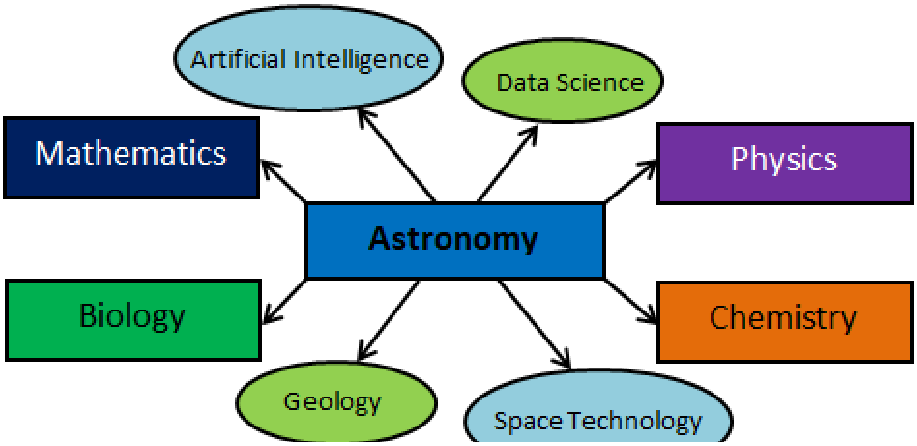

Figure 1: Evolution of natural science and technology from the oldest science; Astronomy

Astronomy and space science have been gaining prominence worldwide as humanity continues to explore the cosmos and unlock its mysteries. While Sri Lanka might not be as well-known for its contributions in these fields compared to some other countries, there have been significant developments and efforts within the country's scientific community to advance astronomy and space science.

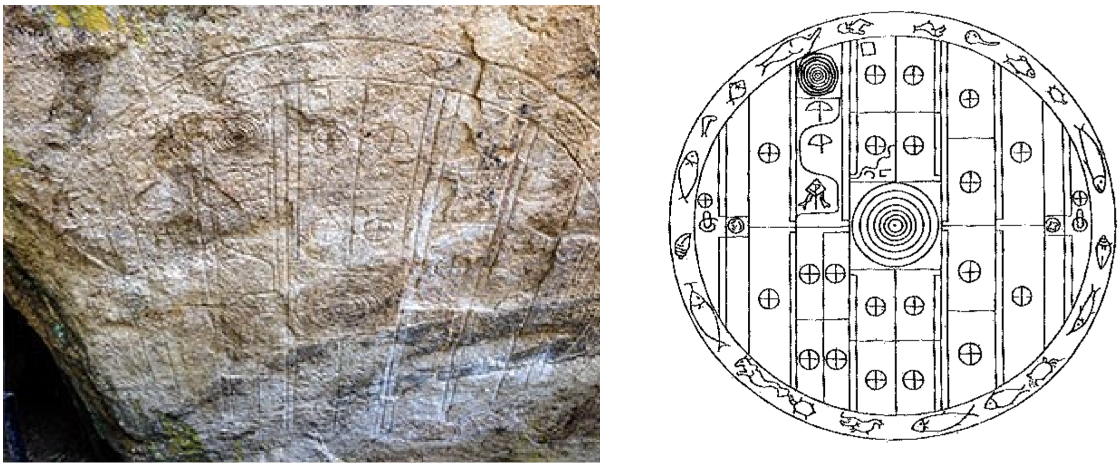

Figure 2. The Star Gate at Ranmasu Uyana, Anuradhapura. Left: reproduced symbols of Star Gate. Source: lakdiva.org.lk and Archaeological Survey of Ceylon, North-Central and Central Provinces. Annual Report, 1901 by H. C. P. Bell.

The historical evidence emphasizes the involvement of astronomy and space science in Sri Lanka. The Star Gate (Sakwala Chakraya) at Ranmasu Uyana, (Figure 2) Anuradhapura is one of the best places to witness that Sri Lankan involvement in astronomy. Our sky observation goes beyond the last century with the 28 cm Molesworth reflector telescopes at the university of Colombo. The telescope was originally owned by Major P. B. Molesworth, who was born in Colombo, Sri Lanka in 1897 and made his astronomical observations in Trincomalee (Jayaratne K. P. S. C. Jayaratne & Dharmaratne G. H. P., 1997). A crater about 16 km in diameter on the southern hemisphere of Mars has been named after him. In our journey of astronomy and space science we have come across a few milestones which are turning points in the field. The Astronomical Society (formerly Mathematical and Astronomical Society) established in 1959 is one of the oldest societies in the Colombo University (Jayaratne K. P. S. C. & Dharmaratne G. H. P., 1997). The establishment of the Sri Lanka Planetarium in 1965 was one of the major milestones in the popularization of astronomy in Sri Lanka for almost 40 years. In 1996, the Arthur C. Clarke Institute for Modern Technologies (ACCIMT) hosted the UN/ESA workshop on Basic Space Science which resulted the commissioning of the GOTO 45 cm Cassegrain telescope donated by the Japanese Government (Kitamura, M. *et al*, 2009). This effected the transformation of existing observational astronomy to research-based quantitative astronomy. Although the pace of the development is slow, it is consistent with well-set objectives. The article further discussed the standard of research carried out in astronomy and space science with the collaboration of global entities. Furthermore, the future of astronomy and space science has to be reformed with the alignments of financial and social strengths and weaknesses of the country.

Research in Astronomy and Astrophysics

Astronomy and astrophysics research in Sri Lanka has been steadily growing over the years, although it may not be as prominent as in some other countries with larger space and research budgets. Sri Lanka has made efforts to establish and promote astronomy and astrophysics research through academic institutions, observatories, and collaborations with international organizations. Some of the key areas of astronomy and astrophysics research in Sri Lanka are up-to-date with the global standards.

Asteroseismology

Asteroseismology allows an unprecedented way to determine the internal structure of stars by studying their oscillations frequencies (Aerts, C. *et al*., 2010). The light curve of a pulsating star shown in Figure 3 reveals the oscillation frequencies. This method can be applied to all types of pulsating stars which have radial and non-radial pulsations. In radial pulsations, star expands and contracts radially while in non-radial, for example, the northern hemisphere contacts while the southern hemisphere expands. The internal waves of a star are basically of two types. The pressure is the primary restoring force in a star perturbed from its equilibrium. The gas motion in these perturbations is vertical which is similar to the radiation pressure procedure by nuclear reaction. These waves are acoustic waves and known as pressure waves or p-modes. The gravity waves or g-modes are transverse and the primary restoring force is buoyancy, and gas motions are horizontal. g-modes are mostly located at the center of the star and hence are more sensitive to the conditions at the core of the star (Adassuriya J. 2022; Adassuriya J. *et al*., 2021) . Therefore, this is the only way of investigating the vastly unknown interior of stars and hence reconfirms the known Physics in thermodynamics, particle, nuclear, plasma etc. The light curve data necessary for asteroseismology is entirely provided by the Kepler mission and its successor, the Transiting Exoplanet Survey Satellite (TESS) mission. These mission data is freely available at Kepler Asteroseismic Science Operations Center (KASOC) and TESS Asteroseismic Science Operations Center (TASOC). Mainly, the data from these two missions and follow-up observations from small scale telescopes such as the 50 cm telescope at Mount Abu observatory, India, have been used to complete undergraduate and post graduate research in this field. At present, 6 undergraduate projects and one post graduate project have been completed in this field.

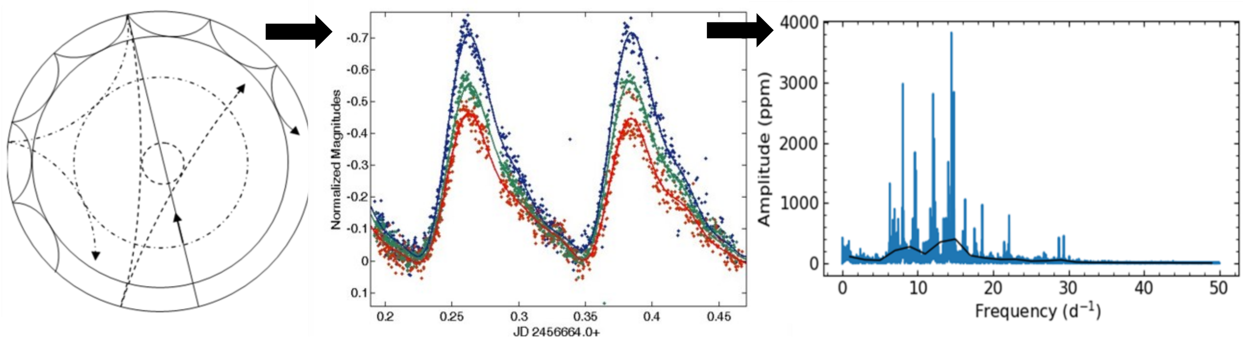

Figure 3: Left: Standing wave patterns within a star penetrating to different depths. Middle: B, V, R Light curves of a pulsating star, SZ Lyn. Right: A part of frequency spectrum of SZ Lyn. (Adassuriya, 2022; Adassuriya *et al*., 2021).

Extrasolar Planets

Exoplanetary Astronomy is the study of planetary systems around stars other than our sun. There are more than 5500 exoplanets that have been confirmed (NASA Exoplanet archive). Major advances in long range telescopes have allowed astronomers to identify thousands of exoplanets in recent decades, and the discovery of new exoplanets is a now a common occurrence. In 2019, we were able make the breakthrough in planet hunting, the finding of two exoplanets by Sri Lankan scientists (Herath, M. *et al*., 2019). The research team led by Mr. S. Gunasekera, Principal Research Scientist at ACCIMT, has used the data released from the Kepler spacecraft to find these new exoplanets. The method of detection is known as the transit method, where the variation in light from a star as an exoplanet passes in front of it is used to determine its existence and the properties. In one of the systems, they found two planets with orbital periods of 13 and 65 days with the sizes of 2.6 and 2.7 Earth-radii, respectively. The two planets have been determined to be what are called "Sub-Neptune" type exoplanets (planets that are most likely gaseous like Neptune, Figure 4). This is a good example of the fact that groundbreaking research can be carried out within Sri Lankan soil. Finding exoplanets is no longer a challenge but the atmospheric and magnetic field characteristics of the Earth-like planets are more demanding (Green J *et al*., 2021; Rodríguez-Mozos, J. M. and Moya, A., 2022; Bellotti, S. *et al*., 2023). Identifying this global trend in exoplanet research, we started working on exoplanet atmospheres using spectroscopic observations with the collaboration of Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) at National Astronomical Observatories, China. As a result of this collaboration, two undergraduate students from Sri Lanka have been selected to the International School for Regional Young Astronomers, Kunming, China in 2023.

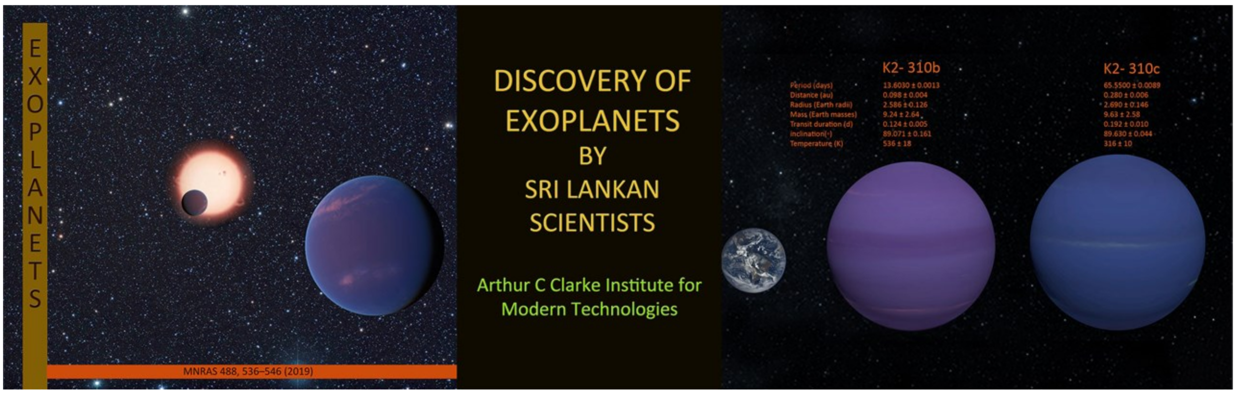

Figure 4: The names and properties of the two exoplanets discovered by Herath M., *et al*. 2019. The planets are animated images and not to scale. Image Credit: S. Gunasekera.

