Proceedings of the international Conference on Geography and Global Sustainability (ICGGS)-2021

09th - 10th of December, 2021

Organized by: The Department of Geography, University of Colombo, Sri Lanka

Proceedings of the International Conference on Geography and Global Sustainability

(ICGGS)-2021

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The Department of Geography

University of Colombo

Sri Lanka

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MISSION STATEMENT

The International Conference on Geography and Global Sustainability (ICGGS – 2021) was organized as a virtual event for the first time in the history of the Department of Geography, Faculty of Arts, the University of Colombo to share geography knowledge of the local and international communities of scientists in parallel with the centenary celebrations of Humanities and Social Sciences in Higher Education in Sri Lanka. The successfully completed ICGGS - 2021 made a platform to discuss various issues, developments and innovations arising in the field of geography and related areas. Organized vibrant panel discussions toured the audience to new dimensions of geography opening eyes to think about the universal applicability of Geography as a subject. It also aimed at unravelling the work of scientists and researchers from the Department of Geography and other universities and institutions of Sri Lanka to the global arena.

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MESSAGE FROM THE VICE CHANCELLOR

I congratulate the members of the Department of Geography for putting together such a wonderful mix of tracks as well as subjects under the banner of a very important topic "Geography and Global Sustainability". The Department of Geography makes our university proud through a research symposium of the study of "Social Sciences and Humanities", particularly at its centenary milestone.

Geography plays an important role, particularly during the Covid-19 epidemic, in teaching and learning as well as research and community outreach, and in addressing sustainability through the integration of different disciplines. I must say that the Chair Professor in Geography and the Dean of the Faculty of Arts, Lasantha Manawadu mesmerized the Senate of the University of Colombo recently with his presentation on Maps and Mapping. The conference track themes have been beautifully depicted. I believe that the students from different disciplines should address the aspects of all these themes. I congratulate the organizers for addressing these and look forward to the university being able to share all findings and discussions, with plans for moving forward in the coming years.

Sri Lanka is a beautiful gem of a country, as we all know. Not only is it a biodiversity hotspot, but we can emphasize the importance of value-added education, particularly through experiential learning. I am very pleased that this year's theme for the overarching theme for the annual research symposium and the dissemination of research findings emphasizing on the role of multi-disciplinary research and, in particular, impactful research.

We eagerly await the outcomes of this meeting, which will clearly address the importance of combating climate change, environmental impact and human development. I am certain this will be a very rich interaction, and that all of our students, not just in Geography, but across the board, will be able to learn from it and think ahead for a better future for our future generations.

Thank you! Stay safe and enjoy the proceedings.

Senior Professor Chandrika N. Wijeyaratne

The Vice Chancellor

University of Colombo

MESSAGE FROM THE DEAN/ FCULTY OF ARTS

As the Dean of the Faculty of Arts, University of Colombo, it is a great privilege and pleasure to address the gathering of the 1st International Conference organized by the Department of Geography, the University of Colombo on the 9th and 10th December 2021.

The idea of the research-teaching nexus has become of increasing importance in thinking about higher education over the last three decades. In literature, it is shown that this idea recognizes the two key functions of higher education – teaching and research – and argues that they are, or should be, closely linked. Therefore, universities have a responsibility to make the research-teaching nexus as strong as possible.

The theme of the ICGGS-2021, ‘Geography and Global Sustainability’ displays the discipline of geography which encompasses both natural and social sciences and has the natural advantage of enabling the study of sustainability from a transdisciplinary perspective. Therefore, the theme of the conference would undoubtedly open up for interactive discussions, arguments, and testing of contemporary issues in the world not only from the geographical perspective but also from the other subjects in the field of humanities and social sciences.

As the Dean of the Faculty of Arts, University of Colombo, I would like to take this opportunity to express my sincere gratitude to the keynote speaker Professor Meththika Vithanage in the Faculty of Applied Sciences, the University of Sri Jayewardenepura, the guest speaker, Emeritus Professor Nimal Dangalla in the Department of Geography, University of Kelaniya and the panelists of the conference. I am delighted to express my sincere gratitude to the Vice-Chancellor of the University, Senior Professor Chandrika N. Wijeyaratne.

I express my appreciation to every member of the Department of Geography, the University of Colombo for your uttermost effort in the success of this event, especially during the challenging time of the Covid-19 pandemic.

I wish all the presenters and participants a memorable and productive conference!

Senior Professor Lasantha Manawadu

The Dean

Faculty of Arts

University of Colombo

MESSAGE FROM THE HEAD OF THE DEPARTMENT

I am delighted to announce that the Department of Geography, University of Colombo is hosting its first international conference online. As a result, I am humbled to be able to address this opportunity. I would like to thank Senior Professor Lasantha Manawadu, Dean of the Faculty of Arts and former Head of the Department of Geography, for initiating the idea for this international conference. It would have been difficult to organize such a conference without his intervention. I would also like to thank all the members of Department of Geography. They worked tirelessly over the last few months to ensure the success of this conference, despite the current pandemic situation.

Holding such a conference at the international level will be extremely beneficial to knowledge dissemination and acquisition for us. That is the primary goal of a conference. Therefore, this is an excellent opportunity to gain new knowledge from both local and international research. On the other hand, it can be considered as an appropriate platform for new researchers in various disciplines to share their new research knowledge. I hope that this conference has provided excellent opportunities for researchers in the field of geography in both Sri Lankan and overseas universities.

I believe that the staff members gained valuable experience by organizing this conference. I hope that the Department of Geography will be able to organize similar seminars in the future as well. I would also like to take this opportunity to thank all the authors, presenters, reviewers, guest speaker, key note speakers, the panelists, moderators and all the participants for their contribution to make this conference a success.

Thank you.

Dr. D.M. Karunadasa

Head

Department of Geography

University of Colombo

MESSAGE FROM THE CO-CHAIRS

Space and time have been contracted with the present-day technological evolution hence global has become a village. The space, as always happening, has been altered daily showing the new patterns of morphological changes either naturally and artificially. Built spaces upon the natural environment have been in trending nature day by day encouraging people to encroach on vertical space rather than the horizontal which is highly restricted. The Earth which is full of resources is becoming more vulnerable to deficiencies and degradation, hence sustainability becomes a major concern at the moment. With the growing population of the world, the natural environment has become more susceptible to disasters and vulnerable situations are needed to be more attentive with some kind of risk reduction strategies. This is because the notion of community resilience has come to the fore.

Geography, the heart behind the science of the Earth, has concerned on the above issues of the world. The avenues initiated in various directions to cater with the global trends are the facets of Geography. Within the context of Geography, physical and social approaches are deemed in characterizing the space and time on the earth. The interactions between the earth's surface and human activities explore the new trends in the development of the field of Geography. Day by day new interfaces is being developed discussing the world sustainability and disaster risk reduction.

The Department of Geography which is one of the oldest academic departments of the University of Colombo explores the new growing trends of the world in the context of Geography. Hence, we planned the first international conference in history to discuss those new trends, solutions, and mitigatory measures for the above-mentioned global issues and new sustainable plans of research to conserve the depleting earth resources and threatened biodiversity. The proposed conference will open new avenues and horizons in introducing findings of their worthwhile research and having opportunities for critical discussions. Each session of the conference is planned to start with a brainstorming session of relevant fields with experts and professionals. The ICGGS 2021 also aligned with the centenary celebration of social sciences and humanities education in Sri Lanka. It is very much happy to declare here that all the scientific sessions of the ICGGS 2021 have successfully concluded.

We, on behalf of the organizers; the Department of Geography extend our sincere gratitude and thanks to all the supporters, collaborators, and researchers actively involved in the process of organizing and conducting the conference and also we encourage them to join us in the future events as well.

Ananda Y. Karunarathne (PhD) and Pathmakumara Jayasinghe (PhD)

Co-chairs of the conference

CONTENTS

KEYNOTE ADDRESS

Microplastics: Sources, Sinks, and Issues

Professor Meththika Vithanage

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Microplastics have become a global environmental concern as they can be ubiquitously found in the environment due to the extensive use and uncontrolled disposal. Primary microplastics are added to the environment from microbeads consisting of personal care products such as toothpaste, face scrubs, and nail polishes while chemical and physical weathering process facilitates the formation of secondary microplastics from macroplastics. The hydrophobic nature of microplastics eases them to act as vectors for potentially toxic organic and metal pollutants influencing their migration through water, soil, and air. Similarly, various additive chemicals may leach from microplastics at different environmental conditions. Therefore, there is a greater risk to expose them to living organisms through accumulation of microplastics through food web and due to its vector transport ability of contaminants. Throughout this speech sources and sinks of microplastics are discussed in detail with scientific evidences. Further, the recent X-Press Pearl shipwreck is used as a case study highlighting the impact of microplastics on coastal environments. Lastly, environmental impact and health issues of microplastics are described with the findings from the literature.

MESSAGE FROM THE GUEST SPEAKER

Powerful Knowledge Embedded in Geography and its Contribution through Sustainability

Emeritus Professor Nimal Dangalla

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Thank you for inviting me to be the Guest of Honor of this conference. It gives me pleasure to involve myself with this international conference, appropriately titled Geography and Global Sustainability.

Today, I intend to draw your attention to a topic which is dear to me and, sincerely think that a large majority of this gathering being geographers, it will be a very close topic to you also.

We are living in a rapidly changing world. During our lifetime of less than 100 years, all of us have been affected by various but interconnected economic, social, cultural, political, environmental and technological transformations in varying degrees. The success of life has been largely determined by our capacity to adapt ourselves to those transformations.

The role of education is to prepare the young generation to make them able to actively participate in all aspects of life in the future world. In fact, they have a relatively shorter period of time than us of the outgoing generation to grasp the dynamics of the future world and educators are charged with the responsibility of making right decisions.

In this short speech I will try my best to bring into light how geography could contribute in the preparation of students for the world of tomorrow. Some are of the view that the content of geography curricula should address the characteristics of the future world but it would be difficult to deal with a rapidly changing world in all its aspects. Rather, it would be more pragmatic to focus on the preparation of students with necessary knowledge, understanding, skills conceptualizing power and attitudes so that they will be active role players of the future world. Butt, in his book entitled 'Geography, Education and the Future', wrote: 'more than any other discipline geography offers the opportunity to acquire knowledge and skills to see clearer how things are running on the planet earth and what we can do differently on a local as well as on a global scale in the time to come (Butt, 2011). The question is however, whether the geographers have utilized that opportunity to the fullest extent possible? I would like to pose this question to you as food for thought.

This is where we have been accused as trespassers of other's land and somewhat ridiculed as jacks of all trades. We have been criticized saying that we do not have a subject of our own. This is not true, but unfortunately, we have not done enough to dispel the accusation.

Geography has a store of powerful knowledge. Powerful knowledge refers to what the knowledge can do or what intellectual power it gives to those who have access to it. Powerful knowledge provides more reliable explanations and new ways of thinking about the world. The discipline of geography is in an advantageous position to adopt the concept of powerful knowledge for obvious reasons.

Owing to the possession of a set of key concepts that helps students to visualize, conceptualize and contextualize the phenomena they study the subject of geography paves ways to strengthen their thinking power.

Although geography possesses a number of key concepts, I will select four major or key concepts that incorporate many other concepts to show how we could augment the thinking power of our student. These key concepts, very familiar to you are, place, space, environment and interconnections. These interconnected and interdependent concepts would provide the foundation to acquire powerful knowledge. What I am saying is instead of relying solely on the contents, this is where we have accused as trespassers, and we should come back to our own basic concepts. Let me allow to elaborate, in a very concise way, the strength of these concepts.

Place is the most fundamental but far reaching and powerful concept in geography. The study of place provides an entry point to step into a complex world waiting to be understood. In geography place is considered as an object of thought rather than an object of study. By being an object of thought it promotes students' thinking and conceptualizing ability; Take, for example, the case of Sri Lanka. How Sri Lanka's location in space has decided its history, culture, economy, politics and, so on. Even in modern day international politics its location continues to play a vital role.

Space is another concept of Geography that enables students to think deeply and powerfully on how the space is organized by the society, how those spatial arrangements have produced specific patterns, relationships and interactions at various scales and to examine the impact of those relationships on people and their environment.

Environment is another concept in geography that encourages students to take an active role in an area which is of critical importance at present. In geography, the students are taught on the reciprocal relationship between man and his bio-physical environment. They learn how man is dependent on environment, resources and services that support his life. They understand the necessity of maintaining a balance between demand and supply in order to sustain human life and would begin to push through their views on a range of environmental issues and problems.

No place on the earth surface lies in isolation. They are inter-connected and inter-dependent. Inter-connection lies at the top of the hierarchy of concepts because it incorporates many other concepts such as location, place, space, scale, time, distance and so on. It becomes powerful, not only because of its richness as a concept but also because of its explanatory power. It equips students with skills to view a place from a holistic perspective. I could go on and on to show how the concepts in geography provides an entry point to equip students with powerful knowledge but the time would not permit to do so.

What I have tried here is to show that coming back to our key concepts would pave way to understand the world realistically. A concept-based pedagogy would produce students with thinking and conceptualizing power. Such a generation would be of immense utility in sustaining our world. It is important to plan and design the curricula based on concepts and the academic research would provide a large amount of content to incorporate with these concepts.

Thank you for your patience.

KEYNOTE ADDRESS; PLENARY SESSION 1

Climate Change Adaptation, Mitigation & Sustainable Development

Dr. Senaka Basnayake

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Year 2021 has seen an unprecedented surge in extreme events globally coupled with the already ongoing impact of COVID-19 pandemic. The sixth assessment synthesis report in its initial findings conclude that changes observed in the climate are unprecedented in thousands of years and some of the changes which has been set in motion is irreversible over hundreds to thousands of years. Countries are experiencing once in 100 years or even higher floods resulting in loss of life and billions of dollars of damage to property. Similarly, heatwaves have also increased considerably and cold waves have become less frequent and extreme which can be attributed to human-induced climate change.

In Paris agreement of 2015, parties to the agreement committed to pursue efforts to limit the temperature increase to 1.5°C in order to 'significantly reduce the risks and impacts of climate change'. But in sixth assessment report it has been assessed with high confidence that it will not be possible to achieve the target of limiting the warming to 1.5°C by end of the century, rather 1.5°C may reach by 2040 or 2050 instead.

Thus, investing in Climate Change Adaptation (CCA) and mitigation becomes more important to combat the changes which are occurring and likely to speed up in the recent future. Though limiting emission of GHGs is one of the main targets, but effect of GHG emission cut-off globally (which is unlikely as can be seen in COP 26 agreement) will not be seen in shorter time scale. The current 2030 action plan as seen in NDCs indicates that globally countries are already off track which could see warming of 2.4°C over the long term.

Thus, CCA becomes a significant measure to manage effects of climate change. Developing economies need to invest in CCA significantly through their own funding or funding from developed economies to adapt to the impacts of climate change, address the loss and damage to people, livelihoods, land and infrastructure that are significantly affected by increasing weather extremes and sea level rise. Adaptation to climate change also complements mitigation efforts e.g. urban greening to reduce temperature rise due to urban heat island effects, mangrove plantation along coastal belts which act as carbon sinks and also acts as buffer to storm surges.

The CCA measures to be adopted nationally or regionally require a buy in from the government and requires mainstreaming in national policies. It also requires to be coherent with global agendas like Paris Climate Agreement, SFDRR, SDGs, and similar global initiatives. Paris Agreement emphasizes significant need for adaptation while sustainable development is an integral part of all the global agendas but disaster risk reduction linkages are underrepresented in Paris Agreement. Loss and damage (L&D) associated with climate change impacts is the key link between the CCA and DRR community where risk assessment carried out by DRR community can be integrated into CCA strategies. These requires awareness raising among policy makers and synergies at regional scale.

CCA and DRR measures also has its limitation or more precisely a threshold beyond which current measures may not be sufficient and solutions are required to avert, minimize and address residual risks and potential L&D. Comprehensive climate risk management may be considered as a way forward to manage the residual risk either through risk insurance, risk financing and transformational changes to address residual risks and L&D. Thus, we can conclude that not only synergy in policies but a close coordinated effort amongst various actors are required to manage climate risks through CCA and climate mitigation measures to achieve sustainability of our planet.

KEYNOTE ADDRESS; PLENARY SESSION 2

Challenges and Opportunities in an Emerging and Changing Disaster Risk Landscape: Ciliwung River Basin, Indonesia

Professor Richard Haigh

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Over the last two years we have seen a lot of reference to the increasingly dynamic and complex disaster risk landscape. In particular, the COVID-19 pandemic has exposed a wide range of vulnerabilities in our society, and the consequences have extended far beyond direct health impacts.

However, this understanding that disaster risk is becoming increasingly complex in a more globalized, highly interconnected world, is not new. Over the last 20 years we have seen growing recognition that we need new structures to govern risk and that allows us to live in and with uncertainty.

A major issue is the complex interdependencies that occur within our tightly coupled urban systems. Urban centres are often acclaimed as engines for economic growth, but in developing countries this expansion is often badly planned and poorly managed. Consequently, cities and towns are linked to social, political, economic and environmental problems, particularly in rapidly developing contexts where increased population density can increase exposure and vulnerability to natural hazards.

When analysed in isolation, most natural hazards do not meet the characteristics of systemic risks. The damage is most often proportional to the energy released, the impacts are local, the relationships are deterministic, and people are aware of these hazards because they have experienced them in the past. However, over time most natural hazards must be seen in the context of much wider vulnerabilities.

For example, and in common with many other countries, flood management in Jakarta has traditionally focused on structural protection measures to lower the probability of the flood hazard through dikes and levees. However, recent years have seen a shift towards a more flood-risk management-based approach in Jakarta. In this approach, flood risk management addresses exposure and vulnerability in combination with traditional hazard-reducing measures.

Despite some progress with these and other measures, local actors increasingly recognise that they are not sufficient to tackle the growing flood threat. A more ambitious strategy is required, from a reduction of climate change and its impacts, controls on pollution, structural measures, basin wide early warning, land use and how it affects discharge and peak river flows, and land subsidence.

More broadly and to address such challenges, there is a need to scale up our efforts to tackle the increasing complexity and interdependency of risks. These efforts must include a move from deterministic to probabilistic analyses. The temptation is to reflect on past experiences as systemic risks are typically obvious in retrospect. But the complexity obscures their workings and inhibits extrapolation from the past to the future. Instead, we need to use models of scenario building to sketch out the non-linear nature of systemic risks.

Society must also embrace uncertainty and acknowledge that building resilience involves making timely decisions based on having good, but not perfect information, and instead focus on an improved understanding of the resilience capacity of communities, institutions, and systems. There is a need to treat resilience as capacity building and take a community-level, place-based approach to understand where risk is realised.

There is also a need to fit governance to the characteristics of the decision context and clarify roles and responsibilities for risk assessment, ownership, and management – a multi-agency approach is required.

KEYNOTE ADDRESS; PLENARY SESSION 3

Urban Futures in Middle-Income Countries: Floods and Slums in Southeast Asia

Professor Edo Andriesse

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Since the 1970s many Asian countries and subsequently other countries situated in the Global South have been able to move on from low-income to middle-income status. However, it has proven to be much more difficult to take the next steps; be successful in manufacturing, advanced producer services, education, and health care, "graduate" to the select group of high-income countries and in the process ensure that the majority of urban and rural populations are free from socioeconomic risks. Instead, more countries are likely to enter the middle-income trap (MIT) in the coming decades. Even for the most successful middle-income countries like China, Malaysia, Botswana, and Mauritius, it remains to be seen whether they can break out from the middle-income group. Furthermore, countries like Chile, Argentina and Greece risk falling back to the MIT.

Consequently, it has become much harder to emulate countries like Taiwan, South Korea, Israel, Chile, and Uruguay. Financial crises, pandemics, automation and robotization, and climate change impacts (e.g. frequent urban flooding) all hamper development of labour markets and stymie the creation of opportunities for middle classes to drive progress towards high-income status. If these concerns are not recognized, the consequences will be the persistence, if not expansion of urban slums, stagnating labour markets, higher levels of socio-spatial inequalities, political polarization, and in the worst-case social unrest. Recurring Latin American debt crises, the 1998 Asian financial crisis, the Greek 2008-2014 economic downfall, the Chilean 2019-2021 unrest, floods in several large Southeast Asian and South Asian metropolises, and the Covid-19 pandemic should be powerful warnings that long-term structural transformation and improving living standards is not a gradual, smooth process.

In light of these concerns, it is necessary to rethink urban futures. This keynote addresses urban challenges in three Southeast Asian capital cities: Bangkok, Jakarta, and Manila. Thailand, Indonesia, and the Philippines are middle-income countries, but it remains to been if the countries can successfully transform themselves and achieve standards of living comparable to Malaysia. I particularly focus on recurring flooding and the persistence of slums. Jakarta and the surrounding urban area host 34 million people, Manila 23 million, and Bangkok 17 million. Both flooding and slum persistence suggest that Southeast Asian metropolises will continue to find it hard to become truly global cities and move from middle-income to high-income status. I also discuss ways as to how the three cities can become flood resistant and how slums can become more sustainable and inclusive. With respect to the former I discuss relocation, creating sponge cities and other adaptative measures, and the new trend of floating neighbourhoods. With respect to the latter attention is paid to improving slum living as well as labour markets.

In conclusion, while urban flooding has received more attention in recent years, urban futures will not be secured without sufficient reorientation towards the poorer urban sections of society.

KEYNOTE ADDRESS; PLENARY SESSION 4

Nature Based Solutions for Sustainability and Resilience

Dr. Ananda Mallawatantri

International Union for Conservation of Nature (IUCN), Sri Lanka

I will be talking about the current global trends in climate change and biodiversity conservation in the post covid-19 setting leading to sustainable development and also nature based solution and their importance and its contribution. I will be mentioning about conservation financing or sustainable financing to ensure the sustainability of ecosystems and ecosystems services and the value of the science based approaches.

We know that today the challenge we have is the climate changed about which many scientific studies and research papers have been published. The climate change effects on agriculture, energy sector of the country, urbanization improvements, monsoons abrupt, quality of life etc. It also many damages due to landslides, floods, sea level rise etc. and also risk is associated with the market. However, the climate risk is unavoidable.

Covid-19, which is zoonotic disease, impact realizes us the broken link with the nature. It emphasizes the need of increasing the attention to the environment and proper collaboration. In post Covid-19 setup, presently people are talking about need of conservation of nature. Around the global the trend is to combine the climate change and biodiversity specially in post Covid-19 context.

Nature based solutions are talking about managing the natural capital. When it comes to Sri Lanka, the country is full of natural capitals including mountains, rivers, forests and well defined natural processes in everywhere.

Disaster profile of the country characterize with the landslides, droughts, floods, cyclones, tsunamis, soil erosion, water pollution, human animal conflicts, industrial pollution and plastics which is the latest etc.

When it comes to sustainability and resilience, sustainability is meeting the needs of the present without compromising the ability of future generations to meet their needs and resilience is the ability to be happy, successful etc again after something difficult or bad happened or bouncing back ability.

Nature based solutions can be applied in many contexts such as climate change, disaster risk reduction etc. There are different types of nature based solutions, some are nature derived, some are nature inspired and some are nature based.

Nature based solution is a timely approach to create the transformational and it is to be promoted with Science, Practices and Policy through multisector and multi stakeholder approaches. Sustainable financing, citizen involvement, awareness and education are success factors among others.

Technical Session - 1

Climate Change, Adaptation and Mitigation

Spatial and Temporal Variations of Air Temperature on Drought Hazard in Sri Lanka: with Special Reference to Hambantota District

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Keywords: Atmospheric, Air temperature, Spatial, Temporal, Climate

1. Introduction

The global climate has been undergoing dramatic changes due to global warming, which is caused by a high rate of industrialization, urbanization, usages of greenhouse gases. Climate change is one of the major environmental issues in both developed and developing worlds (Liyanage et al., 2009), increasing the risk of flood and drought, and other natural disasters, which will finally adversely affect living beings and the country's economy. Therefore, climate change studies have become an essential part of understanding and predicting climate change. (Alahacoon et al., 2021). Agricultural and socio-environmental planning are related to specific climatic conditions to be carried out effectively. An example of this relationship is the adversities of long periods of drought and high temperatures (Caique et al., 2020). Therefore, air temperature is an important phenomenon in weather and climate, which determines all other weather parameters and their changes (Piratheeparajah, 2016). Air temperature records are used to determine all different elements of the climate as well as their changes. Hence, studies on the air temperature of an area will help understand and interpret the climate changes and help predict the future pattern of the climate of the area.

In Sri Lanka, paddy is grown as a major crop all over the country, and there are two main crop seasons in Sri Lanka, called *Yala* and *Maha*. However, crop failures, mainly in the dry zone, have been reported for many years (2001, 2004, 2016, and 2018) due to unprecedented floods and droughts (Prasanna, 2018). In addition, rainfall and air temperature patterns are the primary sources for crop fields, and quantitative value determines whether an area is normal or whether there will be a drought or flood in that area. (Alahacoon et al., 2021). Therefore, a study on air temperature changes during a long period helps identify future trends and the prevalence of drought in a particular area.
The main objective of this study is to analyze spatial and temporal variations of air temperature in Hambantota district, Sri Lanka, from 1997 to 2019.

In addition to the main objective, the following specific objectives were formulated.
1. Identify the monthly changes of air temperature in Hambantota district, Sri Lanka, from 1997 to 2019.
2. Examine the trend and distribution pattern of the annual air temperature in Hambantota district, Sri Lanka, from 1981 to 2019.
3. Predict the annual air temperature for 2030.

2. Methods and Materials

Materials

According to the objectives of the study, secondary data have been used immensely in this research. Air temperature data in the Hambantota district were collected from the secondary sources in the Meteorological Department, Colombo, and NASA Power Data Access Viewer. Temperature data was collected for 28 meteorological stations in Hambantota district including, Agunakolapelessa, Ambalantota, Badagiriya Tank, Bataatha, Bundala Lewaya, Hungama, Katagamuwa, Lunugamwehera, Medamulana, Maha Lewaya, Mamadola, Mattala, Middeniya, Mighajadura, Mirijjawila, Muruthawela Wewa, Palatupana, Ranmuduwewa, Ridiyagama Tank, Sooriyawewa, Talunna, Tangalla, Thissamaharamaya, Uduwila, Uswewa, Weeraketiya, Weerawila and Yala. Monthly average air temperature, Monthly maximum air temperature, and Monthly minimum air temperature for every selected station from 1981 to 2019 were calculated. Further, the number of affected families due to drought hazards in 1997 and 2019 was collected from Hambantota divisional secretariat division.

Methods

The statistical analysis, as well as geospatial analysis, was adopted to accomplish the set objectives. Under the geospatial analysis, the collected data were processed and analyzed in the excel sheet, and geospatial maps were then prepared by using Arc GIS software (10.5 version). A spatial analysis technique in GIS, such as interpolation, was utilized to generate spatial distribution maps of air temperature. Under the statistical analysis, simple linear regression time series analysis was applied to examine air temperature trends in selected meteorological stations because regression is the popular technique used for predicting areas like climate prediction. (Shreehari et al.,2019). The flow chart of the proposed study is shown in Figure 1.

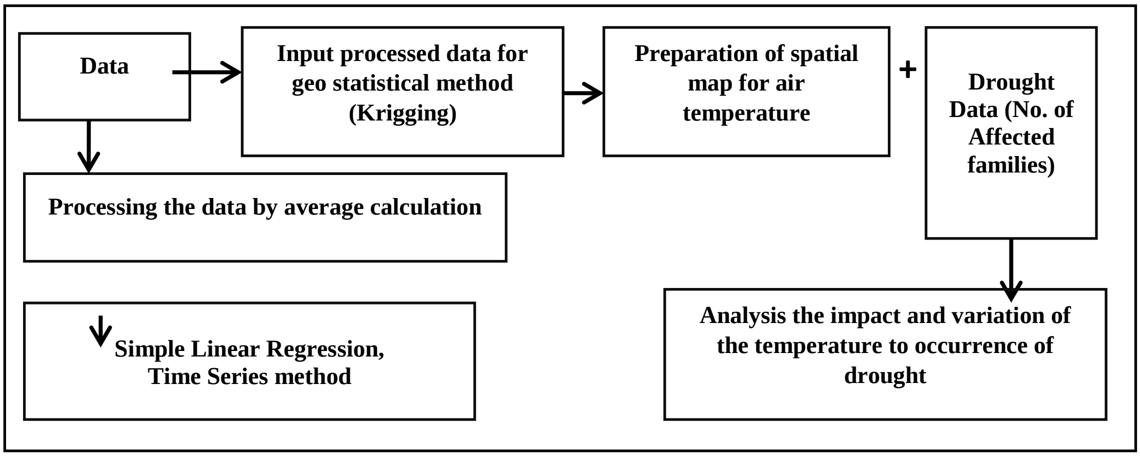

Figure 1: Methodology of the study

3. Results & Discussion

Spatial Distribution of Air Temperature

Air temperature is considered an important parameter that influences the entire weather changes of a place, which can be most affected in the countries which are located near the equator. Temperature over Sri Lanka is measured using standard thermometers as well as maximum and minimum thermometers, which are kept in the Stevenson screen, in accordance with the World Meteorological Organization's (WMO) standard and procedures (Piratheeparajah, 2016).