Introduce Radio Astronomy

Radio astronomy is a fascinating and technologically demanding field of science that plays a crucial role in our understanding of the universe. Achieving excellence in radio astronomy technology is useful in the development of radio frequency technology that transfers knowledge to the communication field. Overall, achieving excellence in radio astronomy technology requires a multidisciplinary approach, combining expertise in astronomy, physics, engineering, and computer science. It also requires a long-term commitment to research and development to stay at the forefront of this dynamic field. We took our first step in radio astronomy through the collaboration of the CALLISTO program (Benz A. O. *et al*., 2004) in 2011. As a result of this, a setup was established in Sri Lanka to observe solar radio bursts (J. Adassuriya *et al*., 2014). With this facility we were able to expand research in astronomy from the optical band to radio. The e-CALLISTO (Benz A. O. *et al*., 2009) observes the solar radio eruptions in 24 hours through a global network of more than 75 stations (Figure 5). The archived data is available at e-CALLISTO[1].

In 2011 we constructed a 6 m tall Log-periodic antenna (Figure 6) for the CALLISTO receiver. The antenna receives the radio signals of the solar flares and Coronal Mass Ejections (CME) within the range of 45 – 870 MHz in North-South plane polarization. In general, the solar radio bursts are circular polarized and therefore the 6 m Log-periodic antenna does not support observations of the entire signal. Due to this, we proposed a Long Wave Antenna (LWA) which has North-South and East-West observation components as shown in Figure 6. The project will be completed in 2025. At present five undergraduates benefit from the existing facility. Public excitement for these discoveries and opportunities have grown alongside with the inclination of more students in space science, thus opening new possibilities for inspiring a new generation of scientists and engineers.

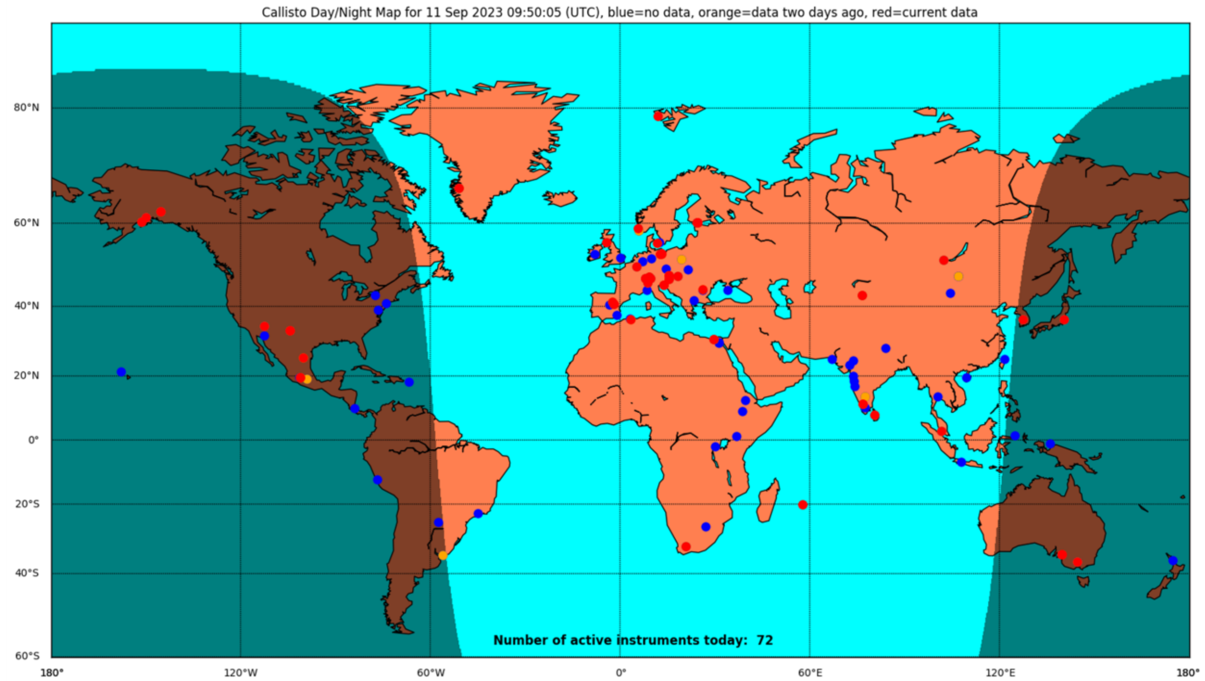

Figure 5: e-CALLISTO worldwide network. Source: https://www.e-callisto.org/

Figure 6: Left: 6 m tall Log-Periodic antenna of the existing CALLISTO receiver. Right: The construction of Long Wave antenna for the proposed polarization measurements of solar radio bursts.

Contribution in Artificial Intelligence (AI) and Data Science

AI and Data Science heavily depend on data. The accuracy of the models, predictions and classifications is proportionate to the amount of good quality data which is used to train a system. In such situation, Astronomy data plays a crucial role in AI and Data Science in various ways. Conversely, Astronomy and Space Science is the most wanted field of AI and Data Science, because of the vast amount of data produced by the missions and surveys. The amount of data cannot be analyzed by conventional techniques except AI and Data Science solutions. Astronomy data provides a valuable testing ground for AI and Data Science techniques due to its complexity, volume, and interdisciplinary nature (Schanche, N. *et al*., 2019; Gordo, J. B. *et al*., 2023; Scully, J. *et al*., 2021). The insights gained from applying these methods to astronomy data not only advance our understanding of the universe but also have broader applications in fields such as healthcare, finance, and environmental science. Most importantly the classification algorithms and techniques such as Random Forest, Artificial Neural Network, Support Vector Machine etc. (Schanche, N. et *al*., 2019) are commonly applied in all other fields. Therefore, the applications of these techniques in Astronomy provide the skills and knowledge to become a data scientist. The Astronomy and Space Science Unit, Department of Physics, University of Colombo has identified the true potential of the AI and Data Science field in order to fulfill the human resource requirements in highly demanding fields in finance, health, trade etc. As a result of that, the department will plan to introduce a special degree course in Astronomy and Data Science. The training of students in AI and Data Science has been started by offering data driven projects. In 2018, the first undergraduate project was completed applying machine learning techniques to classify variable stars. This automated classification is built to identify 6 types of variable star classes, Beta Cephei, Delta Scuti, Gamma Doradus, Red Giants, RR Lyrae, and RV Tarui, using Kepler data (J. Adassuriya, *et al*, 2021). Another application was developed to identify binary and pulsation stars using Kepler data and achieved an accuracy of 93%. Sri Lanka has a few universities and research institutions that focus on astronomy and astrophysics. The number of astronomy and space science related research projects carried out by each university is shown in Figure 7. It is clear that the demand of research interest has significantly increased in undergraduate level in past two decades (Figure 8). Nevertheless, the production of post graduate degrees needs to be addressed in the future.

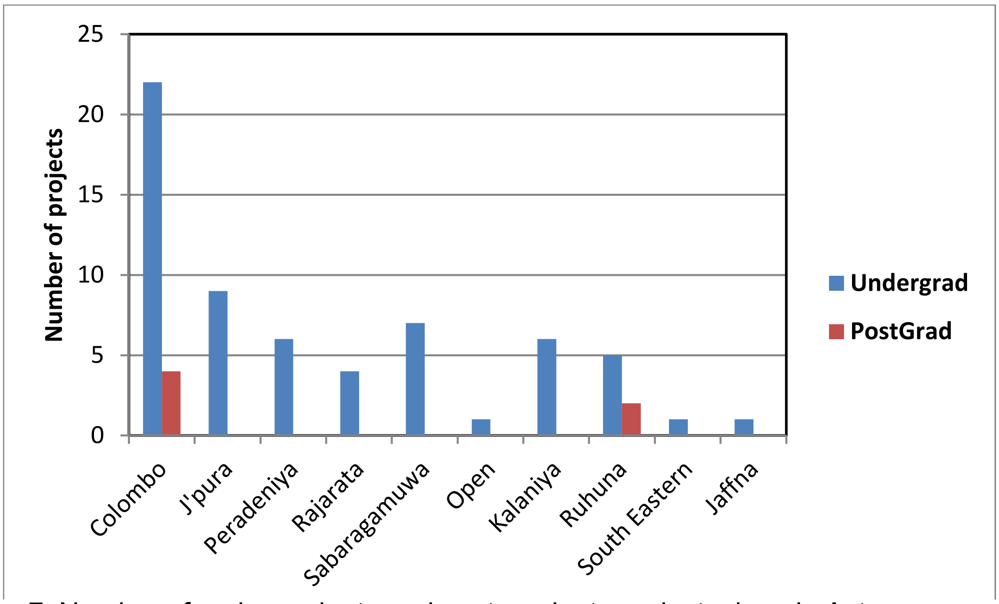

Figure 7: Number of undergraduate and post graduate projects done in Astronomy and Space Science in local universities. Most of the projects were collaborated with the Astronomy Division of the Arthur C Clarke Institute for Modern Technologies.

Researchers in these institutions are involved in studying various aspects of the cosmos, including observational astronomy, stellar evolution, solar astronomy, and radio astronomy. They contribute to the global scientific community by publishing research papers and participating in international collaborations.

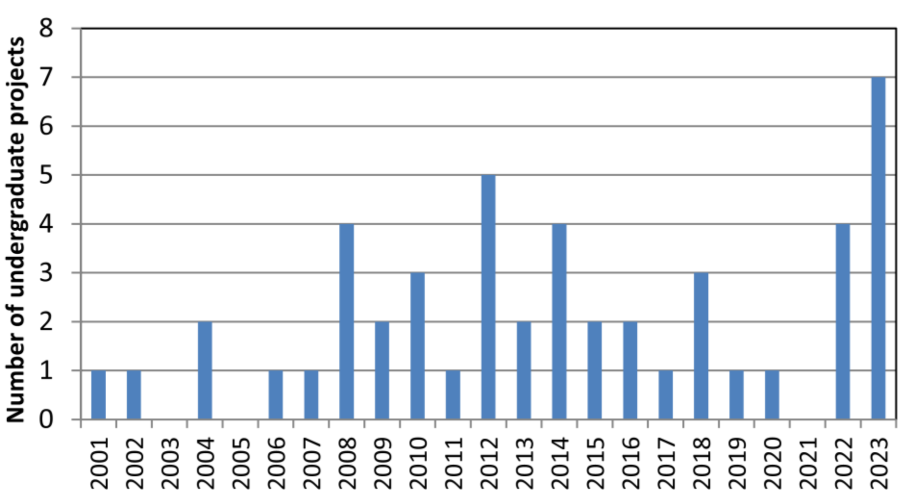

Figure 8: The number of astronomy related projects done with the collaboration of the Astronomy Division at Arthur C Clarke Institute. Source: Astronomy division, Arthur C Clarke Institute and Astronomy and Space Science Unit, University of Colombo.

Research and Development in Space Technology

The Arthur C. Clarke Institute for Modern Technologies (ACCIMT), Moratuwa is the only institute working in the unique field of Space Technologies/Space Engineering in Sri Lanka. The development of a satellite in the Nano satellite family was justified in 2016, as part of gaining national pride. The objectives of the project are accommodating payloads having space research capabilities, and most importantly, developing the local engineers space technology related capacity through practical hands on experience, and thereby transferring knowledge to the next level of engineers in the country. Sri Lanka joined in the third such program (Birds 3) by two of the research engineers participating in the program at Kyutech during 2017, after signing the Corporate Research Agreement for a value of JPY 15 million, which covers costs for the mission plan, preliminary design review, critical design review with engineering model hardware, satellite flight model, testing facility, launching service, and deploying (ACCIMT, 2019; ACCIMT, 2021). The project was a great success as the first Nano-satellite named “Raavana 1” (Figure 9) was launched on 17th June 2019. The ground station was also developed by Sri Lankan engineers at the ACCIMT. Space technology is not available at any cost. Therefore, we have to pledge our own space programme and this was identified as a good initiative.

Figure 9: Left: The 1U Nanosatellite, Middle: Receiving antenna at the ground station, Right: First image of Sri Lanka taken from Space by Raavana 1 satellite. Image Credit: Annual Report (2019), Arthur C Clarke Institute.

SEDS Sri Lanka – a new approach for Space Technology

Students for the Exploration and Development of Space (SEDS) is a non-profit organization that empowers young people to participate and make an impact in space exploration. SEDS helps students develop their technical and leadership skills by providing opportunities to manage and participate in national projects as well as to attend conferences, publish their work, and develop their professional network, in order to help students become more effective in their present and future careers in industry, academia, government, and education. SEDS Sri Lanka consists of 8 main divisions to address all aspects in Space Science and Technology (Wijesinghe T., 2022). The initiation of SEDS in 2018 is significant milestone in Space Science in Sri Lanka. Most importantly this is a student centered organization where all the operations are being done by the students. Therefore, it would be a great opportunity for them to be leaders to drive the country to space age. Serendib 1.0 is one of the great achievements of the SEDS Sri Lanka**.** It was a high altitude balloon that reached a maximum altitude of more than 33,000 meters, which is about two times the flying altitude of regular passenger aircraft. The major highlight of this project is the minimum involvement of the academics and senior researchers. It shows the true potential of the commitment, collaboration, and teamwork of the students with minimum supervision which I thought worth mentioning in this forum.

Public Outreach and Education

Public awareness in space science research is crucial for several reasons. Space science research captures the imagination of people, especially children and young adults. It inspires them to pursue careers in science, technology, engineering, and mathematics (STEM). When the public is aware of space research, it can serve as a powerful educational tool, encouraging lifelong learning. Space science research often involves complex concepts and cutting-edge technologies. By promoting public awareness, we can enhance scientific literacy. When people understand the basics of space science, they can make more informed decisions about scientific issues and policies. Space research requires significant funding and resources. Public awareness can lead to increased support for space agencies and research programs. When the public understands the value of space exploration, they are more likely to support funding initiatives and space missions.

Continuous efforts are being made to engage the public in astronomy and space science in Sri Lanka. The astronomical societies, university entities, public observatories, and planetariums organize events, stargazing sessions, and workshops to raise awareness and interest in these fields among students and the general public. There are a few highlighted events which inspired the students in the past fifteen years. The Astronomy and Astrophysics Olympiad started in 2007 purposing to popularize Astronomy at the national level and attract bright young school students all over the country to the science stream, and especially towards Astronomy and Astrophysics. These Olympiads are currently conducted by the Institute of Physics, Sri Lanka. The Annual Water Boost Rocket competition is another remarkable event hosted by the ACCIMT from the year 2005. Figure 10 shows the demand for the night sky program requested by the schools. However, the fluctuations indicated in the graph shows

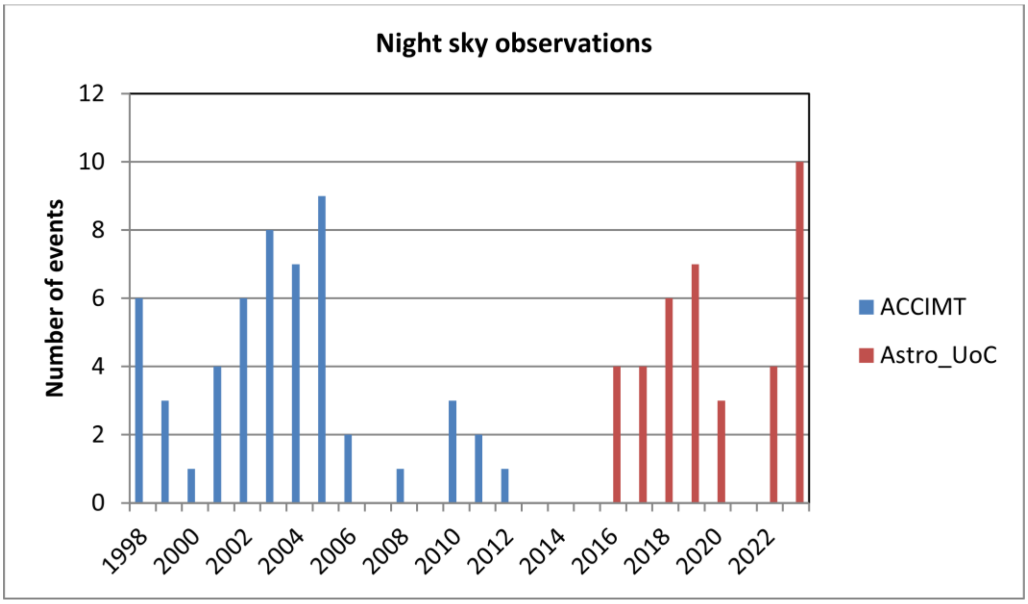

Figure 10: Statistics of the few public outreach programs conducted by the Astronomy and Space Science Unit, Department of Physics, University of Colombo; Astronomy Division, Arthur C Clarke Institute and the Astronomical Society, University of Colombo. Sources: Astronomy and Space Science Unit (UoC), ACCIMT annual reports.

that this important public outreach program was affected by the lack of resources including human resources and funding support. Therefore, a consistent source of funding and other resources should be identified in order to sustain this valuable program. The private entities have been actively involved in introducing new programs in astronomy and space science education. In one way this is a good sign of the development of the field, but on the other hand there should be a monitoring mechanism, because most of these programs are designed based on the commercial benefits. Therefore, it is timely and important to establish a regulatory authority to monitor the standards of the programs introduced by the private partnerships.

In summary, public awareness in space science research not only fosters education, inspiration, and support but also contributes to scientific literacy, international collaboration, technological advancements, environmental awareness, ethical considerations, and cultural enrichment. It plays a vital role in shaping our future as a spacefaring civilization and in addressing global challenges.

Future Prospects

The future of astronomy and space science in Sri Lanka depends on sustained efforts in education, research, and collaboration. By investing in educational programs, research infrastructure, and international partnerships, Sri Lanka can further develop its expertise in these fields. The purpose of the establishment of the Astronomy and Space Science Unit, Department of Physics, University of Colombo is to provide an opportunity to pursue post graduate research while engaging in public outreach programs as well. The department of Physics, University of Colombo is continuously supporting the introduction of educational programs. As a result of this, the first diploma level course in astronomy will be introduced.

National Astronomical Observatory (NAO)

The present trend of astronomy and astrophysics research is to use the mission data available free of charge. In the past few years, the research papers we published are based on mainly space mission data and ground-based surveys (Adassuriya J. *et al*. 2021; Herath M. *et al*., 2019; Dai Z. *et al*., 2018). Nevertheless, the inspiration of doing astronomy and astrophysics research from undergraduate to post graduate level came up with the Sri Lankan largest telescope facility, 45 cm Cassegrain telescope, which we received from the Japanese Government in 1996. I personally believe astronomy is a practical subject, and without the observation part it would be a partial qualification. Since the 45 cm Cassegrain telescope is located in a city with a highly light polluted area, hardly any observation has been done and the telescope is underutilized. In this context, it is high time to propose a National Astronomical Observatory (NAO) for Sri Lanka (Figure 11). The estimated cost for a 1.5 m telescope is 750 million rupees. A detailed proposal has been prepared by the ACCIMT and submitted to the ministry of Science and Technology (S. Gunasekera, 2016).

Figure 11. Left: Proposed site for the National Astronomical Observatory. The location was selected based on the annual rain fall, cloud coverage and the light pollution. Right: Proposed 1.5 m reflective telescope. Source: Project proposal: National Astronomical Observatory of Sri Lanka.

Astro-tourism

A first-class astronomical observatory would be a strong tourist attraction. The proposed telescope site is in close proximity to a wildlife sanctuary, and the tourist attraction is much more increased with the options of dark sky observation sessions and education programs. In addition to the proposed astronomical observatory, building a Science Exploratorium around this facility will serve as an educational tool in astronomy and space science for school children and the general public as well as a place of tourist interest. The observatory can offer night sky observations for tourists residing nearby hotels and this will generate substantial revenue for this facility. Therefore, the investment on the National Astronomical Observatory is redefined with the positive feedback to the economy while serving to the nation's scientific community for a long time.

According to the Table 1 and the highlights of the report of the Statistical Handbook on Research and Development of Sri Lanka (2020) of the National Science Foundation, 47.45% of gross expenditure on research and development (GERD) was devoted to applied research while basic research received 29.30%. Furthermore, by field the Natural Sciences received 22.46%, the Engineering and Technology 27.65% and Agricultural Science 24.20%. The statistics clearly show the priority levels of the fields and from the Natural Sciences, Astronomy and Space Science has the least priority.

Table 1. R & D expenditure – Sector- wise disaggregation. Source: Statistical Handbook on Research and Development of Sri Lanka 2020. National Science Foundation.

Expenditure Description	Government R&D Institutes		Higher Education Sector		Business Enterprises		PNP	
	Rs. Million	%	Rs. Million	%	Rs. Million	%	Rs. Million	%
Capital	1,183.49	19.09	73.56	1.43	2,057.91	29.84	5.05	2.22
Recurrent	5,016.95	80.91	4778.02	98.57	4,837.65	70.16	221.97	97.78
Basic	1,197.92	19.32	1,684.61	34.99	2,320.46	33.65	122.77	54.08
Applied	4,137.51	66.73	2,686.26	55.95	1,696.33	24.60	103.99	45.81
Experimental Development	865.01	13.95	480.70	9.06	2,878.77	41.75	0.27	0.12
Natural Sciences	1,432.93	23.11	1,316.47	25.96	1,315.63	19.08	16.15	7.11
Engineering and Technology	1,033.62	16.67	871.14	17.99	3,121.09	45.26	0	0.00
Medical Sciences	209.87	3.38	870.87	18.43	460.03	6.67	6.1	2.69
Agricultural Sciences	2,601.38	41.95	513.69	10.86	1,202.84	17.44	81.53	35.91
Social Sciences and Humanities	780.94	12.59	905.22	19.17	411.69	5.97	115.1	50.70
Not-Specified	141.7	2.29	374.2	7.60	384.3	5.57	8.14	3.59

Establishment of Institute of Astronomy and Astrophysics

As mentioned, the development of various research areas, introduction of education programs and the number of outreach activities in Astronomy and Space Science broadened the field rapidly. Therefore, a central authority to coordinate, monitor and regulate will be advantageous. Furthermore, it would be the fund-raising authority for the future space program in the country.

Conclusion

Compared to other fields in natural science, astronomy and space science provide an enormous amount of free data. The data archives and mission programs encourage the utilization of the data by introducing post-graduate and post-doctoral programs with minimum financial requirements and infrastructure facilities. We identified that there is a lack in post graduate degrees in astronomy and space science. Therefore, this is an ideal situation to promote astronomy and space science among the universities and institutions and hence achieve the technical excellence sustainably through the human resource development.

While Sri Lanka has made strides in astronomy and space science, there are challenges to overcome. Limited funding, infrastructure, and research facilities can hinder the growth of these fields. However, these challenges also present opportunities for collaboration with other countries, capacity-building initiatives, and the involvement of the private sector.

In reinventing the future of astronomy and space science in Sri Lanka, it is essential for the government, educational institutions, and the scientific community to work together to foster an environment conducive to research, innovation, and education in these fields. By building on the legacy of individuals and leveraging international collaborations, Sri Lanka can carve out a significant role in the global pursuit of space exploration and scientific discovery.

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Section E2

The Secret Life of Enzymes: Dynamics and Functions

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Enzymes are involved in a well-orchestrated series of metabolic reactions that facilitate life processes in all life forms, from bacteria to humans. Enzymes accelerate these chemical reactions, achieving rate enhancements up to 10^{12} compared to uncatalyzed reactions (Copeland, 2000). Thus, understanding what makes enzymes so efficient and the physical features of enzyme-catalyzed reactions is of practical interest and has fascinated scientists worldwide. Despite several hypotheses proposed during the past few decades, from Fischer's "Lock and Key"(Fischer, 1894) model to Pauling's "Induced-fit theory" (Pauling, 1946), debates are continuing about the origin of the catalytic power of enzymes. In 1894, Emil Fischer developed the lock and key analogy for enzyme catalysis. According to the "Lock and Key" model, the enzyme represents the lock and the substrate represents the key. The active site pocket of the enzyme is of a fixed conformation or shape and will only bind the substrate with the correct shape that fits the lock.

Later, the availability of crystal structures revolutionized the field of structural biology, and the fixed shape of the active site was discarded assuming that the active pocket could change its shape to accommodate the substrate shape in the induced-fit theory. According to the induced-fit theory, enzymes are assumed to be partially flexible. When the substrate approaches the enzyme, the attractive forces change the active site pocket to accommodate the substrate.

Enzymes generally make unfavourable reactions possible by lowering the free energy of activation (A) (Punekar, 2018). According to Figure 1, which shows the Energy profile of an enzyme-catalyzed reaction, the enzyme lowers the free energy of activation (to ΔG^*) and forms new intermediate/s (S^*) creating a new reaction pathway that stabilizes the intermediates.

Enzymes increase the rate of the reaction by lowering the transition state energy. However, the relationship between the bond activation and the lowering of the energy of the transition state is still a mystery. Hence, scientists are working on solving the puzzle of enzymes: how they behave in the transition state achieving a lower activation energy.