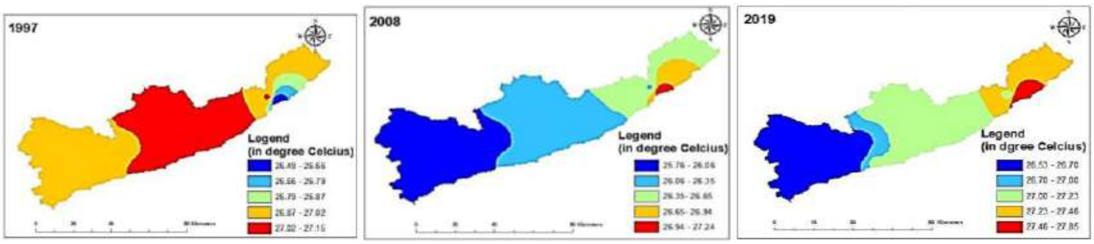

Figure 2: Spatial distribution of annual air temperature in Hambantota district for 1997, 2008 and 2019

According to Figure 2, some variations can be seen in the spatial distribution of annual air temperature in Hambantota district for 1997, 2008, and 2019. Compared with 1997, the maximum air temperature range (27.02-27.15˚C) is recorded in the location of Thissamaharamaya, Palatupana, Lunugamwehera, Uduwila, Bundala Lewaya, Weerawila, Mahalewaya, Mirijjawila, Amabalantota, Badagiriya Tank, Mattala, Ramuduwewa, Suriyawewa and Meegahajandura However, compared to other locations in Hambanthota district, the Yala has recorded the minimum air temperature range of 26.49 - 26.66 ^{0}C compared to other areas in Hambantota district. But in 2008, the maximum air temperature value was recorded as 26.94 – 27.24˚C and recorded in Yala, while the minimum air temperature range (25.76-26.06˚C) was recorded in the rest of the locations. It can be stated that the reason for this increase in the maximum air temperature for 2008 in the Yala area is the influence of deforestation and urbanization.

When comparing the maximum and minimum air temperature ranges in 2008 and 2019, the maximum air temperature value range is increased as 27.46 - 27.85℃ and the minimum air temperature range is increased as 26.53-26.70˚ C that shows the specific increment of minimum and maximum air temperature values compared to 1997 and 2008 values. This temperature increment has been specifically observed after 2008 due to a considerable loss of forest cover under large-scale development projects in the Hambantota district, introduced by local and foreign authorities.

Distribution of the Air Temperature

According to the monthly air temperature data for 1997, 2008, and 2019, some variations are identified in the Hambantota district that can be discussed with four-time durations: December to February, March to April, May to September, and October to November. In 1997, the study area experienced a maximum temperature of 28.65˚C in March and April. In 2008 and 2019, the highest temperature value was recorded from May to September as 27.78˚C and 28.96˚C, respectively. From May to September Hambantota area experiences the highest temperature compared to other months. In 1997, the minimum temperature of 25.75˚C was recorded in October and November which most of the cyclonic activities happened in the Bay of Bengal. Minimum temperature values in 2008 and 2019 were noticed from December to February, as 24.94˚C and 25.45˚C due to the influence of the dry and cold wind blowing from the Indian land-mass. This is because the sun's angle is almost 90^0 to Sri Lanka during March-April. Therefore, the hottest month of the Hambantota district is March and the coldest month is January.

Trend in Annual Air Temperature

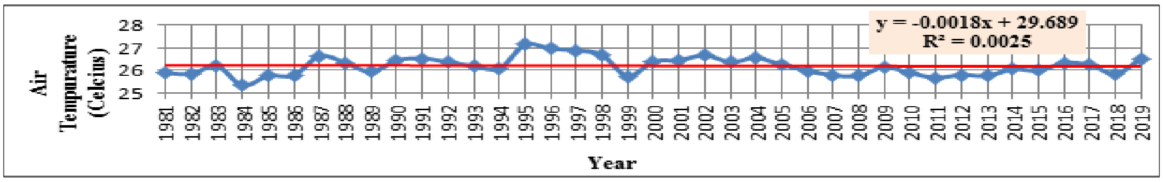

Figure 3: Locations A- Annual air temperature trend for Agunakolapelessa, Bataatha, Hungama, Medamulana, Mamadola, Middeniya, Muruthawela Wewa, Ridiyagama Tank,Thallunna, Thangalle, Uswewa and Weeraketiya in Hambantota District (1981- 2019)

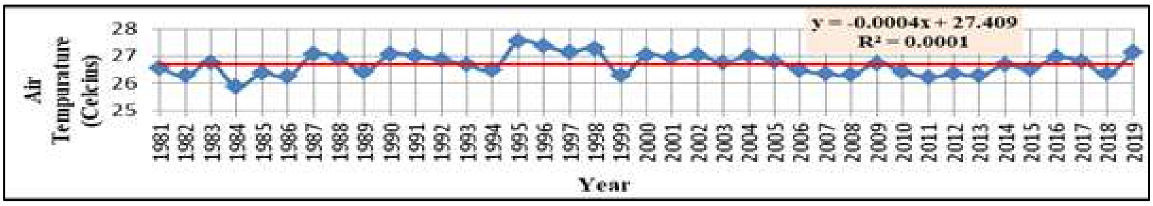

Figure 4 : Locations B - Annual air temperature trend for Amabalantota, Badagiriya Tank, Bundala Lewaya, Lunugamwehera, Mahalewaya, Mattala, Meegahajandura, Mirijjawila, Palatupana, Rammuduwwa, Thissamaharamaya, Weerawila and Uduwila in Hambantota District (1981- 2019)

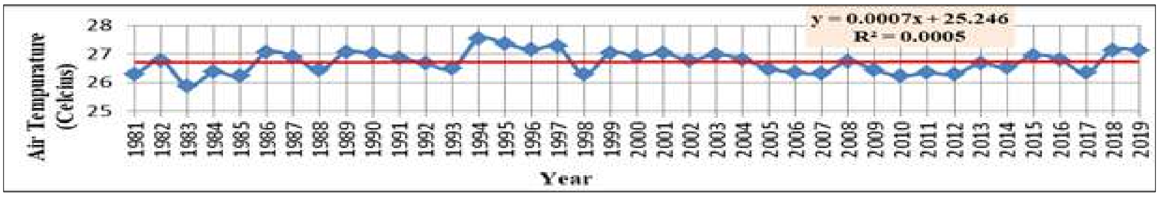

Figure 5: Annual air temperature trend for Katagamuwa in Hambantota District (1981- 2019)

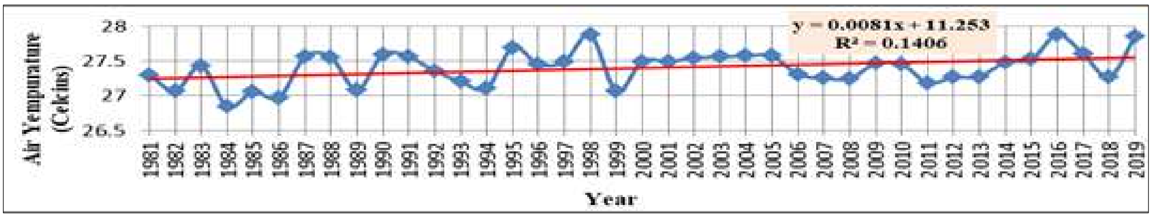

Figure 6: Annual air temperature trend for Yala in Hambantota District (1981- 2019)

The annual air temperature distribution graphs show the temperature pattern in Hambantota district, Sri Lanka, between 1981 to 2019. (Figure 3, 4, 5 & 6). The trend line gives the relationship between annual air temperature variation between 1981 to 2019. The correlation coefficient (R^2) provides necessary evidence for the appropriation of the curve fitted over the range. Based on the regression line, the average air temperature for 2030 at Locations A, B, Katagamuwa, and Yala will obtain 26˚C, 26.6˚C, 26.7˚C, and 27.7˚C respectively.

Table 1. Regression parameters for selected stations

Station	Equation of the Trend Line	Intercept	Slope	R^2
Locations A Agunakolapelessa,Bataatha,Hungama, Medamulana,Mamadola,Middeniya, Muruthawela Wewa, Ridiyagama Tank, Thallunna, Thangalle, Weeraketiya	y = -0.0018x + 29.689	29.689	-0.0018	0.0025
Locations B Ambalantota,Badagiriya Tank, Bundala Lewaya, Lunugamwehera, Maha Lewaya, Mattala, Meegahajandura, Mirijjawila, Palatupana, Rammududuwa, Thissamaharamaya	y = -0.0004x + 27.409	27.409	-0.0004	0.0001
Katagamuwa	y = 0.0007x + 25.246	25.246	0.0007	0.0005
Yala	y = 0.00081x + 11.253	11.253	0.0008	0.1406

According to the regression parameters given in Table 1, Yala shows the highest slope value that recorded the high increment of annual air temperature in 2030. On the other hand, comparing the correlation coefficient of locations A and B shows the most negligible slope value in the regression analysis recording the lower increment of annual air temperature.

Identification of Most Critical Areas

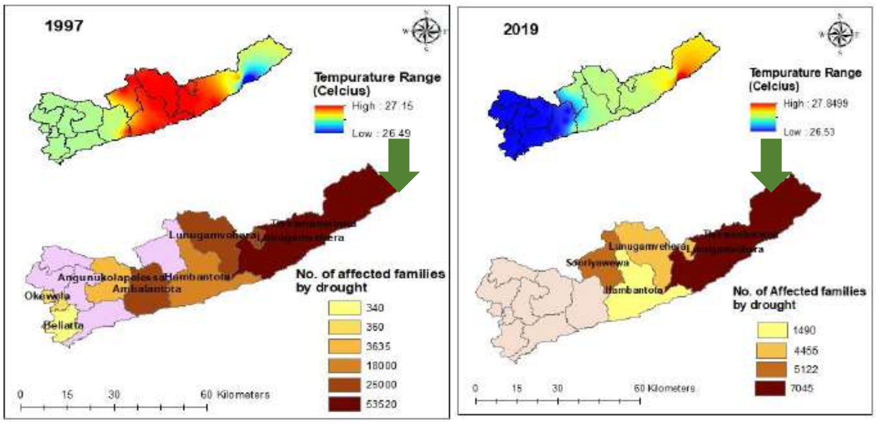

Figure 7: Geographical distribution of drought hazards and the temperature variations across the divisional secretariat divisions in the Hambantota district

Lack of rainfall and high temperature are the main reasons that make any area vulnerable to drought hazards. Figure 7 illustrates the geographical distribution of drought hazards and the temperature variations across the divisional secretariat divisions in the Hambantota District. In 1997, the spatial distribution of drought hazards was uneven, and the affected population count ranged from more than 340 to less than 53,520 at the DS level in 1997 in the Hambantota District. Tissamaharamaya, Lunugamwehera, Hambantota, Sooriya Wewa DS Divisions recorded the highest number of affected populations for drought hazards, and the temperature of those areas represented as the highest value at 27.15˚C. While Beliatta, Okewela represented the minimum temperature value and the lesser amount of affected population for drought hazard in the area for 1997. Accordingly, the spatial distribution of drought events is again uneven in the area, and the affected population count ranges from more than 1,490 to less than 7,045 at the DS level in 2019. The highest number of the affected population in 2019 is recorded in Tissamaharamaya DS. According to the results, the maximum temperature in 2019 is concentrated in Thissamaharamaya DS, and the recorded value of the temperature was 27.85˚C. It revealed that there is a relationship between the drought disaster and the temperature distribution of the area. Moreover, the cluster of Lunugamwehera, Sooriyawewa DS represented average temperature values within the range of 27.23˚C in 2019 and recorded the second-highest DS divisions for drought disasters. In the same year, the least disaster-prone DS with the minimum number of affected population counts recorded in Katuwana, Angunukola Pelessa, and Thangalle received a minimum temperature of 26.53˚C.

4. Conclusion

Hence Climate change can influence humans directly through impacts on health and the risk of extreme events on lives (Mahmoud, 2015). Therefore, climate studies are very important for future planning and development activities in countries like Sri Lanka. This study shows significant spatial changes in air temperature in the Hambantota district within the last 20 years. According to the results, the geographical distribution of drought hazards and the temperature variations are correlated. Although the maximum temperature in the study area in 2019 is higher than in 1997, the affected population count is less than in 1997. In 1997, there was no disaster management plan established in Sri Lanka. After 2005, with the establishment of the Disaster Management Act, the National Disaster Management Council, Ministry of Disaster, Disaster Management Center; coordination of awareness programs for both natural and manmade disasters, disaster management plans, early warning systems, forecasting, research, and developments, generating hazard zonation maps, preparedness was introduced. Through this proper planning and management process, people who live in hazard-prone areas were well educated and they follow proper mitigation actions such as, storing rainwater by the establishment of agricultural wells, introducing tree planting programs, preservation of natural water catchment areas, reducing illegal deforestation, introducing alternative energy to reduce the wood for fuel, etc. Therefore, the number of affected counts, disaster risk, and vulnerability was reduced through systematic disaster management throughout a society. That led to preventing and limiting the negative impacts of drought, within the broad context of sustainable development.

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The intensity of Daily Rainfall over the *Iranaimadu* Tank in Kilinochchi District, Sri Lanka

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Keywords: Intensity, Iranaimadu tank, Monsoon, Rainy days

1. Introduction

The intensity of rainfall events and the number of rainy days must be regarded as an exact event which causing drought or floods as hydrological threats. The frequency of more intense rainfall events in many parts of Asia has increased whereas the number of rainy days and total annual precipitation has decreased (Rajeevan et al, 2008). Changes in climate over the Indian region, particularly the Southwest Monsoon (SWM) (Manikandan, 2014). Domroes, (1998) reported that Sri Lanka's weather is highly dynamic during the SWM and Northeast Monsoon (NEM). The rainfall pattern in Sri Lanka has multiple origins and this pattern is influenced by monsoon winds of the Indian Ocean and the Bay of Bengal (Rekha, 2012). Thevakaran, (2019) stated that, the country is vulnerable to extreme rainfall which leading to droughts and floods. The Northern region predominantly has climatic features pertaining to the dry zone (Piratheeparajah, 2015). Kandiah, (2014) reported that, the Northern region of Sri Lanka has suffered a lot due to droughts and floods.

The *Iranaimadu* tank is a major tank in Northern Province, Sri Lanka. It is located in Kilinochchi district, this district has dry zone agriculture, then the *Iranaimadu* tank is the main water source to farmers for their agriculture activities. Especially, the rainfall pattern determines the farm activities in this area. The daily rainfall pattern over the *Iranaimadu* tank in Kilinochchi District is very much important for future implementations in irrigation and disaster risk reduction. Detailed knowledge of the intensity of the daily rainfall events is essential for proper water management practices. Thus, understanding the variations in the intensity of daily rainfall temporally and improving the ability of forecasting rainfall may help in planning crop cultivation as well as in designing water storage, planning drainage channels for flood mitigation. Therefore, it is necessary to understand the intensity of daily rainfall events. The research problem is to analyse how the intensity of daily rainfall falls over the *Iranaimadu* tank. For that reason, the main objectives of the study are to examine the temporal variation (monthly, seasonal and annual) of the intensity of daily rainfall and the trend of daily rainfall over the *Iranaimadu* tank. Identification of the objective will be much useful to the *Iranaimadu* tank management and future irrigation plans.

2. Methods and Materials

The daily rainfall data for the period of 30 years (1984 - 2018) has been collected from the Regional Irrigation Department, Kilinochchi. Limitation of the study, from 2004 to 2008 on daily rainfall data was not used in this study. Based on the Department of Meteorology, Colombo, Intensity rainfall was categorized into six groups: very light rain (<12.5 mm/ day), light rain (12.5-25 mm/ day), moderate rain (25-50 mm/ day), rather heavy (50-100 mm/ day), heavy (100-150 mm/ day), and very heavy (>150 mm/ day). The intensity of daily rainfall was counted into the categories as per each month, season and annual.

This study used 5 years period (Pentad) daily rainfall data as 6 points to trend analysis. Such as 1984-1988, 1989-1993, 1994-1998, 1999-2003, 2009-2013, and 2014-2018. The trend of the intensity of daily rainfall was analyzed by regression analysis. The magnitude of trend in a time series is determined by regression analysis (parametric test). This method assumes a linear trend in the time series. Regression analysis is conducted with time as the independent variable and rainy days as the dependent variable. A linear equation, $y = mx + b$, defined by b (the intercept) and trend m (the slope), can be fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable. The data analysis was done by descriptive analytical techniques such as tables and charts.

3. Result and Discussion

The count of total average rainy days annually during the period of this research is 61.3, in those days very light rainy days have the highest frequency of 30.7 days. Light rain, moderate rain and heavy rain frequency was stated as 12.7, 10.7 and 0.9 days respectively. Very heavy rainfall was recorded as the lowest daily rainfall in the particular area which is 0.5 days. (Figure 1).

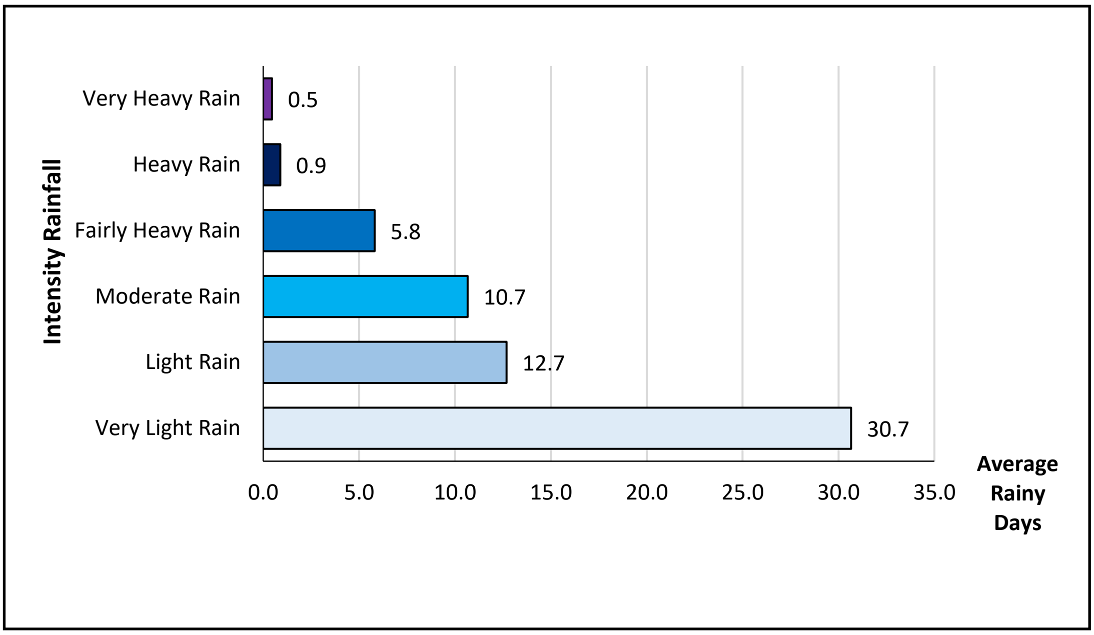

Figure 1: Annual intensity of daily rainfall
Source: Calculated by the author, based on rainfall records of Regional Irrigation Department, Kilinochchi.

According to the seasonal category, the Second Inter monsoon (SIM) has a high number of daily rainfall (23.1 days) and NEM has 19.1 days (Figure. 2). The lowest daily rainfall was noted in the First Inter-monsoon (FIM) as 6.8 days. Lathiscumar, (2020) revealed the highest seasonal rainfall was recorded in SIM season and the lowest seasonal rainfall was recorded in FIM season (that research findings supported this result). In the SIM season the very light rainy day's frequency is high (11.1 days) which is followed by the NEM season (9.29 days). In the seasonal wise analysis, very heavy rainfall (>150 mm) has a total of lowest frequency during all the seasons and very light rainfall (<12.5 mm) was the highest during all the seasons. Very light rainfall, light rainfall, and moderate rainfall was obtained highly during FIM, SWM and NEM seasons and in the season of SIM very light rainfall, moderate rainfall and light rainfall can be obtained (Figure 2).

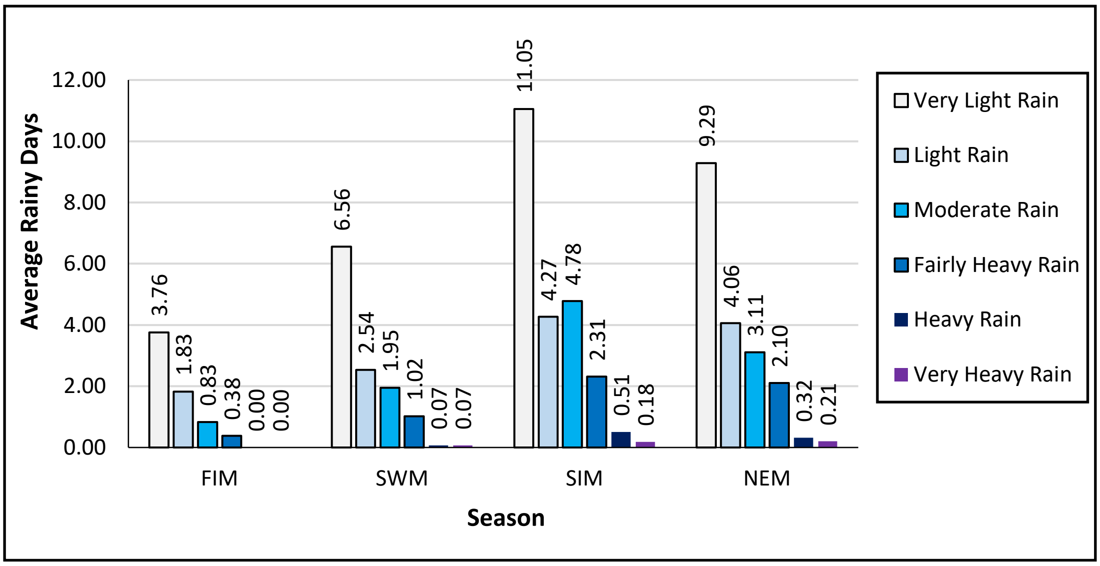

Figure 2. Seasonal intensity of daily rainfall
Source: Calculated by the author, based on rainfall records of Regional Irrigation Department, Kilinochchi

The results indicated that, the month of November was recorded 14.74 days as the highest daily rainfall and 1.07 days noted as the lowest daily rainfall in June (Table. 1). The number of days that received very heavy rainfall (>150 mm) was the lowest daily rainfall in all months. Followed by heavy rainfall (100-150 mm). Very light rainfall (<12.5 mm) was the highest in all months. In order to obtain the three lowest daily rainfall were very heavy rainfall, heavy rainfall and fairly heavy rainfall respectively (Table 1).

Table 1. Monthly intensity of daily rainfall

Months	Intensity of rainy days in each month of the year					
	Very Light	Light	Moderate	Fairly Heavy	Heavy	Very Heavy
January	2.63	1.17	0.70	0.33	0.10	0.10
February	1.52	0.52	0.59	0.34	0.07	0.03
March	1.34	0.69	0.17	0.24	0.00	0.00
April	2.41	1.14	0.66	0.14	0.00	0.00
May	1.90	0.86	0.45	0.24	0.00	0.07
June	0.62	0.17	0.21	0.07	0.00	0.00
July	0.93	0.29	0.25	0.11	0.00	0.00
August	1.25	0.39	0.47	0.18	0.07	0.00
September	1.86	0.82	0.57	0.43	0.00	0.00
October	4.37	1.48	1.70	0.74	0.15	0.11
November	6.88	2.79	3.07	1.57	0.36	0.07
December	5.14	2.37	1.82	1.43	0.15	0.07

Source**:** Calculated by the author, based on rainfall records of Regional Irrigation Department, Kilinochchi

Table 2. Seasonal trend of intensity of daily rainfall

Seasons	Intensity of Daily Rainfall	1984 -1988	1989 -1993	1994 -1998	1999 - 2003	2009 - 2014	2015 - 2018	R^2 value
FIM	Very Light	6.6	2.9	3.4	3.0	3.3	3.4	0.3476 (-)
	Light	2.4	1.6	1.6	1.7	3.0	1.0	0.0386 (-)
	Moderate	1.6	0.4	0.2	0.5	2.5	0.2	0.004 (-)
	Fairly Heavy	0.4	0.1	0.0	0.2	1.0	0.8	0.4180
	Heavy	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Very Heavy	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWM	Very Light	8.2	4.4	7.6	4.8	4.3	10.0	0.0179
	Light	2.6	2.5	3.0	2.0	2.3	3.0	0.0058
	Moderate	2.5	2.2	3.2	0.7	1.8	1.6	0.2676 (-)
	Fairly Heavy	0.9	1.8	1.4	0.5	0.5	1.0	0.1935 (-)
	Heavy	0.0	0.0	0.0	0.2	0.0	0.2	0.3925
	Very Heavy	0.0	0.0	0.0	0.0	0.0	0.4	0.4163
SIM	Very Light	7.9	11.4	12.0	14.0	8.0	11.8	0.0624
	Light	3.1	5.9	3.4	3.2	5.3	5.2	0.1361
	Moderate	4.3	4.0	4.4	4.8	3.3	7.6	0.2637
	Fairly Heavy	1.9	2.5	2.6	0.7	2.8	3.8	0.1898
	Heavy	0.4	0.5	0.2	0.4	0.8	0.8	0.4485
	Very Heavy	0.0	0.4	0.0	0.2	0.3	0.2	0.0308
NEM	Very Light	13.6	9.1	7.4	8.5	8.8	8.4	0.4046 (-)
	Light	4.4	4.0	2.6	3.8	5.0	4.8	0.1495
	Moderate	3.4	1.7	2.0	4.1	4.0	3.4	0.2235
	Fairly Heavy	2.0	1.5	2.0	2.2	3.5	1.6	0.0948
	Heavy	0.4	0.6	0.2	0.0	0.3	0.4	0.1206 (-)
	Very Heavy	0.4	0.2	0.2	0.0	0.3	0.2	0.2354 (-)

Source: Calculated by the author, based on rainfall records of Regional Irrigation Department, Kilinochchi

Table 2 shows the seasonal trend of the intensity of daily rainfall. Here in the season of FIM shows a decreasing trend in very light rain, light rain, and moderate rain. In Particular, very light rain was recorded as decreasing trends as R^2 value is 0.3476 and fairly heavy rain was recorded an increasing trend (R^2 value of 0.4180). In the season of SWM heavy rain and very heavy rain were noted as a significant increasing trend and moderate rain and fairly heavy rain were having decreasing trend. In the SIM season, very light rain, light rain, moderate rain, rather heavy rain, heavy rain, and very heavy rain were recorded as having increasing trends. In this season heavy rain was noted as a significant increasing trend as the R^2 value is 0.4485 and very light rain was noted as a decreasing trend (R^2 value of 0.4046). In the season of NEM, light rain, moderate rain, and fairly heavy rain were having increasing trends (Table2).

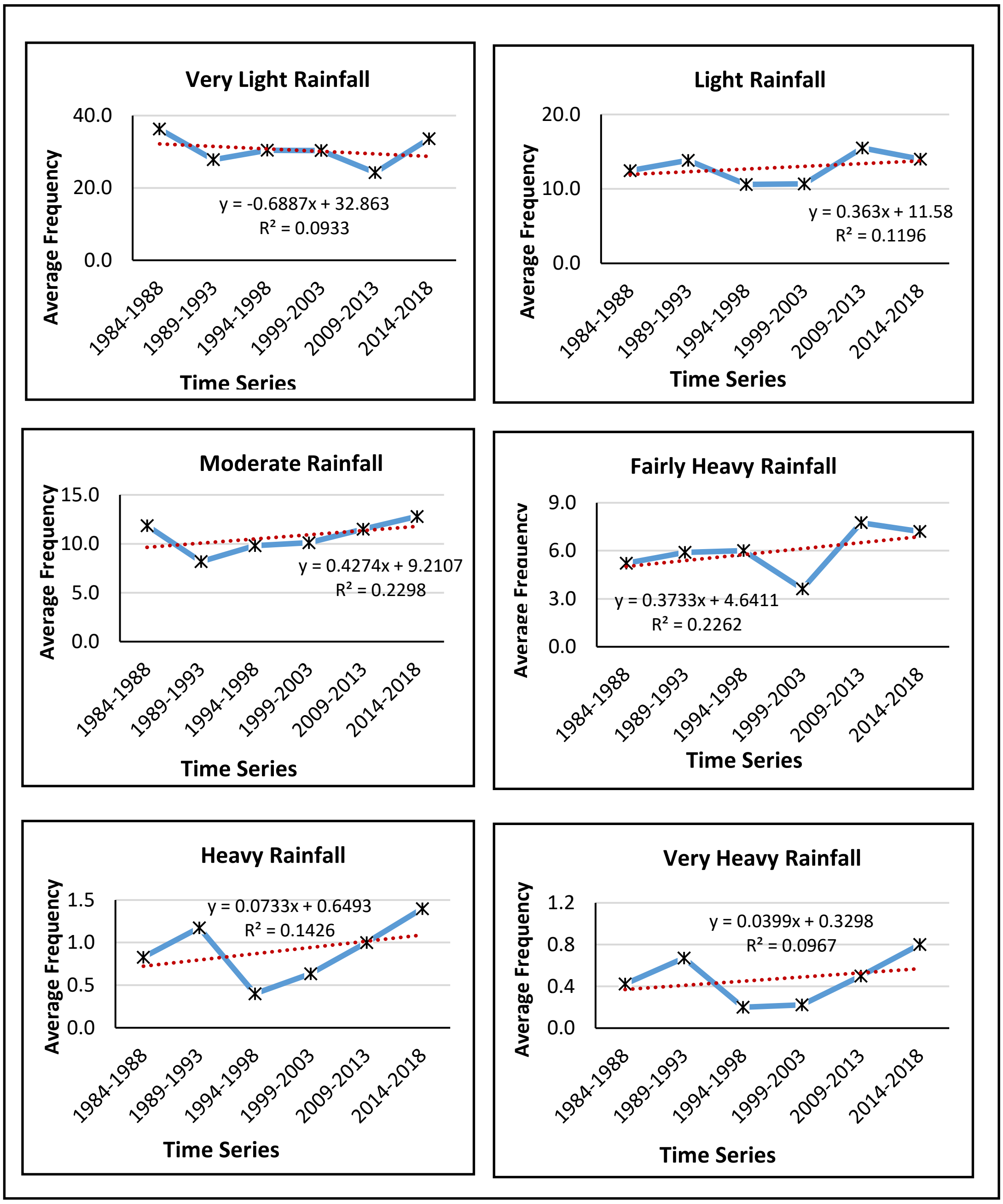

Figure 4. Annual trend of intensity of daily rainfall
Source: Calculated by the author, based on rainfall records of Regional Irrigation Department, Kilinochchi

The results show that there is no significant annual trend in the intensity of daily rainfall. Very light rain only shows annually decreasing trends, with the R^2 value of 0.0933. Light rain (R^2 value of 0.1196), moderate rain (R^2 value of 0.2298), fairly heavy rain (R^2 value of 0.2262), heavy rain (R^2 value of 0.1426), and very heavy rain (R^2 value of 0.0967) show increasing annual trends but not statistically significant (Figure 4).