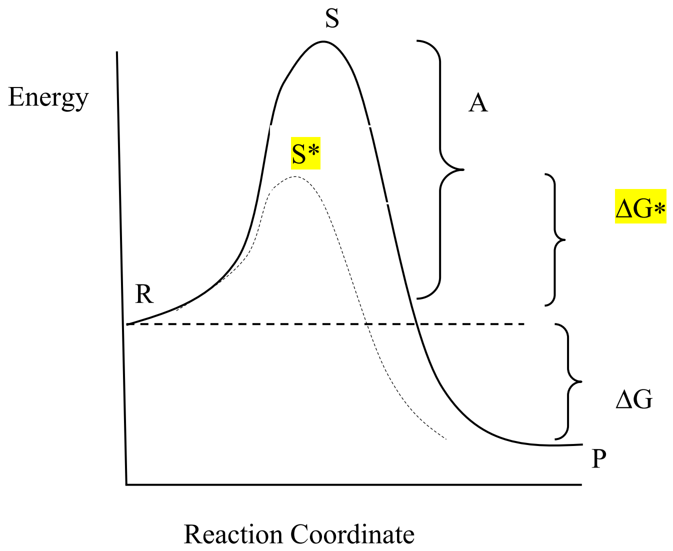

Figure 1: Energy profile of an enzyme-catalyzed reaction (enzyme-catalyzed reaction ….. and uncatalyzed reaction ——— , R= reactants, P= products and S= intermediates of the enzyme-catalyzed reaction)

In the current context, the idea of a more dynamic view of enzyme catalysis has attracted the scientific community with recent approaches involving both computational and experimental methods (Singh et al., 2015). To explore the relationship between protein dynamics and bond activation, while keeping evolutionary pressures that preserve the native dynamics of a model enzymatic system, thymidylate synthase (TSase) is used as a model system. TSase is one of the best-known enzymes due to its vital role in DNA synthesis, making it one of the most relevant targets for anticancer therapy (Ghosh, 2018).

Thymidylate synthase is responsible for the last step of *de novo* synthesis of a precursor of the DNA base thymine. It catalyzes the reductive methylation of 2'-deoxyuridine-5'-mono phosphate (dUMP) to 2'-deoxythymidine-5'-mono phosphate (dTMP) using (6*R*)-N^5, N^{10}-methylene-5,6,7,8-tetrahydrofolate (CH_2H_4folate) as a cofactor (Figure 2). Since TSase is present in most living organisms and is overexpressed in actively proliferating cells such as tumor cells and bacterial infections, it has been a target for developing chemotherapeutic and antibiotic drugs for many years (Carreras & Santi, 1995). Figure 3 shows a crystal structure of wild-type (WT) *Escherichia. coli* (*ec*)TSase with CH_2H_4folate and 5-fluoro-dUMP (PDB entry 2KCE).

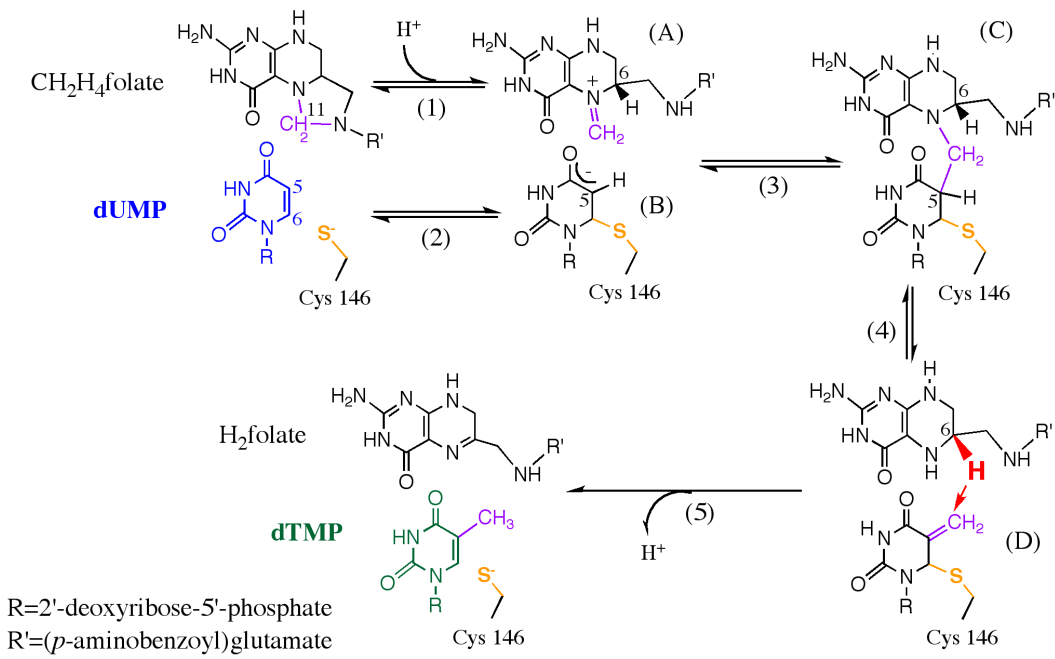

Figure 2: The reaction catalyzed by thymidylate synthase.

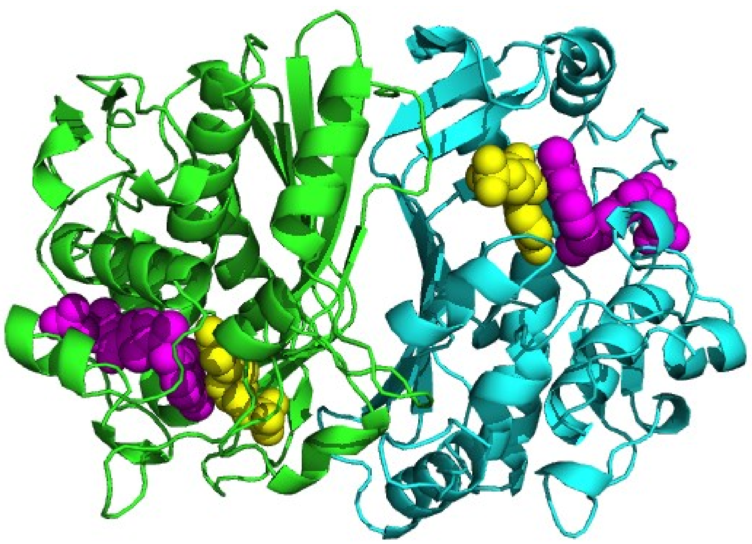

Figure 3: The crystal structure of WT *ec* TSase with the two sub-units in green and cyan (PDB ID 2KCE) with CH2H4folate and 5-fluoro-dUMP (magenta and yellow, respectively).

TSase is a homodimer with a molecular mass of 60 kDa having two identical active sites. The dimer interface is composed of two six-stranded sheets and the active site is deeply buried in each of the subunits (Wang et al., 2013).

The temperature dependence of the kinetic isotope effect (KIE) method has been used in recent years to study the nature of H-transfer enzymatic reactions and is a powerful tool for understanding the role of dynamics in enzyme catalysis. According to Figure 2, hydride transfer from CH_2H_4folate to dUMP making dTMP and H_2folate, is the chemical step that is catalyzed by TSase. Therefore, to investigate the effect of isotopic substitution of TSase on this step, the intrinsic KIEs (KIE_{int}) on the hydride transfer of wild type (WT) and Y209W *ec* TSase were determined using radiolabeled substrates as shown in Figure 4.

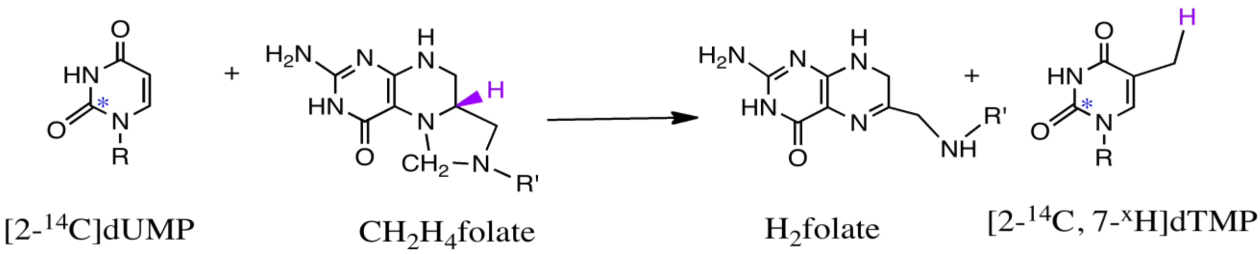

Figure 4: Studying the hydride transfer step with radio-labeled substrates

The temperature dependence of KIEs has stimulated the development of various phenomenological models, often summarized as the Marcus-like model (Marcus, 2006) (Figure 5).

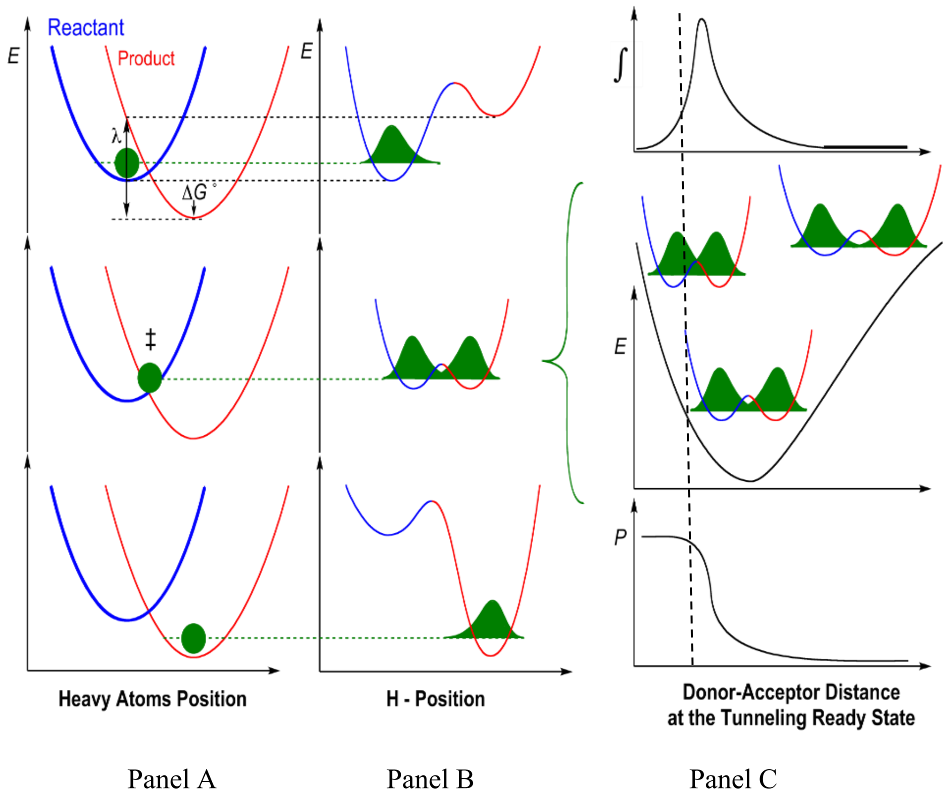

Figure 5: Marcus-like Model

$$k = \frac{|V|^2}{\hbar}\sqrt{\frac{\pi}{\lambda k_B T}}\, e^{-\frac{(\Delta G^{\circ}+\lambda)^2}{4k_B T\lambda}} \int_0^{\infty} F(m, DAD) e^{E(DAD)/k_B T}\, dDAD \qquad (1)$$

Figure 5 depicts the Marcus-like model (equation 1) of hydrogen tunneling, which explains how the active site of an enzyme re-arranges during catalysis in a H transfer. Here, three slices of the potential energy surface along components of the reaction coordinate show the effect of heavy-atom motions on the zero-point energy in the reactant (blue) and product (red) potential wells.

Panel A presents the heavy atom coordinate (representing all other chemical bonds except the C-H) of the enzyme and Panel B shows the position of the H-atom, which is orthogonal to the heavy atom coordinate. Before catalysis, the hydrogen atom is located in the reactant well and the zero-point energy of the product state is higher than that of the reactant state. During catalysis, the reorganization of heavy atoms brings the system to the tunneling-ready state (TRS, middle diagram of panels A and B). Now, the zero-point energy in the reactant and product wells is degenerated. Therefore, the hydrogen can tunnel between the reactant and product wells. The rate of reaching the TRS depends on the reorganization energy (λ) and driving force (ΔG°).

In panel C, the middle diagram shows the effect of Donor-Acceptor Distance (DAD) on the wavefunction overlap at the TRS. The top diagram of panel C presents the contribution to H-transfer at each DAD as a function of the Probability of tunneling (*P*) and the population at each DAD (*i.e.*, the integrated terms in Equation 1). The tunneling probability of hydrogen is inversely proportional to DAD. The vertical dashed line represents the DAD where the Zero-point energy (ZPE) exceeds the barrier height. At such distances, the process of a wavefunction spreading from reactant well to product well is no longer known as "tunneling", but one can still use the transmission probability of a particle analogously to the tunneling probability at more extended DADs.