4. Conclusion

The study reveals that 61.3 days were recorded as the annual average intensity of daily rainfall in the study area. The highest intensity of daily rainfall was recorded during the SIM and followed in NEM. According to the monthly, seasonally and annually category analysis, very light rain was recorded as the highest daily rainfall and very heavy rain was noted as the lowest daily rainfall. The intensity of daily rainfall shows increasing seasonal trends in SIM only. Very light rain only showed decreasing annual trend and other intensity of daily rainfall show increasing annual trend but not statistically significant. The SIM and NEM seasons are key roles in the water storage of the *Iranaimadu* tank. Therefore decision- makers should create an action plan to flood control measures during the SIM and NEM.

5. Acknowledgement

My sincere thanks to the Regional Irrigation Department, Kilinochchi for giving the daily rainfall data.

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Spatiotemporal Analysis of Droughts using Standardized Precipitation Index (SPI) over Sri Lanka

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Keywords: Drought, Standardized Precipitation Index, hydro-meteorological disaster, Dry Events

1. Introduction

Drought is a recurrent natural phenomenon, which causes a large area of natural or artificial water resource depletion for a long time due to the extensive evaporation of surface water caused by delayed rainfall, insufficient rainfall, and overheating. Therefore, drought has a significant adverse impact on agriculture, socio-economic activities, and natural ecosystems. Drought is more severe than any other hydro-meteorological disaster, affecting more people and their crops in a wider geographical area. In the past two decades, the economic losses caused by drought to the world have reached billions of dollars, and the number of people affected by drought has exceeded one billion (Alahacoon et al., 2021). According to the World Health Organization (WHO), it is estimated that 55 million people are affected by drought every year globally. They pose the most serious threat to livestock and crops almost all over the world. Drought threatens people's livelihoods, increases the risk of disease and death, and encourages large-scale migration. Water shortage affects 40 percent of the world's population, and by 2030, as many as 700 million people will be at risk of displacement due to drought (World Health Organization, 2021). The rising temperature caused by climate change makes already dry areas more dry and humid areas more humid. In arid areas, this means that when temperatures rise, water evaporates faster, increasing the risk of drought or prolonging the drought period. Of all the natural disasters recorded in the past ten years, 80-90 percent were caused by floods, droughts, tropical cyclones, heatwaves, and severe storms (World Health Organization, 2021).

Sri Lanka is an island in the southernmost part of India, with nearly 65,610 square kilometers and a population of 21.4 million. The total annual rainfall divides the country into three climatic zones: dry, wet, and intermediate. According to the global climate risk index, in 2017, 2018, and 2019, Sri Lanka ranks 2nd, 6th, and 30th, respectively (Eckstein et al., 2021). Therefore, Sri Lanka is highly vulnerable to climate change. Drought is the most severe disaster in Sri Lanka (Abeysingha & Rajapaksha, 2020; Chandrasekara et al., 2021). As a tropical country, it has been affected by many extreme to severe droughts over the past few decades. Therefore, it is essential to identify drought-prone areas by studying the occurrence and spatial distribution of the Historical and present situation of drought in Sri Lanka (Alahacoon & et al., 2020). There are four categories to measure droughts: (a) meteorological drought; (b) hydrological drought; (c) agricultural drought; (d) socio-economic drought (Abeysingha & Rajapaksha, 2020; Alahacoon et al. 2021; Pani et al., 2016; Chandrasekara et al., 2021).

The standardized precipitation index (SPI) is the most widely used index to detect and describe drought globally. SPI index was developed by McKee et al. In 1993 and described in detail by Edwards and McKee in 1997 (Thomas et al. 1993). Over several decades, the standardized precipitation index – SPI has been successfully used to describe the world's drought conditions and monitor drought conditions at various spatial scales. In 2010, the World Meteorological Organization (WMO) selected SPI as a key indicator of meteorological drought for operational purposes (European Commission, 2020). Therefore, the WMO recommends the SPI to characterize meteorological droughts worldwide.

Recent decades have seen many numbers of researches based on droughts over the world and Sri Lanka. However, a few researches have been done on the whole country (Abeysingha & Rajapaksha, 2020). Most of the research studied drought's spatial and temporal distribution in a small country area (Alahacoon & et al., 2020). Most of these researches have assessed drought conditions using standardized precipitation index (SPI) at 3, 6 and 12-month scales (Abeysingha & Rajapaksha, 2020; Alahacoon et al. 2021; Pani et al., 2016 and Chandrasekara et al., 2021). In addition, some studies have focused the cropping seasons ('*Yala*' and '*Maha*' seasons) in Sri Lanka (Pami & et al., 2016 and Abeysingha & Rajapaksha, 2020). Furthermore, it can be notified the drought conditions were categorized differently in these studies. Most of the studies have used monthly rainfall data observed manually from weather stations on different periods as well as the selected different weather stations to assess the drought conditions (Abeysingha & Rajapaksha, 2020; Alahacoon et al. 2021; Pani et al., 2016; Chandrasekara et al., 2021 and Thomas, 1993). However, in this study, satellite, estimated daily rainfall data over 38 years (1982 – 2020) were used to identify the drought conditions in Sri Lanka. Therefore, this study is important to identify drought conditions in an area using secondary data. Consequently, it can be seen that there are some differences between the research done and the current research.

This study mainly focused on examining the long-term spatiotemporal variability of drought events over Sri Lanka. To achieve the main objective, the study formulated two specific objectives; [1] To assess the drought events using SPI over Sri Lanka, [2] To examine the spatiotemporal pattern of Droughts, and [3] To analyze the seasonal changes of droughts in Sri Lanka from 1982 to 2020.

2. Methods and Materials

Study Area: Country Sri Lanka was selected as a study area of this research. It was located between latitude 05°55'N and 09°50'N; longitude 79°42'E and 81°52'E (Figure 1). Sri Lanka is an island in the Indian Ocean with nearly 65,610 km2 and 21.4 million. Four rainy seasons have been identified in the country, first inter-monsoon (March-April), southwest monsoon (May-September), second inter-monsoon (October-November), and northeast monsoon (Burt & Weerasinghe, 2014). Mean annual rainfall varies from 1000 mm in the South-eastern and North-western coastal areas to over 5000 mm in the western slope of the central hills. The area of Sri Lanka is divided into three main climate zones: dry, wet, and intermediate. Air temperature of the country slightly varies throughout the year except in the central highlands. In the lowland, the mean annual temperature is 27°C with an approximate daily range of 6°C.

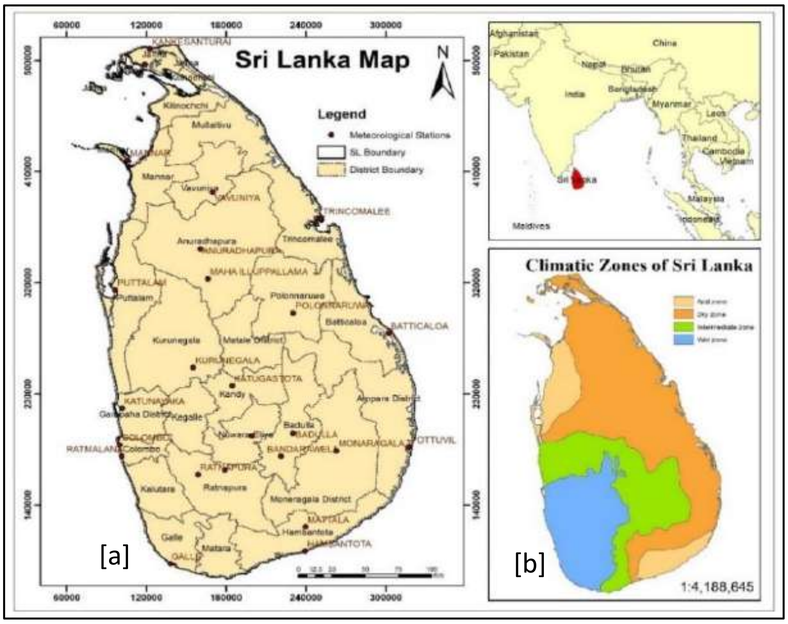

Figure 1: Map of the study area shows [a] Major administrative divisions [b] Climatic zones

Data Collection: The daily rainfall data of 25 met stations from 1982 to 2020 were used in SPI calculations. Daily rainfall data estimated by the satellites were downloaded from the NASA POWER weather database. The NASA POWER Data Access Viewer (DAV) contains meteorology-related parameters and, according to the research conducted by Monteiro et al., 2017, indicated a high positive significant performance for air temperature (Wijeratne & et al., 2020)

Data Analysis: The droughts in Sri Lanka were assessed using the standardized Precipitation Index (SPI) at SPI-1, SPI-3, SPI-6, and SPI-12 months scale. The SPI was calculated using the following equation:

$$SPI = (Xj - Xm)/\sigma \qquad \textit{Equation 1}$$

Xj= is the seasonal precipitation and, Xm is its long-term seasonal mean, and σ is its standard deviation of the long-term seasonal period. Calculated SPI values of SPI-1, SPI-3, SPI-6, and SPI-12 months scale were interpolated to identify the distribution changes of droughts in different time scales. The calculated SPI Values has ranged between <-3 to +3< and the value of SPI can be divided as exceptional wet (3<), extremely wet (2.5 - 3), severely wet (2 – 2.5), moderately wet (1.5 – 2), wet (1 – 1.5), normal (-0.5 – 0.5), dry (-1 – -1.5), moderately dry (-1.5 – -2), severely dry (-2 – -2.5), extremely dry (-2.5 - -3) and exceptional dry (<-3) (Table 1). Figure 1 shows the distribution of SPI values and the classes. All analyses were carried out using ArcGIS 10.1 and Excel 2013 software.

Table 1: Distribution of SPI values and the classes

SPI Value	Class
SPI ≥ 2.5	Exceptional Wet
2.5 ≤ SPI < 2	Extreme Wet
2 ≤ SPI < 1.5	Severely Wet
1.5 ≤ SPI < 1	Moderately Wet
1 ≤ SPI < 0.5	Wet
0.5 ≤ SPI < -0.5	Normal
-0.5 ≤ SPI < -1	Dry
-1 ≤ SPI < -1.5	Moderately Dry
1.5 ≤ SPI < -2	Severely Dry
-2 ≤ SPI < -2.5	Extreme Dry
SPI >-2.5	Exceptional Dry

3. Results and Discussion

Temporal variability of droughts in SPI-1 Month Analysis: The results of the SPI- 1-month analysis revealed that five Extreme dry events (-2 > SPI-1 > -2.5) were recorded during the study period (1982-2020), and it can be identified in Vavuniya (1995), Katunayake (1987), Colombo (1987), Rathmalana (1987) and Galle (1987) areas are as vulnerable to the extreme dry droughts in Sri Lanka. Moreover, the study results shown that 139 severely dry events (-1.5 > SPI-1 > -2), 1,074 of moderately dry events (-1 > SPI-1 > -1.5) and 2,920 of dry events (-0.5 > SPI-1 > -1) in 25 stations during study period of 1982 to 2020. When it discusses each month, 55 severely dry events were recorded in November, which is the highest number of dry events recorded in this study area. Also, 20 and 24 total severely dry events were recorded in September and October, respectively. Most of the moderately dry events can be identified in October, recorded as around 150 events. More than 350 total drought events have been reported in January and February during the last 38 years (Figure 2)

Table 2: Total number of drought events by month in 25 met stations (1982-2020)

Month	Total Drought Events	-0.5 > SPI > -1	-1 > SPI > -1.5	-1.5 > SPI > -2	-2 > SPI > -2.5	SPI >-2.5
		Dry	moderately dry	severely dry	extremely dry	Exceptional Dry
January	370	358	12	0	0	0
February	377	356	21	0	0	0
March	374	295	79	0	0	0
April	394	279	115	0	0	0
May	294	196	91	7	0	0
June	373	271	93	9	0	0
July	296	216	64	12	4	0
August	369	210	150	9	0	0
September	330	196	114	20	0	0
October	306	146	136	24	0	0
November	302	154	92	55	1	0
December	353	243	107	3	0	0
Total	**4138**	**2920**	**1074**	**139**	**5**	**0**

Spatiotemporal Distribution of Drought Events: Spatial variability of droughts in the first study year (1985 – 1986 water year), severely dry and moderately dry events were distributed in October, December, June, and July months in the 1985 – 1986 water year. According to the map Northern, Western and Southeastern areas have become the most affected area by droughts this year. January and March can be seen as wet months of this year. According to the spatial variability of droughts at the SPI – 1 Month scale in the 2015 – 2016 water year, October, November, December, and May can be identified as wet months. This year there are four months, and the month of May became an extremely wet month because of the extreme rainfall received from the Southwest monsoon season in Sri Lanka. Because of that, there are not any drought events in these months. When focusing on the drought events reported this year, most regions faced severely dry and moderately dry events in August and September (Figure 2).