Measuring the temperature dependence of intrinsic KIEs is a sensitive probe of the nature of the reaction coordinate and chemical reactions. According to the Marcus-like model, temperature-independent KIEs result from a narrow distribution of DADs at the transition state (TS). Temperature-dependent KIEs, on the other hand, indicate a broader distribution of DADs at the TS (poor reorganization of the reactants at the reactive state and lower frequency of DAD fluctuations). In most WT enzymes, including *ec* TSase, the intrinsic KIEs are temperature-independent, suggesting that the enzyme active-site dynamics bring the donor-acceptor distance to a well-defined short and narrow ensemble for hydride transfer. Therefore, mutations on any conserved residue of the enzyme would lead to a perturbation of KIEs.

During enzyme catalysis, conformational fluctuations of the protein create a favourable environment for the formation of the "reactive complexes" and this step is known as the preorganization, which occurs at second to sub-millisecond timescales. Once the reactive complex is formed, the active site reorganizes on the nanosecond to picosecond timescales. The "reorganization" occurs due to the faster motion of protein, solvent, and ligands assisting the conversion of the reactant state to the TRS. At the TRS, the fluctuation of DAD affects the H-tunneling probability. At the same time, the DAD fluctuations at TRS determine the magnitude and temperature dependence of the intrinsic KIE.

The experimental procedure of the temperature dependence of intrinsic KIEs requires substrates labeled with hydrogen isotopes H and D, and the difference between energies of activation for hydrogen isotopes, $\Delta E_a = E_a(D) - E_a(H)$. In many cases, for the most active wild-type enzymes, ΔE_a is nearly 0 (temperature-independent KIE), suggesting that DAD is sufficiently short to ensure effective tunneling of both H and D isotopes. Impaired or mutated enzymes show increased values of ΔE_a (temperature-dependent KIE) and poor overlap of deuterium wavefunctions that necessitate further DAD sampling to achieve adequate DAD for tunneling.

Mutations that are remote from the chemical reaction site of an enzyme are of particular interest in addressing how enzyme motions contribute to chemical bond activations during catalysis since their effect usually requires structural and dynamic perturbations through an extended range of interactions in the protein-ligands complex. Therefore, a mutation of *ec* TSase was introduced to address this question. A highly conserved tyrosine residue of *ec* TSase (Y209) forms one of only two H-bonds with the ribose ring of dUMP, which is remote from the chemical reaction site in *ec* TSase (Wang et al., 2012). The crystal structures of the WT and Y209W mutant ternary complexes with dUMP and an analog of the cofactor, CB3717 (PDB IDs 2G8O and 2G8M, respectively), closely overlapped at a resolution of 1.30 Å (Figure 6).

The study of Y209W, integrated the kinetic data with high-resolution crystal structures and anisotropic B-factors to analyze the effects of protein motion on different aspects (*e.g.*, pre- and re-organization, and H-tunneling at the TRS) of a C-H→C transfer in a complex catalytic cascade.

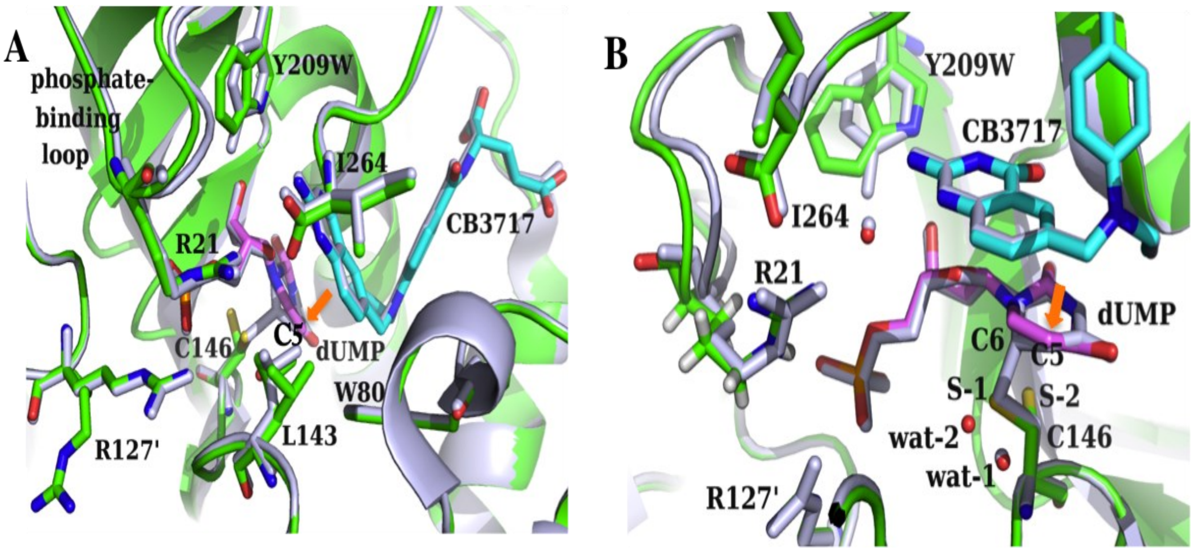

Figure 6: Crystal structures of the ternary complexes of the WT and Y209W. (A) Crystal structures of the ternary complexes of the WT (gray; PDB ID 2G8O) and Y209W (green; PDB ID 4GEV) *ec* TSase with dUMP (magenta) and CB3717 (cyan) (B) A closer view of the active site

In the experiments of Y209W with various thiols, an intermediate was trapped prior to the hydride transfer reaction. Trapping of the intermediate suggests that the mutation deteriorates the ability of the protein to preorganize the active site for hydride transfer, and further supported by additional conformations of several active site residues in its crystal structure.

Figure 7 shows the temperature dependence of intrinsic KIEs (KIE_{int}) on the WT- and Y209W-catalyzed hydride transfer and the observed KIEs for the mutant at 35 °C. The intrinsic KIEs were fit to the Arrhenius equation (Francis & Kohen, 2014):

$$KIE_{int} = \frac{k_L}{k_H} = \frac{A_L}{A_H} exp\left(\frac{-\Delta E_{a,L-H}}{RT}\right) \qquad (2)$$

Where the subscripts L and H denote the light isotope (H or D) and the heavy isotope (T) of hydrogen, respectively; *k* is the microscopic rate constant of the isotopic sensitive step (the hydride transfer step in this case), and ΔE_a is the difference in the activation energies of that microscopic step between the light and heavy isotopes ($\Delta E_a = E_{aL} - E_{aT}$); A_L/A_T is the isotope effect on the pre-exponential Arrhenius parameter; R is the gas constant and T is the absolute temperature.

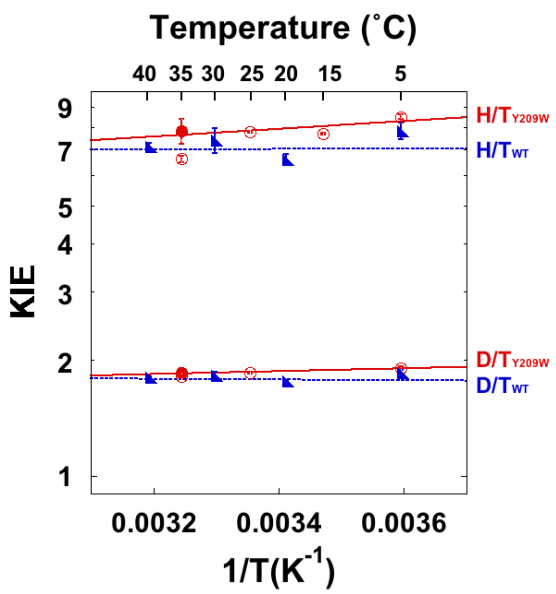

Figure 7: KIEs on the hydride transfer catalyzed by the WT and Y209W *ec*TSase

Compared to the WT enzyme, the KIE on the hydride transfer of Y209W is more temperature-dependent with a slightly larger magnitude in the 5-35 °C temperature range, suggesting a negligible isotope effect on the pre-exponential parameter (A_L/A_T). However, A_H/A_T is still above the semi-classical limit, suggesting that Y209W-catalyzed hydride transfer occurs predominantly *via* quantum mechanical tunneling. Based on the Marcus-like models, these observations suggest that although the mutation is remote from the reaction site, the altered structural and dynamic properties of the mutant slightly change the DAD distribution at the TRS.

Therefore, the poorly preorganized protein environment causes a higher penalty of reorganization energy for the hydride transfer in Y209W. Some rigid-body vibrations in the WT crystal structure are lost in the mutant, suggesting the potential contribution of these high-frequency motions to the reorganization of the protein environment for the hydride transfer.
The measurement of the temperature dependence of KIEs indicates the distribution of conformations at the reactive state.

However, the temperature dependence of KIEs does not indicate whether fast protein vibrations are coupled to the chemical step of bond activation. One of the recently developed tools to address this question uses enzymatic isotopic substitution to alter the bond vibration frequencies at femtosecond (fs) – picosecond (ps) timescale. It is expected that this tool would resolve the heated debate about the coupling of protein dynamics in catalysis. Since the study of heavy enzymes in 1969 by Rokop *et al* (Rokop et al., 1969) using a deuterated version of alkaline phosphatase, modifying the regular isotopic composition of the protein by substituting ^{15}N, ^{13}C, and non-exchangeable hydrogen atoms has garnered the attention of many laboratories (Guengerich, 2017).

The combination of the temperature dependence of KIE_{int} and their modulations using heavy proteins is a tool that could more directly address this question. Since most of natural enzymes have a narrow distribution of donor-acceptor distance at the reactive state, they commonly present temperature-independent KIEs. As the heavy protein has slower atomic fluctuation, if more temperature-dependent KIEs are present with it, that could reveal a role of those fast fluctuations in the natural, light enzyme, which are distorted in the heavy one.
Therefore, using *ec* TSase, the effect of altered mass vibrations of the enzyme on the chemical step was evaluated. The mass of TSase was increased by 12% by isotopic substitution, altering the bond vibrational frequencies at faster fs–ps timescale. ^{1}H-^{15}N TROSY-HSQC spectra of light and heavy *ec* TSase indicated the presence of isostructural proteins (Figure 8).

A substantial temperature dependence on KIE_{int} for the hydride transfer of heavy *ec* TSase over the whole temperature range (5°C - 40°C) was observed and this is the first time such observation for any heavy enzyme reported so far, suggesting a direct coupling of such vibrational frequencies to bond activation in *ec* TSase (Figure 9).

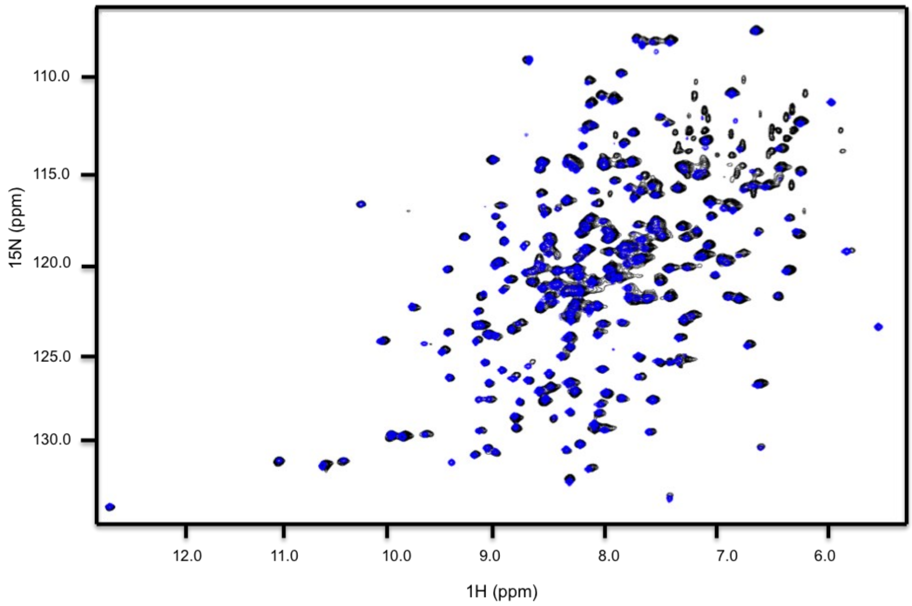

Figure 8: Confirmation of isostructural proteins. ^1H-^{15}N TROSY-HSQC spectra of light (^{15}N only), shown in black, and heavy (^2H, ^{15}N, ^{13}C), shown in blue, *ec* TSase

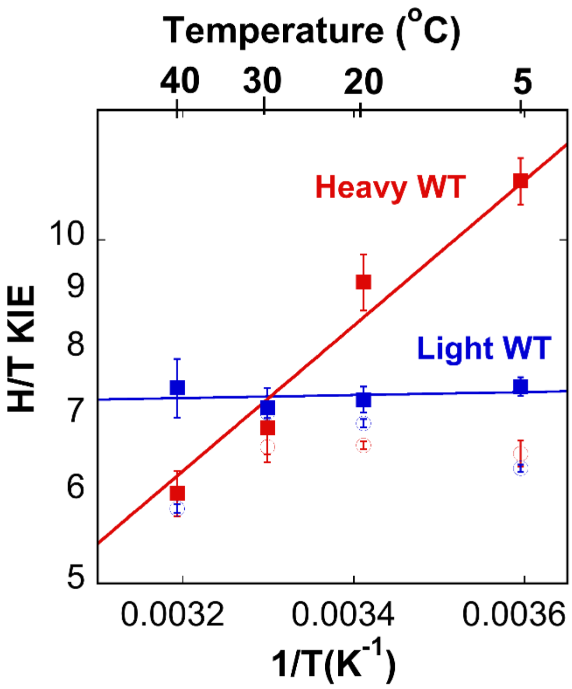

Figure 9. Arrhenius plots of the H/T KIE_{int} on the hydride transfers catalyzed by the light and heavy WT *ec* TSase

These results, for the first time, provide direct evidence for the possible coupling between fast protein vibrations and the chemical step in an enzymatic system. Therefore, this technique can be extended to explore other enzymatic systems that have not been studied previously and address the heated debate about the contribution of fast dynamic motion to catalysis.

Conclusion

The role of protein motions in enzyme-catalyzed bond activation has been extensively studied for many years, revealing the secrets behind catalysis. The experiments described above illustrate how protein motions affect the H-transfer step in a model enzyme system, thymidylate synthase, and expand our understanding of enzyme catalysis. Recent studies have used different experimental techniques to study the model enzymatic system TSase including temperature dependence of intrinsic KIEs, site-directed mutagenesis, and X-ray crystallography. One of the contemporary advances in enzymology is the use of KIEs in exploring the role of motions in enzymes' function. The relevance of temperature dependence of KIEs to the dynamics of enzymes has played a pivotal role in enzymology. The findings presented in the above text will help solve another piece of the grand puzzle describing the relationship between motions and catalysis in enzymes. Such investigations may provide new insights into rational drug designs, allowing to exploration of novel biochemical pathways for drug targets. Ultimately, understanding the relationship between enzyme function, structure, and dynamics during covalent bond activation will enable better designing of synthetic biocatalysts and significantly contribute to improving our knowledge and the ability to control enzyme catalysis.

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Section E3

Advances in Deep Learning for Medical Image Analysis

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Background

In the realm of researching and managing human infections, the realms of Artificial Intelligence (AI), machine learning (ML), and deep learning (DL), including generative AI, have become areas of burgeoning exploration as shown in Figure 1. Defining AI can be multifaceted; Wikipedia characterizes it as the embodiment of human-like intelligence within machines. Meanwhile, in the field of computer science, AI is framed as the study of "intelligent agents," which are devices endowed with the capability to sense their surroundings and make decisions to optimize their chances of achieving specific objectives (Poole et al., 1998). This conjunction, the "and" bears significant weight in this definition. AI has emerged as a pervasive and captivating theme in our contemporary landscape, making appearances in news, social media, and even within the pages of medical literature. Its applications in tackling human infections hold great promise and are actively unfolding on the frontiers of scientific inquiry and healthcare management.

Indeed, there has been exponential growth in publications relating to AI, machine learning and deep learning.

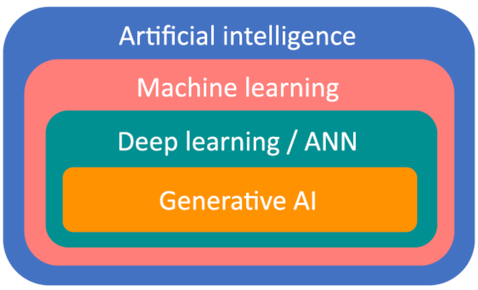

Figure 1: Exploring the connections between artificial intelligence (AI), machine learning (ML), Deep Learning (DL), or artificial neural networks (ANN), and Generative AI

In the realm of medicine, the initial adoption of machine learning occurred during the 1980s and 1990s, primarily through the development of computer-assisted diagnosis systems, particularly in the field of medical imaging. The field of ML, in its broader context, encompasses three main categories: supervised, unsupervised, and reinforcement learning (Thuseethan et al., 2021) as illustrated in Figure 2.

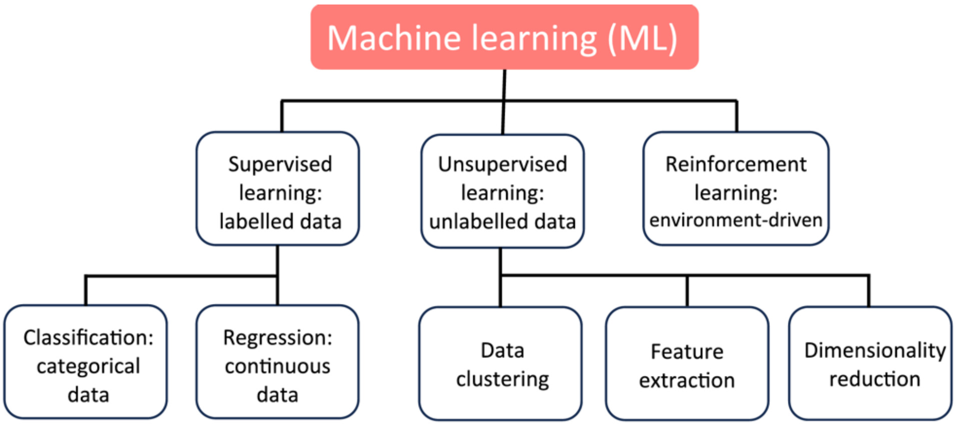

Figure 2: Subdivisions and Applications of Machine Learning

Supervised learning, a fundamental approach, involves training algorithms using labelled data, such as histological specimens previously expertly categorized as normal or diseased. These trained algorithms, when confronted with unlabelled categorical or continuous test data, excel in predicting outcomes, either by classifying data into specific categories or by performing regression to estimate numerical values.

In contrast, unsupervised ML operates on unlabelled data, employing data-driven processes rather than human-guided ones. These models prove invaluable for tasks like data clustering, feature extraction, and dimensionality reduction, enabling the identification of patient subgroups based on clinical data without prior labels.

Reinforcement learning takes a distinctive path, driven by interactions with an environment. It operates through iterative learning cycles, with actions leading to either rewards or penalties based on alignment with predefined targets. An exemplar application in healthcare is continuous blood glucose monitoring and insulin administration, where the objective is to maintain glucose levels within a specific range.

In clinical AI models, it is commonplace to integrate multiple of these ML approaches to address diverse healthcare challenges. Furthermore, each of these approaches can be further subdivided into a plethora of algorithm types, each bearing its own intricacies and nuances. These versatile ML techniques hold significant potential for transforming healthcare by enhancing diagnostics, treatment planning, and patient care.

Deep learning (DL) refers to an increasingly-popular branch of ML employing artificial neural networks (ANN) with multiple processing layers, which may employ supervised, unsupervised, and reinforcement ML approaches (Janarthan et al., 2022).
Deep learning stands out when it comes to tackling intricate tasks that involve copious amounts of data and high-dimensional information. However, it demands more computational resources compared to traditional machine learning methods. Additionally, because many of its processing layers operate behind the scenes, it introduces greater complexities in terms of understanding and holding models accountable.

The idea of AI's transformative potential in healthcare isn't new; early predictions can be traced back to the 1950s. However, in line with Moore's law, the exponential advancements in computing speed, memory, portability, affordability, and algorithmic capabilities, coupled with the increasing availability of digital clinical data, have accelerated this progression. Such rapid development makes it challenging to make precise predictions about AI's future role. In this context, we focus on recent and present-day applications of AI in diagnosing and managing infections. We aim to shed light on the obstacles hindering its integration into clinical practice and the ongoing concerns and limitations. This discussion is not meant to be an exhaustive or specialized review but rather a practical reference for infection clinicians seeking to navigate the realm of AI within their field.
The delivery of healthcare services is undergoing a significant evolution driven by rapid technological advancements, with particular emphasis on the growing potential of artificial intelligence innovations to bring about transformative changes and disruptions in healthcare provision.
Radiological images have exhibited promising results in patient prognosis. Deep learning offers a robust method for conducting comprehensive analysis of imaging data and incorporating multi-modal data for modeling purposes (Thuseethan et al., 2021).
The rest of this work is organized as follows: Section 2 offers a concise introduction to the existing literature on Deep Learning for Chest X-ray images. Section 3 delves into the specifics, including the state-of-the-art deep networks under comparison, details about the dataset employed, implementation particulars encompassing standard training and testing

procedures, and an extensive discussion of the results. The paper concludes in Section 4, with a comprehensive discussion and the potential for future directions in research.

Systematic Literature Review

Chest radiographs hold significant importance in the medical field, with chest X-rays playing a crucial role in diagnosing conditions like pneumonia and COVID-19. Recent advancements in deep learning have shown great promise in classifying and predicting medical image outcomes. As the availability of chest X-ray datasets grows and data engineering techniques continue to evolve, there has been a surge in related publications. However, only a handful of survey papers have tackled the subject of chest X-ray classification using deep learning, often lacking an analysis of recent trends. In this systematic review, we aim to provide a comprehensive analysis of studies utilizing deep learning techniques for chest X-ray image analysis. We cover the state-of-the-art solutions for pneumonia and COVID-19 detection, highlight recent trends, showcase publicly available datasets, offer guidance on implementing a deep learning process, address challenges, and propose potential future research directions within this domain. The insights and conclusions drawn from the reviewed studies are presented in Figure 3 to assist fellow researchers and developers in making informed decisions for their own research endeavors.

Comparative Analysis

I. State-of-the-art Deep Networks

Various state-of-the-art deep networks are evaluated in this study. The list of state-of-the-art deep networks that are compared in this study is given below.

- VGG16 and VGG19
- DenseNet121 and DenseNet201
- InceptionV3
- ResNet101 and ResNet152
- Xception
- EfficientNetB0 and EfficientNetB7
- NASNetLarge and NASNetMobile
- MobileNetV2, MobileNetV3 Small and MobileNetV3Large

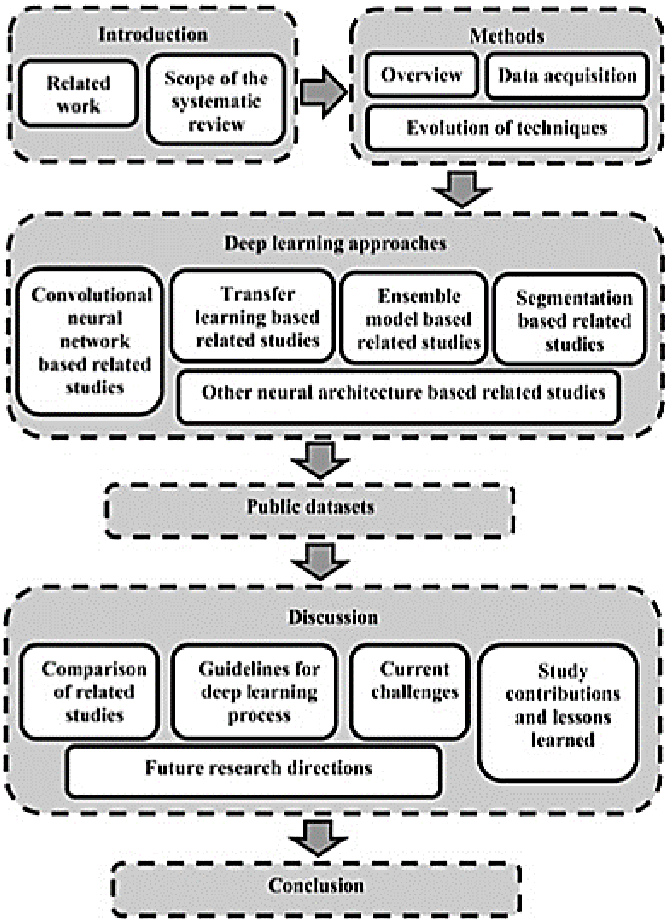

Figure 3: High level implementation of the Background Study

II. Chest X-ray Dataset

The chest X-ray image dataset2 used in extensive experiments contains four classes, such as COVID-19, Normal, Pneumonia Bacteria and Pneumonia Viral. Figure 4 shows two samples for each class available in the dataset. The publicly available version of the dataset consists of 320, 445, 449 and 424 image samples for COVID-19, Normal, Pneumonia Bacteria and Pneumonia Viral classes, respectively. The images available within this dataset are in different resolutions, which are later resized to the same dimension during the training process in supporting the deep networks individually. For instance, images in the dataset are resized to 224 x 224 in order to match the input image size of the VGG16 network.