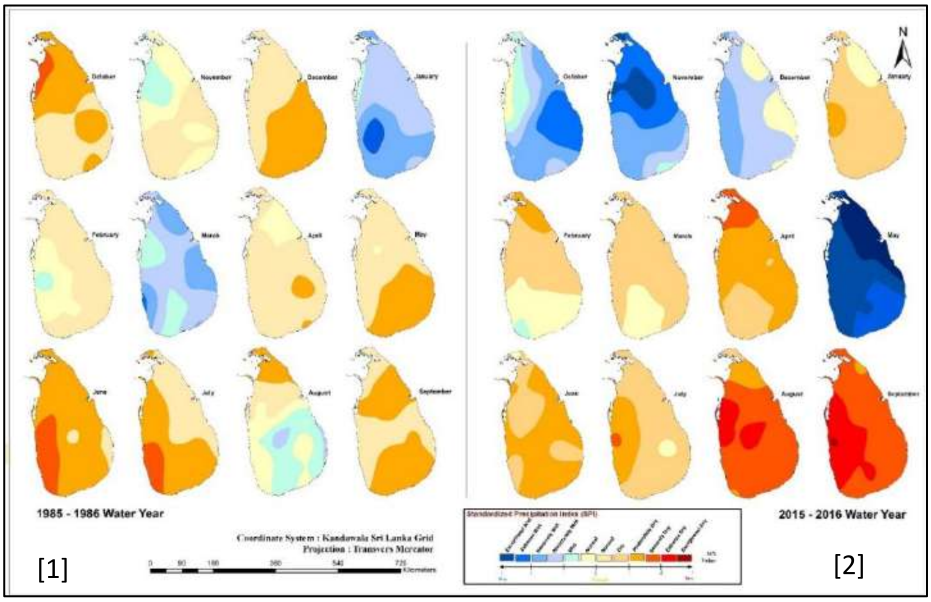

Figure 2: Spatial variability of droughts in Sri Lanka (SPI-1 month scale)

Seasonal variability of Droughts: According to the seasonal and spatial droughts, variability was analyzed using the SPI – 3 months analysis for selected water years of 1985/1986, 1995/1996, 2005/2006, and 2015/2016 in the study period; during the 1985/1986 water year (April to June), most of the areas of the country has experienced the highest number of drought events (-0.5 > SPI). The same experience can be seen again in the water year of 2005/2006. Compared with other selected water years, more drought events were reported between July and September in the 2015/2016 Water year, and the 1996/1997 water year has happened every three months. Analysis was done in different time sequences, and October to March and April to September periods were used as a 6-month time scale (SPI-6) as these periods are cropping seasons of "*Maha*" and "*Yala*", respectively, in Sri Lanka. The total number of reported drought events in the *Maha* and *Yala* seasons from 1982 to 2020. According to this, drought events were reported in 24 stations in the *Yala* season in the 1994/1995 water year in Sri Lanka. Moreover, drought conditions can be detected over the whole country during the *Maha* season in 1988/1989, 1994/1995, 1995/1996, and 1996/1997 water years during the past 38 years (Figure 3).

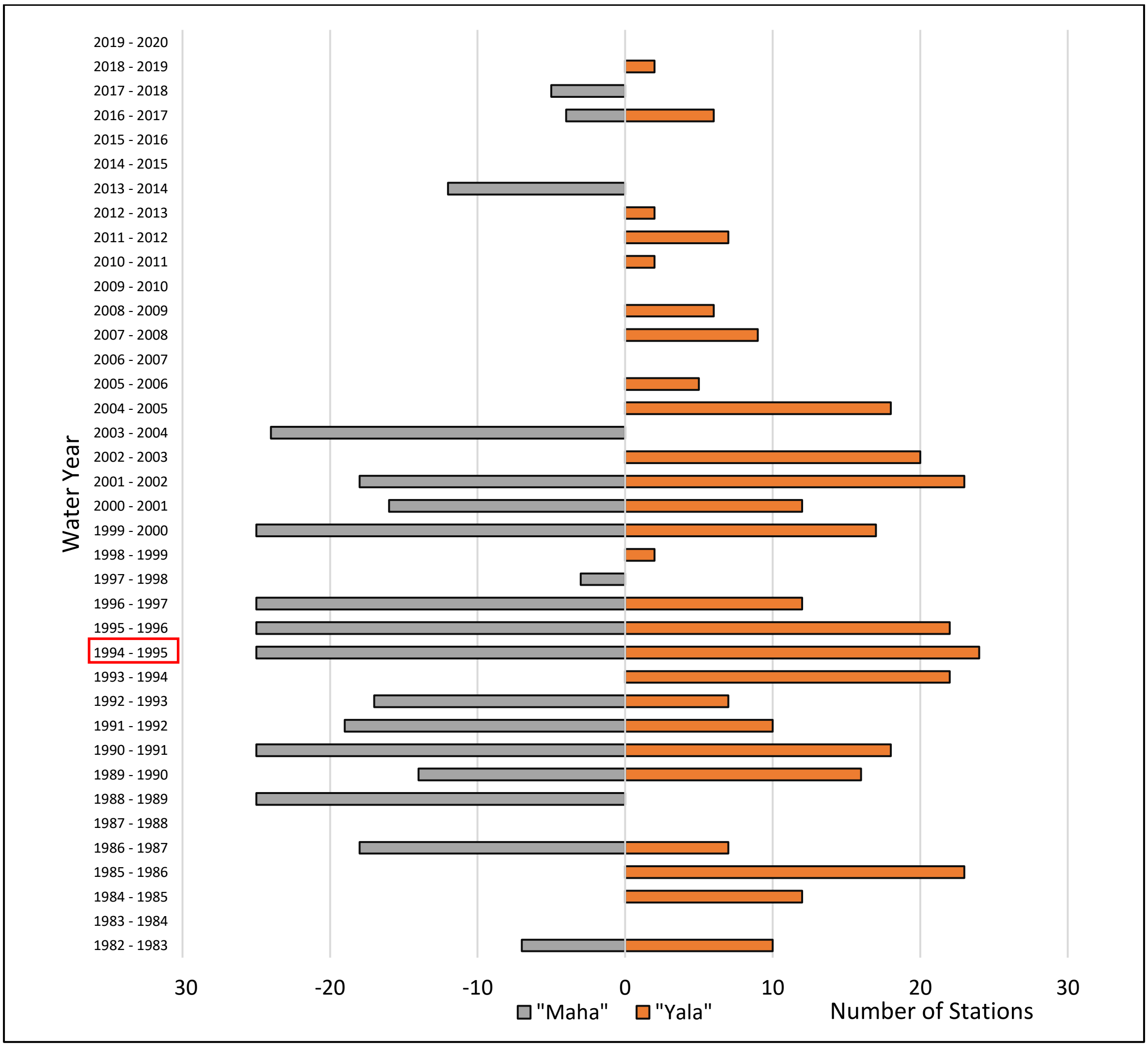

Figure 3: Droughts variability in *Yala* and *Maha* seasons

According to the findings of SPI – 12 Month (Year) calculations, it can identify the most critical drought events identified in the whole country from the 1994/1995 water year to the 1996/1997 water year (Figure 4). According to research (Wijeratne & et al., 2020) conducted on air temperature during this period in Sri Lanka, 1994 to 1998 can be identified as a warm year with very high air temperature. Therefore, the air temperature has contributed to the increment of droughts events in the above-mentioned period.

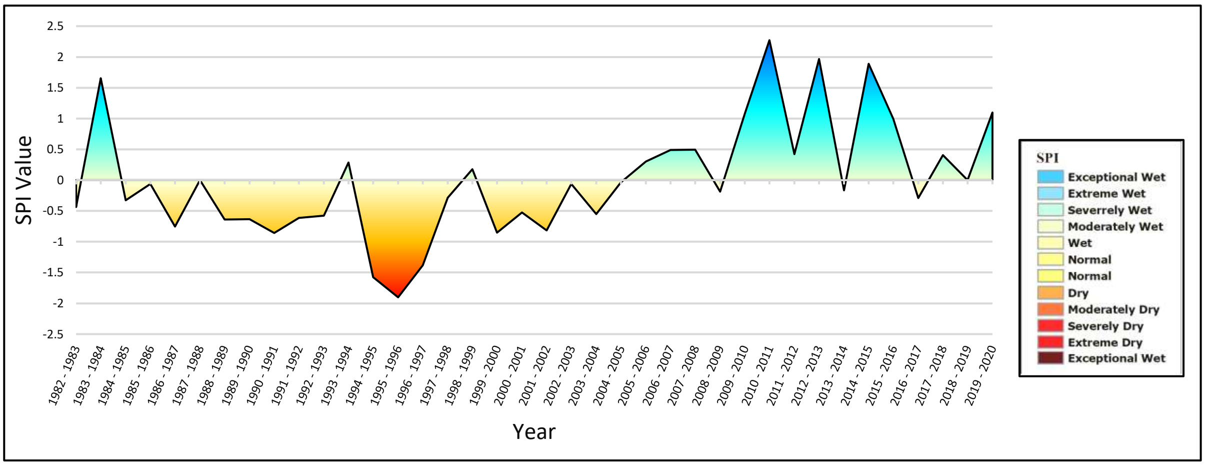

Figure 4: Annual drought events associated with the six rain gauge measurement centers (SPI-12)

4. Conclusion

According to the analysis carried out using the SPI-1 Month scale in 38 years (1982 – 2020), there are five extremely dry events (-2 > SPI-1 > -2.5) that can be identified in Vavuniya, Katunayake, Colombo, Rathmalana, and Galle Meteorological Stations in Sri Lanka. Furthermore, 139 severely dry (-1.5 > SPI-1 > -2) events, 1,074 Moderately Dry (-1 > SPI-1 > -1.5) events and 2,920 dry (-0.5 > SPI-1 > -1) events can also be identified in Sri Lanka during this time period. When focusing on the finding of the SPI - 3 Month scale, a higher number (350) of drought events (SPI < -0.5) can be seen in April, May, and June. According to the SPI-6, there are 314 drought events occurred in the *'yala'* agricultural season (April to September**).** Moreover, the year 1996 can be identified as a year with critical drought events in Sri Lanka. According to the study results, it can be identified that the SPI-3 and SPI-6 is the most effective calculation for defining the drought situations in Sri Lanka. This kind of study enables us to measure current situations as well as identify past situations and patterns. It has the potential to predict future droughts. It enables us to take long-term action on potential problems and find answers to potential problems in the future.

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Land Surface Temperature (LST) Variations and their Impact on Glacial Behaviour in Hunza Nagar, Pakistan, using Landsat Imagery

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Keywords: GLOF, surge, retreat, snow index, Hunza

1. Introduction

Glaciers in many parts of the world have retreated dramatically (Benn & Owen, 2002). Central Asian Mountains are the most glaciated areas other than Polar Regions (Owen, Finkel, & Caffee, 2002), having about 33 times the glacier cover of the European Alps (Mayewski & Jeschke, 1979). Massive loss in glacial ice has been observed over the planet due to global warming since the end of the little ice age (D'Agata, Diolaiuti, Maragno, Smiraglia, & Pelfini, 2020). Runoff from glaciers is the primary source of water supply to rivers, providing water for irrigation and other purposes. Fluctuations in temperature and precipitation patterns cause glaciers to advance or retreat. Glaciers of the European Alps are also retreating due to unfavorable changes in precipitation patterns after 1850 (Mölg, Hardy, Cullen, & Kaser, 2008). According to the latest studies, glaciers are retreating and increasing the occurrence of glacier-related hazards and also increasing sea levels. According to Fifth Assessment Report IPCC (, 2013), global temperature has been increased by 0.85 °C since 1880 (Shafique, Faiz, Bacha, & Ullah, 2018). Melting of Greenland ice sheet can increase 25 feet global sea level (Carey, 2010). The average temperature in the Indian Sub-continent can be increased by 3.5°C to 5.5°C by 2100 (Bajracharya et al. 2008). Glacier meltwater increases the river discharge, but in the longer term, it reduces it (Scherler, Bookhagen, & Strecker, 2011). The Indus irrigation system is an important part of Pakistan's economy (Akhtar, Ahmad, & Booij, 2008). The meltwater of glaciers is the main source of the Indus River (Abid & Zia, 2019). Like other regions, Pakistan is also dealing with the increasing trends in temperature as 0.76°C temperature increased in the last four decades and 1.5°C increased in high elevation regions such as Gilgit Baltistan. This change in temperature influences glacier activities (Din, Tariq, Mahmood, & Rasul, 2014). The Karakorum, Himalayas, and Hindu-Kush are the highest mountain ranges of Northern Pakistan and have the world's biggest glaciers (Shafique et al., 2018). Siachen is the longest glacier outside Polar Regions, about 75km long, located in Karakorum Mountains. Hispar glacier is 61km in length (Mayewski & Jeschke, 1979). The Indian monsoon highly influences Karakorum glaciers. Glaciers of Karakorum have steep hillslope and are mostly debris-covered (Scherler et al., 2011). Mainly, precipitation occurs in spring and winter in the form of snow on glaciers of Karakorum because they are at extremely high altitudes. The climate of Karakorum is altered by Tibetan anticyclones and westerlies, increasing snowfall in winters (Farinotti et al.2020). The average annual precipitation in the Baltoro glacier is 2500mm at 8000m. The highest precipitation occurs in the summer monsoon in the Hunza basin (Immerzeel et al. 2012). Global warming causes a mass loss of 10% in the high mountains of Asia, which increased almost 3% sea level (Wu et al. 2020). Climate change is responsible for glacial advance and retreat and monsoon rain also increases the risk of lake bursting (Ashraf et al. 2012).

The HKH region is also influenced by climate change, and Glacial Lake Outburst Flood GLOFs came out like a looming threat. Glacier area variations are a severe menace in the Karakorum region (Begum, 2019). Climate change can intensify natural hazards such as Glacial Lake Outburst Flood (GLOF), which can harm the population (Ashraf et al., 2012). LST is the major factor that drives mass loss. Land surface temperature alters the physical, chemical, and biological processes and has a major role in hydrology and climate change studies (Wu et al., 2019). Land Surface Temperature is used to observe the land surface physical processes and estimate air temperature in mountainous regions (Zhang et al., 2018). Glacial lakes are usually formed at the glacier's snout as a result of the glacier’s melting. The Karakorum, Himalaya and Hindukush (HKH) are the most affected regions of GLOF. Critical glacial lakes can cause the destruction of the CPEC route along the Karakorum highway (Khan et al., 2021). More attention is required to unceasing extension in lakes created by debris-covered glaciers because of their potential burst. The glacial hazard of GLOFs can destroy the farmlands and downstream settlements (Gilany & Iqbal, 2020).

Glaciers of Karakorum have been retreating since1990 but surging in glaciers have also been noticed. Climate is the most important factor of change in the glacial behavior of Karakorum (Hewitt, 2014). Some glaciers of Karakorum are surging, such as the Hassan Abad glacier (Mayewski & Jeschke, 1979). In the last 15 years, the Passu glacier has undergone a forceful retreat and increased danger in Atta Bad Lake, which can burst in the near future. The Passu glacial lake experienced two outbursts in two decades, destroying houses and bridges on Karakorum highway and debris flowing downstream, consuming the structures on the way (Rasul et al. 2011). This paper aimed to explore LST variations on the behavior of Passu, Ghulkin and Gulmit glaciers, lying in the Hunza Nagar district of Gilgit Baltistan, Pakistan, for the last three decades.