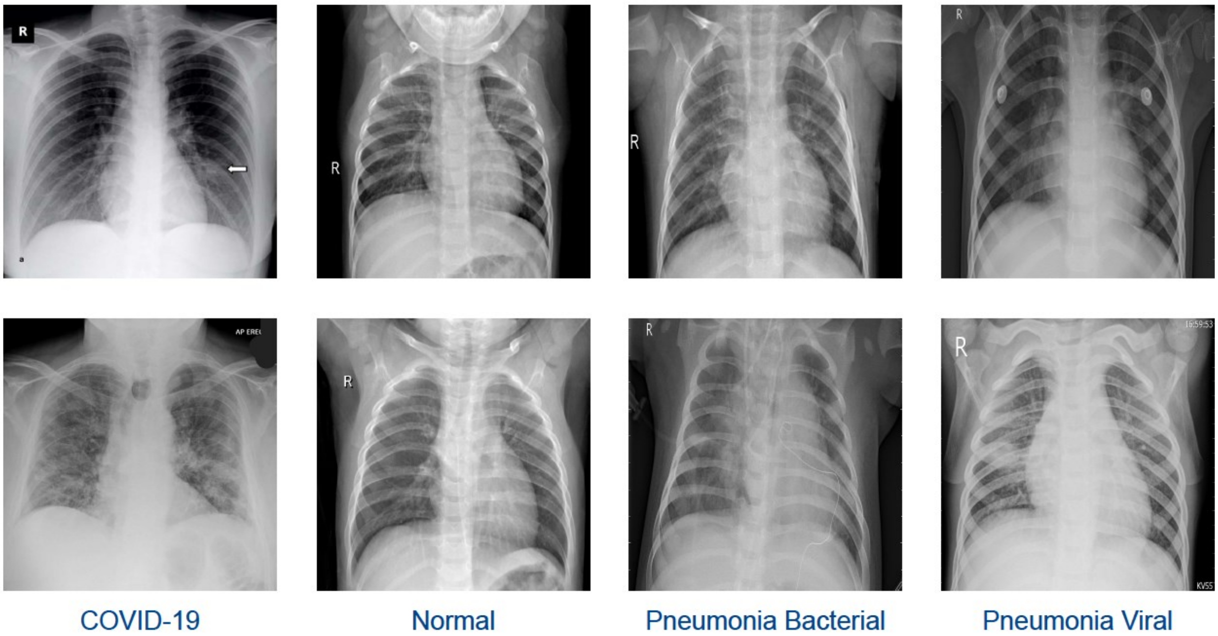

Figure 4: The standard training and testing procedure employed

III. Implementation, Training and Testing

All the networks are implemented using the TensorFlow platform and evaluated on Google Colab. The deep networks are used as defined in TensorFlow Core v2.6.0. A traditional training and testing procedure is adapted, where 80%, 10% and 10% samples of the whole dataset are used to train, validate and test the networks, respectively. Figure 2 shows the overall training and testing procedure. A stochastic gradient descent (SGD) optimizer is used with a momentum of 0.9, an initial learning rate of 0.05 and a decay of 0.0001.

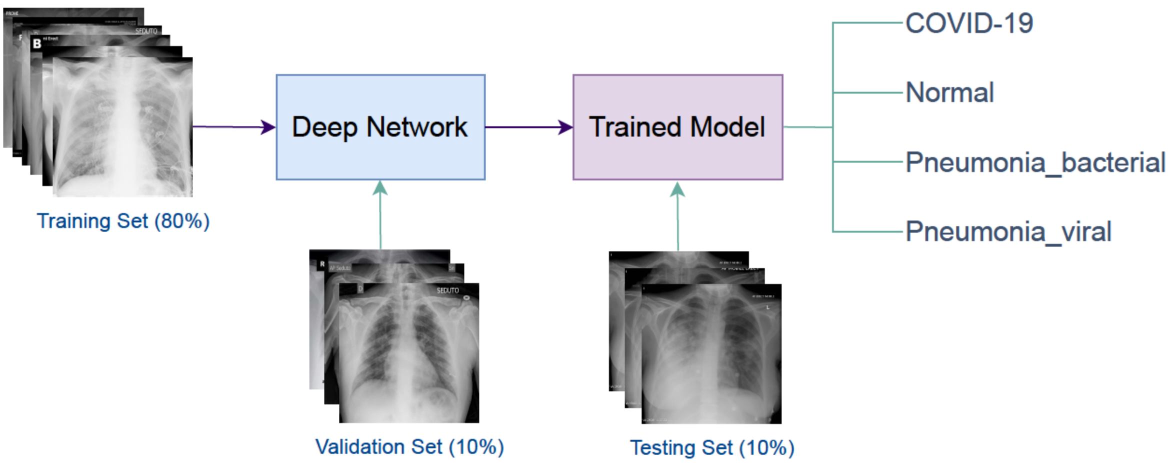

Figure 5: The standard training and testing procedure employed

IV. Results and Discussion

The classification accuracy obtained for fifteen state-of the-art deep networks are compared in this research. Table I illustrates the comparison results, where the deep networks that showed the best performances are highlighted.

As can be seen, the EfficientNetB7 achieved the best results with 95.54% of classification accuracy. The second and third best performances were shown by both ResNet variants, obtaining slightly more than 90% classification accuracies. The lightweight networks, such as NASNetMobile, MobileNetV2, MobileNetV3 Small and MobileNetV3 Large also showed comparable performance in recognizing COVID-19. Among them, the MobileNetV2 yielded the best accuracy with 81.47%, followed by MobileNetV3 Large, MobileNetV3 Small and NASNetMobile. It is interesting to note that the very deep networks like InceptionV3 and DenseNet201 performed comparably low in COVID-19 recognition, which could be because of the lack of training data.

*Table 1: Comparison of state-of-the-art deep networks. The three best performing models are in **bold**.*

Deep Network	Accuracy	Rank
VGG16	0.8040	11
VGG19	0.8162	9
DenseNet121	0.8639	7
DenseNet201	0.8792	5
InceptionV3	0.8863	4
ResNet101	**0.9037**	**3**
ResNet152	**0.9138**	**2**
Xception	0.8215	8
EfficientNetB0	0.8769	6
EfficientNetB7	**0.9554**	**1**
NASNetLarge	0.7608	14
NASNetMobile	0.7215	15
MobileNetV2	0.8147	10
MobileNetV3 Small	0.7628	12
MobileNetV3 Large	0.7635	13

Figure 6 illustrates the saliency maps acquired by the best performing EfficientNetB7 model for one sample taken from COVID-19, normal, pneumonia bacterial and pneumonia viral classes. Note that the selected images are picked from the set of correctly classified samples. As can be seen, the corresponding spatial support attained for each class are clearly distinguishable. The confusion matrix generated for the EfficientNetB7 deep network is presented in Figure 4. The COVID-19 class achieved a slightly lower accuracy of 94.06%, in comparison to other classes. The majority of the misclassified COVID-19 samples are confused with the normal class. Amongst all other classes, Pneumonia Viral achieved the best accuracy of 96.70%. The Normal and Pneumonia Bacterial classes also reached more than 95% of accuracy. Overall, the performance manifested all of the classes are at the expected level.

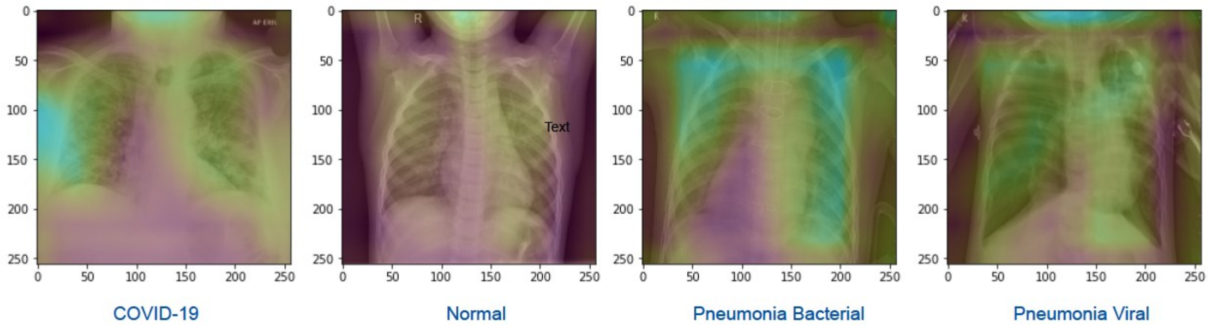

Figure 6: The visual illustration of the spatial support obtained for each class by the EfficientNetB7 model

Conclusion

The global outbreak of COVID-19 has impacted almost every country and its people. Hence, it is vital to devise an effective and timely way of recognizing COVID-19. Adapting the superiority of deep learning techniques, many approaches have been proposed in the past. Many of them are limited due to integrated pre-processing, complex structures, and the use of multiple model data. Knowing the fact that the existing deep networks are end-to-end trainable and powerful in extracting visual features, in this paper, a comprehensive comparative analysis is performed. The results obtained for fifteen widely used deep networks are compared and analysed. Comparison results reveal that the EfficientNetB7 network demonstrated the best classification accuracy in recognizing COVID-19 with chest X-ray images. Analysing other COVID-19 datasets could be a potential future work of this research.

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Section F

Shifting paradigm towards wellbeing Assessment

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In early 1990s, expectations and the formalized euphoria on sustainability came to a reality at the Earth Summit in Rio De Janeiro, Brazil, which held in June 1992. Laying the foundation, Agenda 21 was adopted to build a global partnership towards sustainable development aiming to uplift human lives and environment. Through several rounds of discussions and amendments, the 2030 Agenda for sustainable development was introduced with 17 Sustainable Development Goals (SDGs) at the UN Sustainable Development Summit in September 2015. From that day onwards, the world is marching to achieve SDGs by the year 2030. Yet the world is undergoing a polycrisis forming food shortages, conflicts, pandemic, adverse socioeconomic issues—poverty and inequality, resource depletion and exploitation, financial crisis, polarization, environmental disasters (both natural and anthropogenic), unmanaged trade, unethical values, violence, and many more. These are threat multipliers that are interrelated and synergistic. On top of all that, climate change plays the most detrimental role ramifying its impact over all the sectors, localities, and the globe. Further, the present trend of consumption, production, and governance seems to be unsuccessful in achieving the SDGs or failing to capture the actual depth and breadth of socio-economic progress. Close examination of facts may prove that the cause root for many of these issues/disasters is unsustainable living pattern and societal behavior. This situation pleads for a mass movement towards sustainable consumption aiming at a green transition effort through greener technology, reskilling initiatives, equality, sustainable capital flow with supportive hands to reduce the burden of communities and developing countries. Thus, a radical transformation of individual and societal behavior is of paramount importance together with new measurement matrices of growth assessing overall wellbeing and social development of the population. Gross Domestic Product (GDP) based measurements of economic growth do not show the full picture of the scenario but focus only on economic aspects undervaluing social and environmental facts generated by the economy/country. Therefore, this speech deliberately presents the shortfalls of SDGs while emphasizing the importance of an inclusive development approach for future planning. At the end, guiding principles to promote sustainable consumption are presented.

Pitfalls in SDGs

Nations around the world are trapped in a vicious cycle undergoing recurring challenges that lead to regression in SDGs.

> "Since the time of adoption of the SDGs, the number of food insecure people worldwide has risen each and every year, from 1,544 million in 2014 to 2,309 million in 2021 (FAO, 2022:26). Even before the current phase of global pandemic and geo-political crisis, 42 percent of humankind were reportedly unable in 2020 to afford a healthy diet valued at 3.54 USD per person per day on average (ibid.: 51). With the global average income at around 55 USD per person per day (IMF, 2023:142), over 3 billion human beings are left behind."

As indicated by FAO and statistics published in world recognized reports prove that the inequality, poverty, and insecurity are soaring further exacerbating the marginalized communities in developing nations, especially in the global south. The 'business–as–usual' approach, which we follow from past to present seems to be no longer effective; it has lost its credibility, failed to achieve SDGs, failed to overcome global challenges; rather, it worsens them. Hence, an institutional reform is needed focusing financial flows for environmentally and socially responsible enterprises.

On the other hand, governments are trapped into the fixation of increasing GDP of the country – the sole measurement of so-called development, which labels the country as developed or not. However, GDP only assesses the economic strength of the economy. It excludes impacts on wellbeing particularly welfare and losses to the nation. In addition, it excludes the impact on the ecosystem. Neither sustainability measures adopted, nor the damage/losses made to the environment are accounted for. Thus, GDP has been recognized as a partial measure of growth and development of an economy crippling the other sectors, which are contributing largely but kept unrecorded and off the books. Realizing these limits of GDP as a measurement of sustainable development and inclusive growth, a few countries and global institutions are now working on more holistic approaches. A wellbeing economy, inclusive wealth, and green GDP are some alternatives. In spite of the complexities of the interactions, networking, consumption, human behavior, and global transactions, a certain degree of convergence is required with a full range of indicators. It should internalize the ecological footprint without excluding social and ecological aspects which contribute to the development process. Inclusive development is a novel concept, which envelopes all these aspects in a nuanced way yet focuses on human and social wellbeing, inclusivity, equality and freedom.