2. Methods and Materials

Study Area

The study area is comprised of Hunza Nagar district, Upper Hunza, Gilgit Baltistan, which is a large glaciated area in North Pakistan. The Hunza valley is situated at an elevation of 2,438 meters (7,999 feet). Hunza lies between 36.3167° N and 74.6500° E. Some of the Highest Mountain Peaks are located in the region, such as Batura Muztagh. Selected glaciers are Passu, Ghulkin, and Gulmit, located to the south of the Batura glacier. Passu Glacier lies between 36.4698° N, 74.7732° E, Gulmit glacier lies between 36.4098° N, 74.7726° E and Ghulkin lies between 36.4075° N, 74.8639° E. The remote sensing datasets used for the study are coarse to high-resolution satellite imagery and Digital Elevation Model. Since LANDSAT data is available from 1972, various LANDSAT data were used in the research. By comparing all the available images for the study area, the images were selected with the least cloud cover for April, September, and December. A total of 12 LANDSAT(TM/ETM+/OLI/TIRS) images were downloaded from the United States Geological Survey (USGS). As the area is mostly cloud-covered, images for April, November, and December were selected, ensuring the least snow coverage. Following are the details of the datasets. The study area covered four tiles with path and row 149-34, 149-35, 150-34, 150-35. Images were downloaded for the years 1993, 2001, 2010, and 2020. As the two tiles of the study area were not available for the year 2001, so two images of two tiles were downloaded for the year 2002.

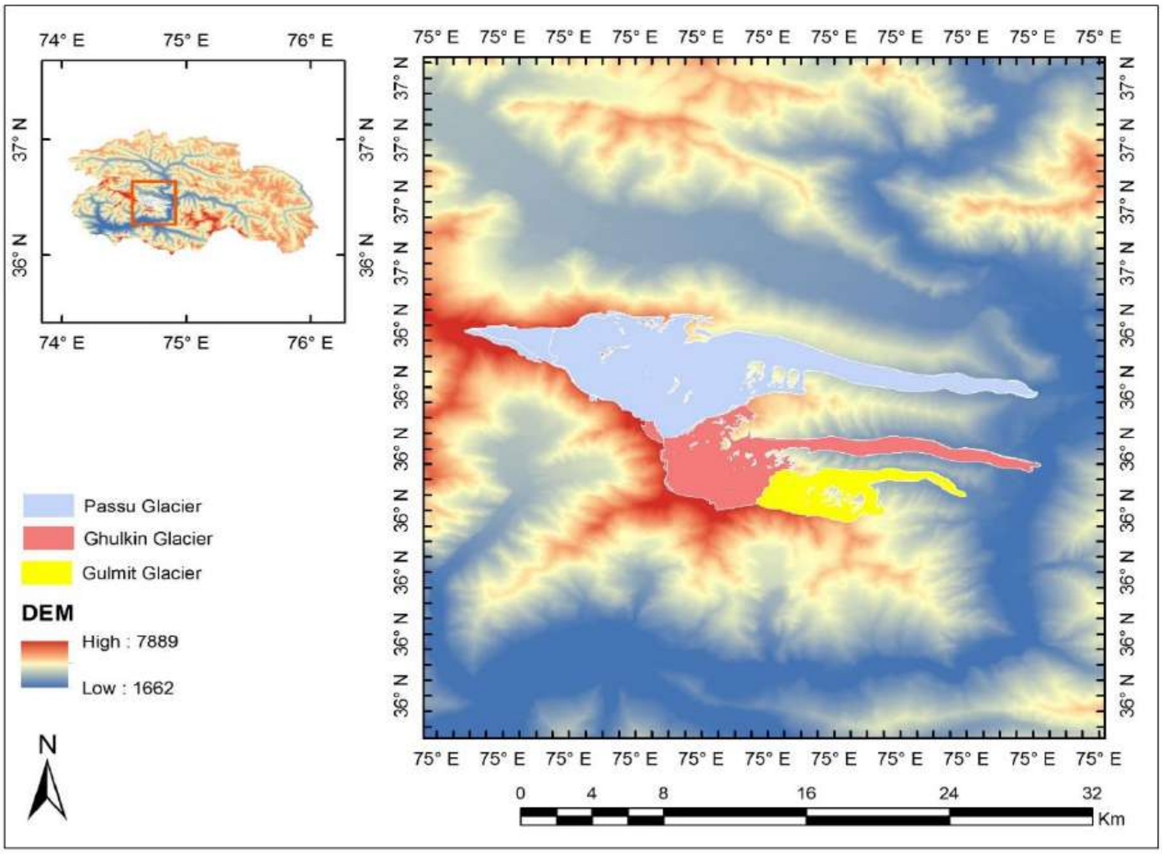

Figure 1**:** Location map of study area

Table 1. Details of Datasets

Data	**No. of Bands**	**Spatial Resolution(m)**	**Month**	**Year**
Landsat 5(TM)	2,3,4,5,6	30	Nov, Dec	1993,2010
Landsat7(ETM+)	2,3,4,5,6	30	Nov	2001
Landsat8(OLI/TIRS)	3,4,5,6,10	30	April	2020

Data Analysis

For LST calculations, Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (OLI, TIRS) collection 2 level 2 data of the study area were downloaded from USGS Earth Explorer.

Formulae applied for LST calculations are shown as follows:

Calculation of TOA (Top of Atmospheric) Spectral Radiance:

$$L\lambda = \left(\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right) - (QCAL - QCALMIN) + LMIN\lambda$$

(Debnath et al., 2018)

$L\lambda$= Spectral Radiance in watts

$LMAX\lambda$=RADIANCE_MAX_Band 6(From metadata)

$LMIN\lambda$=RADIANCE_MIN_Band 6 (From metadata)

QCALMAX=QUANTIZE_CAL_MAX _Band 6 (From metadata)

QCALMIN=QUANTIZE_CAL_MIN_Band 6 (From metadata)

Qcal = Band 6

ii) Brightness Temperature:

BT= (K2/(In(K1/L)+1))-273.15

K1= K1_CONSTANT_BAND_6

K2= K2_CONSTANT_BAND_6

L= TOA

Normalized Difference Snow Index (NDSI)

NDSI is used to identify snow from clouds and other non-snow-covered conditions (Salomonson & Appel, 2004). NDSI has been widely used for mapping the snow extent.

The following formula was used for calculating NDSI.

$$\text{NDSI} = \frac{Green\ Band\ Reflectance - SWIR\ Band\ Reflectance}{Green\ Band\ Reflectance + SWIR\ Band\ Reflectance}$$

Here ‘‘green’’ is the reflectance of the visible band (0.52–0.60 mm) and SWIR is the reflectance of the shortwave-infrared band (1.55–1.75 mm) (Shimamura, Izumi, & Matsuyama, 2006).

For Landsat 5 and Landsat 7:

$$\text{NDSI} = \frac{B2-B5}{B2+B5}$$

For Landsat 8:

$$\text{NDSI} = \frac{B3-B6}{B3+B6}$$

Normalized Difference Water Index (NDWI)

NDWI is a technique that was developed primarily to delineate open water features enhancing their visibility in remotely sensed digital imaging while removing soil and vegetation features (McFeeters, 1996).

Following formula applied for calculating NDWI.

$$\text{NDWI} = \frac{Green-NIR}{Green+NIR}$$

Where NIR is near-infrared band reflectance. The same formula was used with the different band no for Landsat 5, 7 and 8.

For Landsat 5(TM):

$$\text{NDWI} = \frac{b2-b4}{b2+b4}$$

Where b2 is the visible band, while b4 is the near-infrared band.

For Landsat 7(ETM+):

$$\text{NDWI} = \frac{b4-b5}{b4+b5}$$

Where b4 is the near-infrared band, while b5 is the short-wave infrared band.

For Landsat 8 (OLI):

$$\text{NDWI} = \frac{b3-b5}{b3+b5}$$

Where b3 is green while b5 is near-infrared.

Normalized Difference Glacier Index (NDGI)
Normalized Difference Glacier Index (NDGI) is a numerical indicator that helps to detect and monitor glaciers by using the green and red spectral bands. The main remote sensing applications that NDGI is used are glacier detection and monitoring.

The following formula was applied for calculating NDGI (Das and Rai, 2018).

$$\text{NDGI} = \frac{Green\ band - Red\ band}{Green\ band + Red\ band}$$

For landsat 5(TM) and landsat 7 (ETM+):

$$\text{NDGI} = \frac{b2 - b3}{b2 + b3}$$

Where b2 in Landsat 5 and 7 are visible (0.52 – 0.60 µm, and b3 is 0.63 – 0.69 µm.

For landsat 8 (OLI):

$$\text{NDGI} = \frac{b3 - b4}{b3 + b4}$$

Where b3 is green and b4 is red.

Table 2: Source and utility of spectral indices used in the study

Spectral Indices	Source	Utility
Normalized Difference Glacier Index (NDGI)	Keshri et al. (2009)	Mapping and differentiating between snow-ice and ice mixed debris class
Normalized Difference Snow Index (NDSI)	Mazhar et al. (2020)	Mapping and differentiating between snow-covered and snow-free areas
Normalized Difference Water Index (NDWI)	Shukla and Ali (2016)	Mapping surface water

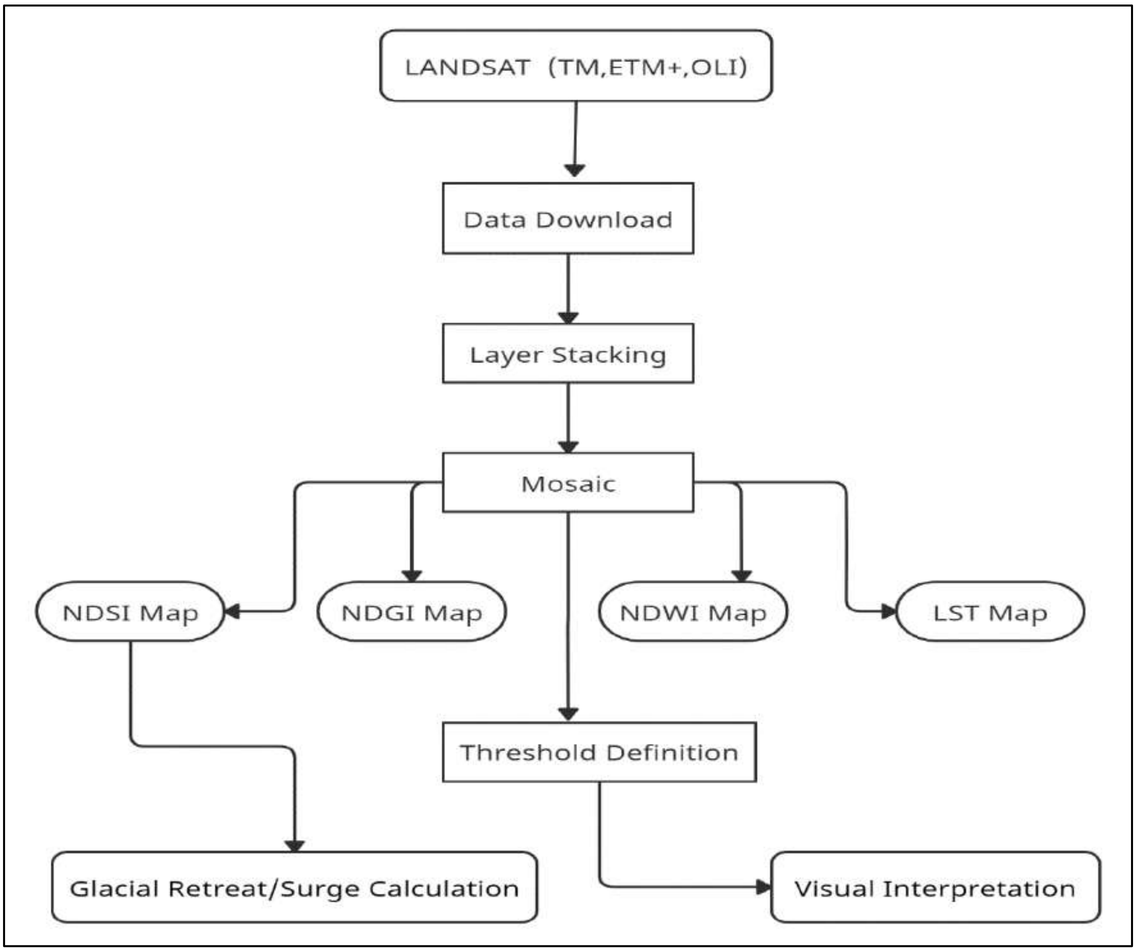

Figure 2**:** Methodology of the study

4. **Results and Discussion**

Land Surface Temperature (LST)

The land surface temperature of four years of the study area was calculated considering 1993 to 2020 (Figure 3). The figure shows that LST had increased in the study area with the time, within the period 1993 to 2010. In 1999, the highest value of LST was 37.0ºC and, in 2010, it was 42.9ºC. Relatively, a decrease of LST could be identified in 2020 due to the COVID-19, the climate repaired itself, and the situation improved, as the study area experienced consistent snowfall and less retreat. As a result, the highest value of LST was 37.5ºC in 2020.

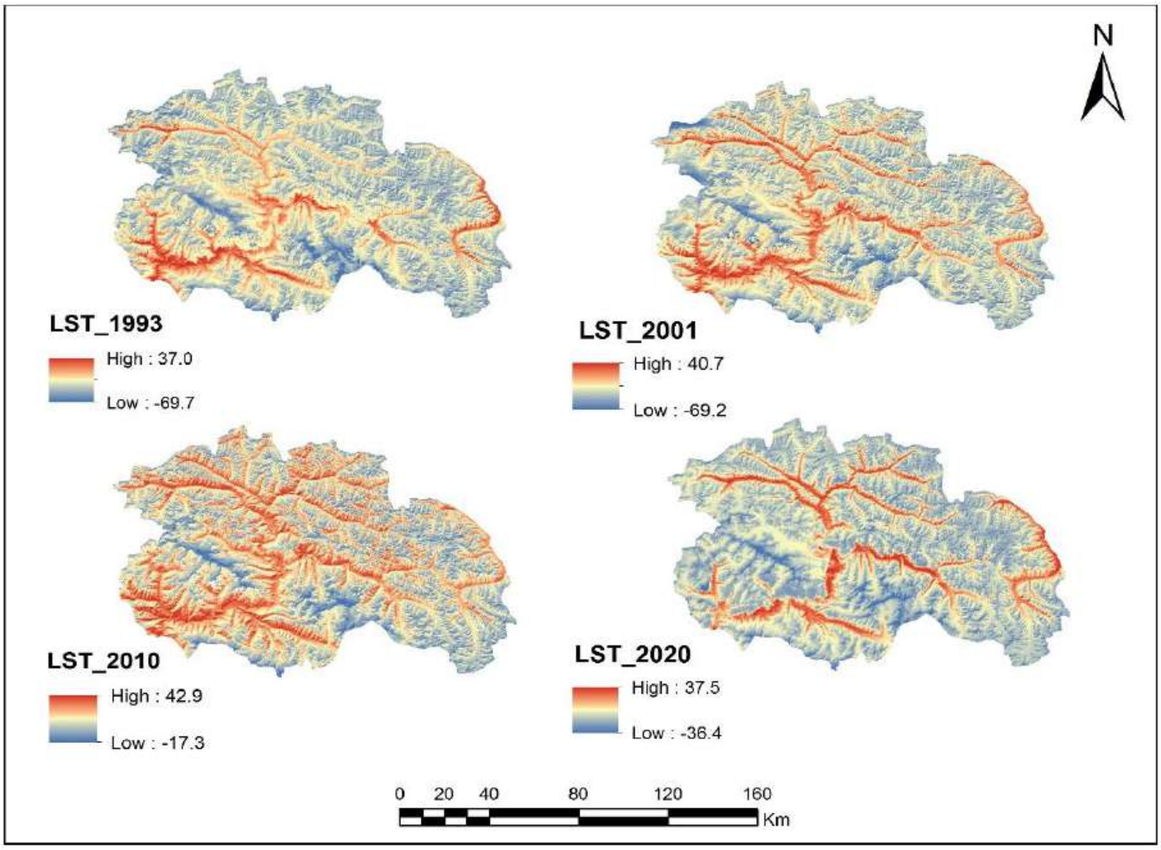

Figure 3**:** LST map of Hunza

Normalized Difference Glacier Index (NDGI)

The range of NDGI varies from -1 to 1. The threshold value chosen for study area dataset was 0.025.Keshri et al. (2009) used the same threshold to differentiate snow and ice from debris. Pixels with values less than 0.025 were reclassified as snow, ice and pixels with values greater than 0.025 were reclassified as ice mixed debris. In 1993 there was maximum snow, ice cover and in 2020 there was maximum debris cover, with the passage of time snow cover decreased and debris cover increased as we can see in Figure 4. From 1993 to 2020 we can see that high value of NDGI is 0.26 in 1993 as the years went by, we saw that the value decreased to 0.25 in 2020, it was lowest in 2010. In 2010 as we see in figure 3 highest value of LST which increases the snow melting which in turn increase river flow and lead to flood conditions therefore glacierized region decreased in 2010. In Figure 3 LST has minimum high value in 1993.