Inclusive development

From the 1990s, international development policies aimed at improving human security, alleviating poverty, and increasing ecological sustainability, framed within the concept of sustainable development (Gupta 2014). In 2015, the global community of nations adopted 17 Sustainable Development Goals (UNGA 2015) with 169 targets and implementation measures to promote economic, social, and environmental dimensions of human development (UNDP 2017). However, these trade-offs are often made in favour of economic aspects, so as the SDGs (Chatterjee 2005; Sachs 2004) and stakeholder participation in local to international arenas (UNDP 2017). Inclusive development is a relatively new concept defined as "development that includes marginalized people, sectors, and countries in social, political, and economic processes for increased human well-being, social and environmental sustainability, and empowerment. Inclusive development is an adaptive learning process, which responds to change and new risks of exclusion and marginalization" (Gupta et al. 2015:546).

The focus of inclusive development is inclusivity, leaving no one behind, a secured human right, and a justice approach. Inclusive development defines inclusiveness of social, relational, and ecological aspects in contrast to the social, economics, and environmental dimensions in the sustainable development approach. Here, justice has been unpacked into accessibility to resources and markets, fair allocation of resources, and issues of risks and responsibilities. Social inclusion begins from recognition of the rights of humans to access their basic needs for a decent life: water, food, energy, education, health, *etc.* It basically calls for equality or in other words equal access and fair allocation. However, such targets cannot be met through the business-as-usual approaches presented in SDGs. Evidently, the top 1– 4% consume as much as the bottom 3 billion. This autonomous concentration of wealth among the richest people affect the dignity of the poor and poorest people. Although the SDGs are there to ensure a 'social floor' (*a la* Raworth, 2012) and 'planetary boundaries' (*a la* Rockstrom et al., 2009), ecological aspects are not adequately addressed in it as included in inclusive development. In contrast, SDGs are embedded in social aspects (11 out of 17 goals) paying minor attention to ecological and relational aspects as well as justice.

Social inclusiveness

Social inclusiveness addresses five basic principles (Gupta et al. 2014) including (i) ensure equity principles to share the opportunities for development; (ii) include the knowledge of all;

(iii) build targeted capacity building to enable effective participation; (iv) enhance protection for the poorest; (v) engage all in the politics and development. Moreover, social inclusiveness addresses multilevel challenges extending from local to global spheres. It ensures no one is left behind and enables the furthest behind to reach first by encouraging meaningful participation through equity principles, capacity building, technology transfer, and financial support. At the regional level, it pays attention to the most vulnerable countries for equitable sharing and accessibilities. At the national level, marginalized sectors, places, and communities are targeted. Hence, social inclusiveness is non-discriminating based on age, gender, caste, sect, and/or creed. In essence, with respect to social inclusiveness, inclusive development policies aim to enhance social wellbeing over material, relational and cognitive dimensions without leaving behind people/ societies based on the place (rural and peri-urban), natural resource based livelihoods (small scale farming, fishing, and community forests), arenas (home-based activities, street vendors) and so on.

Ecological inclusiveness

Ecological inclusiveness has been perceived over multiple levels, from local to global. At the local level, it focuses on protecting access to and ownership of resources as well as local ecosystems. Well managed sustainable ecosystem services are expected at the national level. At the global context, equitable access and causes that do no harm to other countries with differentiated responsibilities are focused. A different vision on prosperity, wellbeing and the currently practiced unsustainable consumption, and business-as-usual approach may jeopardize the ecosystem health and balance while challenging the need for inclusive growth (Lorek and Spangenberg, 2014). Three strands of arguments have aroused on the reliability of SDGs. First, the livelihood argument – the poor depend on their local ecosystems for their survival (Chambers and Conway, 1991); second, the vulnerable argument – vulnerability of the poor may be exacerbated by the effects of climate change (Paavola and Adger, 2006); third, the Anthropocene argument – great acceleration in demand for natural resources may lead to ecospace grabbing, establishing large corporations by richest, and changing rules in favour of the access to scarce but valuable resources by affluent. In par with the increasing population, materialistic lifestyles demand limited resources unlimitedly that may end up with exploitation, depletion and extinction of resources but the cost has to be paid by rural poor. Therefore, several questions arise; who has the right to access these resources and when can these rights be curtailed? Who has relevant responsibilities and how can such responsibilities be monitored and implemented? Who faces the risks caused by abuse of the rights and responsibilities, and who compensates for these risks? (Gupta and Lebel, 2010).

This calls for five principles namely (i) adopt ecocentric limits from local to global level; (ii) equitably share rights, responsibilities, and risks, (iii) build resilience and adaptive capacity, (iv) green international cooperative instruments, and (v) involve all stakeholders.

Relational inclusiveness

Relational inclusiveness discusses poverty, social inequality, exclusion, and vulnerability (Laven, 2010; Ros-Tonen et al. 2015). Social inequality is due to difference in income, wealth, opportunities, and access between rich and poor. Although historically inequality reduced in the 20th century, it is rising again, especially due to globalization—worsening the situation further to polarization. Uneven taxation (tax evasion and tax avoidance), exploitation of capital markets, development of intellectual property rights, and power vested on to exploit natural resources and sinks are noticeable shortfalls. The rich and leading economies dominate over helpless and powerless marginalized communities/countries creating ecological inequalities where the rich escape from their responsibilities with impunity by influencing the rules of governance through power. The five principles in relational inclusiveness are (i) ensure that public goods and merit goods do not become privatized or securitized; (ii) address all drivers and actors, and combat offshoring, tax havens, and other instruments that lead to concentration of wealth and ecospace; (iii) address discourses that concentrate wealth to ensure that markets and growth take place within an inclusive development paradigm; (iv) test instruments for inclusiveness and ensure downward accountability; and (v) ensure global rule of law and constitutionalism.

Inclusive development largely discusses wellbeing in accordance with social inclusiveness, relational inclusiveness, and ecological inclusiveness because it is the ultimate goal of individuals and societies. Although the SDGs mention wellbeing, its application and implication have been restricted only to social dimensions. Yet, wellbeing is to be achieved in relation to ecological, relational, and economic aspects. The next section elaborates the wellbeing approach in detail.

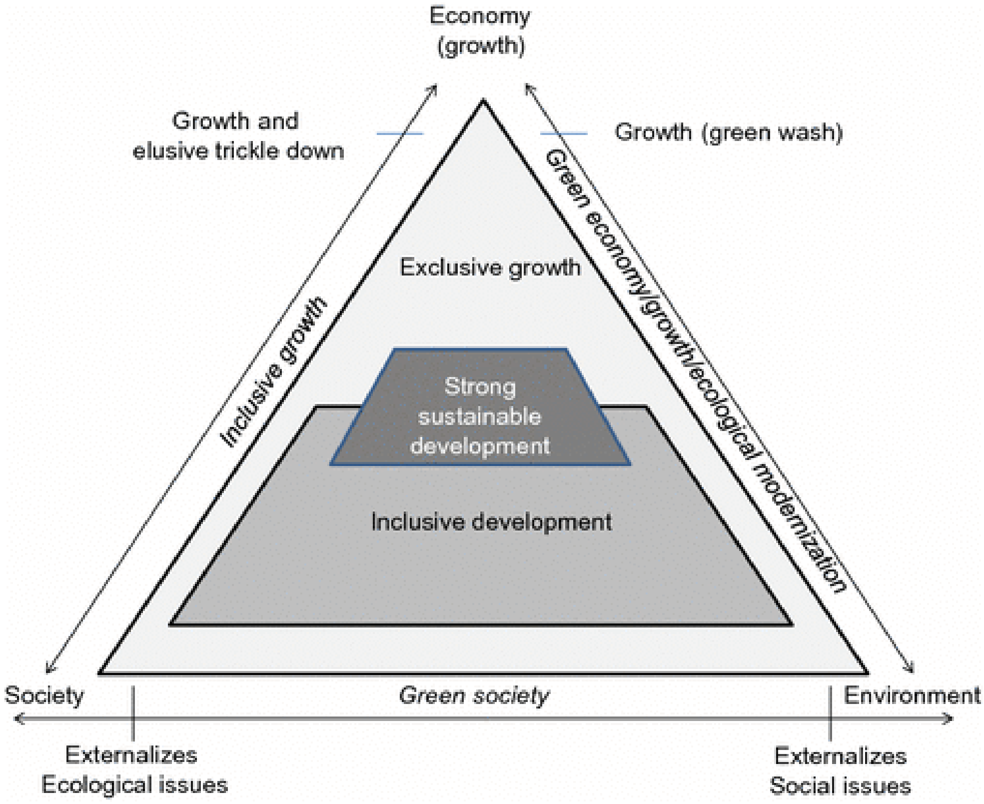

Figure 1: Relationship between inclusive development and Sustainable development

(Source: Gupta and Vegelin, 2016)

Introducing wellbeing approach to assess inclusive development

The social sustainability component emphasizes human wellbeing as the ultimate objective of development (McGregor 2009; McGregor et al. 2009; White 2009). Human wellbeing theory conceptualizes the human being as a social being, for whom social relationships and identity are important (Pouw and McGregor 2014; McGregor 2007). Human wellbeing also has a subjective dimension, apart from the material and relational aspects. Such a comprehensive approach enables the understanding of people's resource needs and priorities, as well as the complex trade-offs made or enforced between economic, social, political, and ecological dimensions.

In the post-financial crisis years, the concept of wellbeing is explained as a way to address the shortcomings of existing economic prosperity indices (Aked et al. 2010). Wellbeing is a critical goal of social inclusiveness, which is one of the ingredients of inclusive development, the others being ecological inclusiveness and relational aspects (Gupta et al. 2015). Wellbeing is a signpost to “shift emphasis from measuring economic production to measuring people’s wellbeing” (Stiglitz et al. 2009: 10). It is a vital part of the current development agenda to achieve individual and community aspirations and the need for a better and content life with appropriate assessment tools (Woodhouse et al. 2015).

As a concept to evaluate a person’s life or ‘being’ (Gasper 2002; Travers and Richardson 1997), wellbeing covers not only the material wealth of individuals but also other aspects in day-to-day life such as social relationships and networks, beliefs, ideologies, security, and satisfaction whereby objective measurements are impossible (Gough 2004). This vast coverage with multiple attributes makes the concept common to different disciplines. Development economics views wellbeing as a subjective concept associated with happiness that is derived from material accomplishments (Lerner 1997). Social psychology views wellbeing as an internal expression of the psychological aspects of individuals. However, the overarching wellbeing approach takes objective and subjective aspects into account (Woodhouse et al. 2015; MEA 2005) and has evolved over decades.

A key imperative is to go beyond GDP, which is basically upon economic growth and productivity, but more meaningfully wellbeing measurements need to be incorporated with ecological and natural capital, relational and cognitive aspects, holistic health, and climatic vulnerabilities. An inclusive development approach is essential in this regard to balance the dominance of the growth approach, especially at the doorstep of the global recession. Disaster resilience infrastructure, especially for island nations like Sri Lanka and other less developed countries, developing future-ready cities and habitats that lessen urban–rural disparities and inequalities, integrity in banking and finance are much needed. Hence, more robust, just and inclusive economic systems are claimed through values and ethic-based approaches, thus wellbeing priorities based inclusive development would be much more effective and appropriate than conventional measures. Further, ecosystem supportive social enterprise should be mainstreamed within a green innovation system.

Guiding principles for a better future

Sustainable consumption and circular carbon economy

As explained by Prof Mohan Munasinghe in his speech delivered on the 5th of April, 2018 at the Sustainable water management and policy forum, he elaborated more on sustainomics, a sustainable living tradition is needed that inspire individuals, communities, institutes, and the world to adopt ecologically conscious practices, conservation, adaptation, and balance between sufficiency and efficiency imperatives are promoted. The Circular Carbon economy, in this regard is a novel concept in advancing sustainable consumption production (reduce wasteful consumption and rebalance), growth, clean energy transition (repair, reuse, and recycle), and ecological sustainability through decarbonisation (remove Carbon Footprint).

Reduce inequalities and disputes across region that would maintain urban–rural balance nurturing traditional and local knowledge systems

Urban–rural migration occurs in large numbers particularly fuelled by climate change and inequality. It increases the number of migrants in urban areas, but they are unable to ensure their wellbeing due to lack of resources, opportunities, congested living environment with limited or poor living conditions, and soaring negative externalities contributed to erosion of human, plant, and animal wellbeing. This calls for rural–urban balance with new models of physical, technological, and social infrastructure development.

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