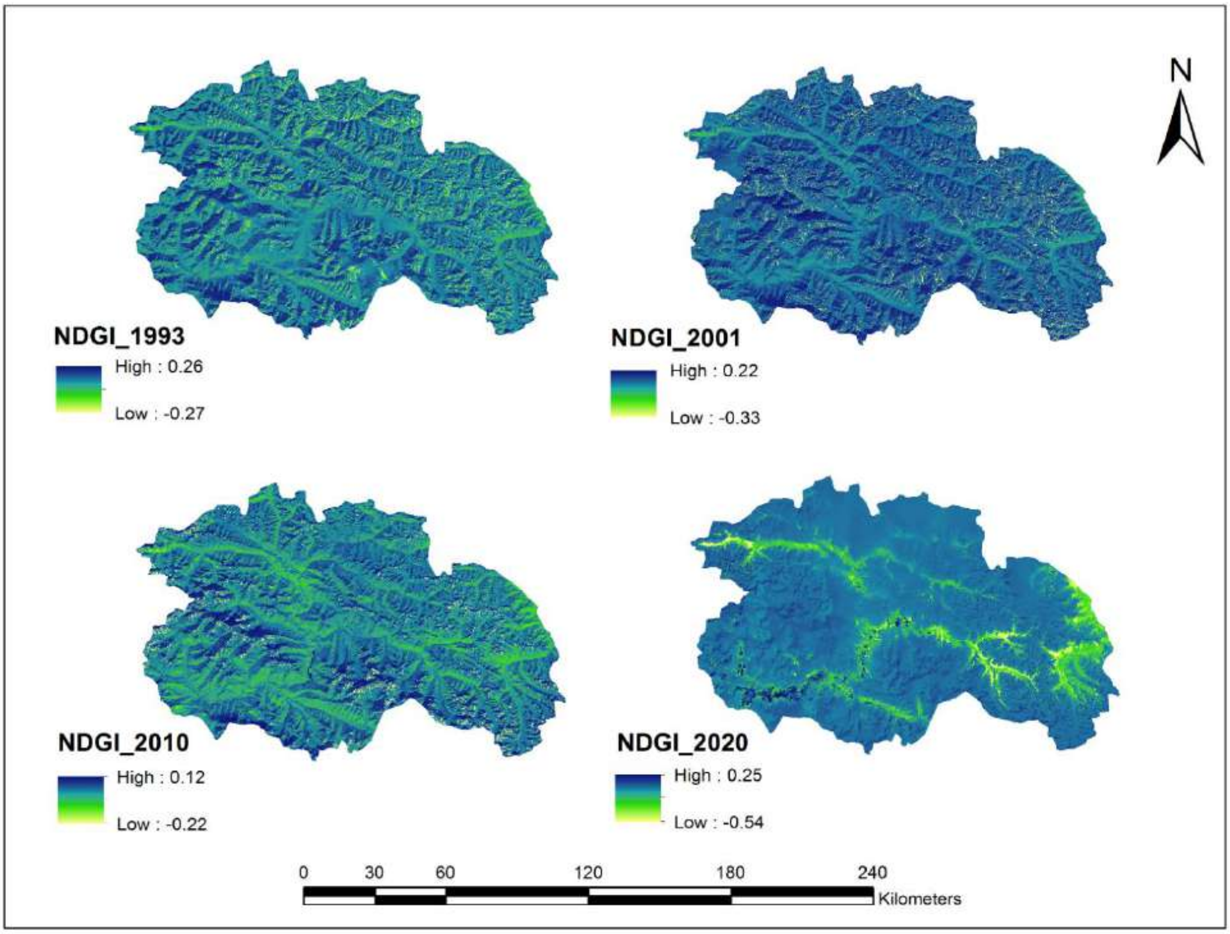

Figure 4**:** NDGI map of Hunza

Normalized Difference Snow Index (NDSI)

The range of NDSI varies from -1 to 1. The threshold of 0.40 was used to differentiate the snow. Numerous researchers have used the same threshold, such as Mazhar et al. (2020) and others. Based on this threshold value, pixels with less than 0.40 were reclassified as snow-free areas, and pixels with values greater than 0.40 were reclassified as snow-covered areas. From 1993 to 2020, the highest value of NDSI in the area (0.77) was identified in 2001, as shown in Figure 5. This gives the idea that the maximum snow-covered in the study area was in 2001. In contrast, the lowest value of NDSI in the area (0.74) was identified in 2010. That means the snow-covered area of the study area decreased in 2010 compared to the rest of the years.

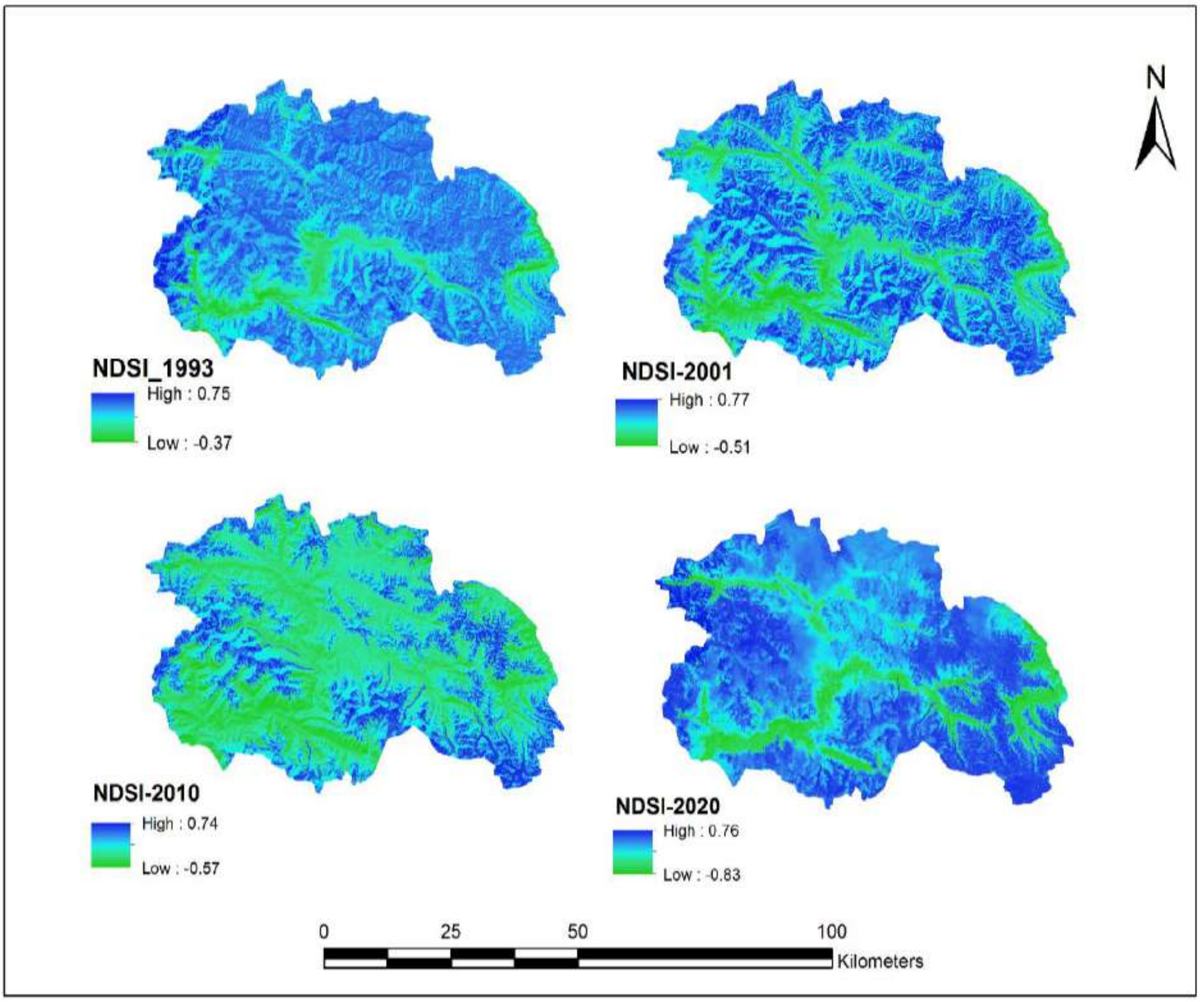

Figure 5**:** NDSI map of Hunza

Normalized Difference Water Index (NDWI)

NDWI was calculated to identify water and water-less areas. The range of NDWI varies from -1 to 1. The threshold value used for the study area is 0.35. Shukla and Ali (2016) also used the same threshold. Pixels with values less than 0.35 were reclassified as water. Pixels with values more than 0.025 were reclassified as waterless. As shown in Figure 6, from 1993 to 2020, the highest value of NDWI (0.81) was seen in 1993 and 2001. As the years went by, the value kept decreasing, and the lowest value was observed in 2010. As shown in Figure 6, areas with less water had been reduced in 2010 and 2020 when compared to 1993 and 2001.

Glacial Retreat/ Surge

The Passu Glacier, Ghulkin Glacier, and Gulmit Glacier were chosen to identify their surge or retreat. After calculating the snow index, the snow-covered and snow-free areas of glaciers were calculated for 1993, 2001, 2010, and 2020. In Figure 6, the brown color indicates a snow-free area, and the blue indicates a snow-covered area. The snow-covered area was maximum in 2020, while the snow-free area was maximum in 1993 and 2010. Therefore, the highest LST in the study area in 2010 could be aligned with the maximum snow-free area in 2010. In 2020, instead of a decrease, the snow-covered area increased, which means that instead of retreating, glaciers are advancing.

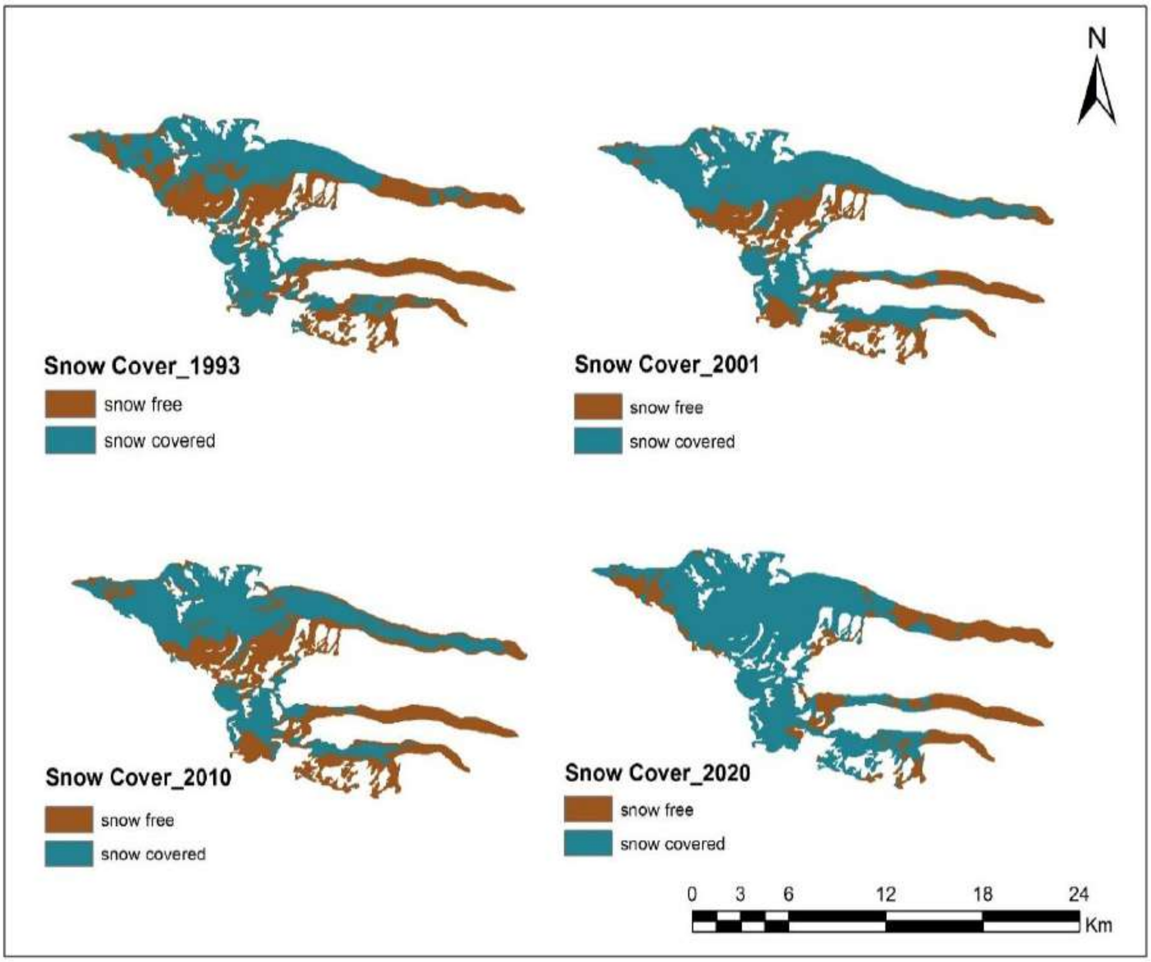

Figure 6: Map of snow cover of selected glaciers

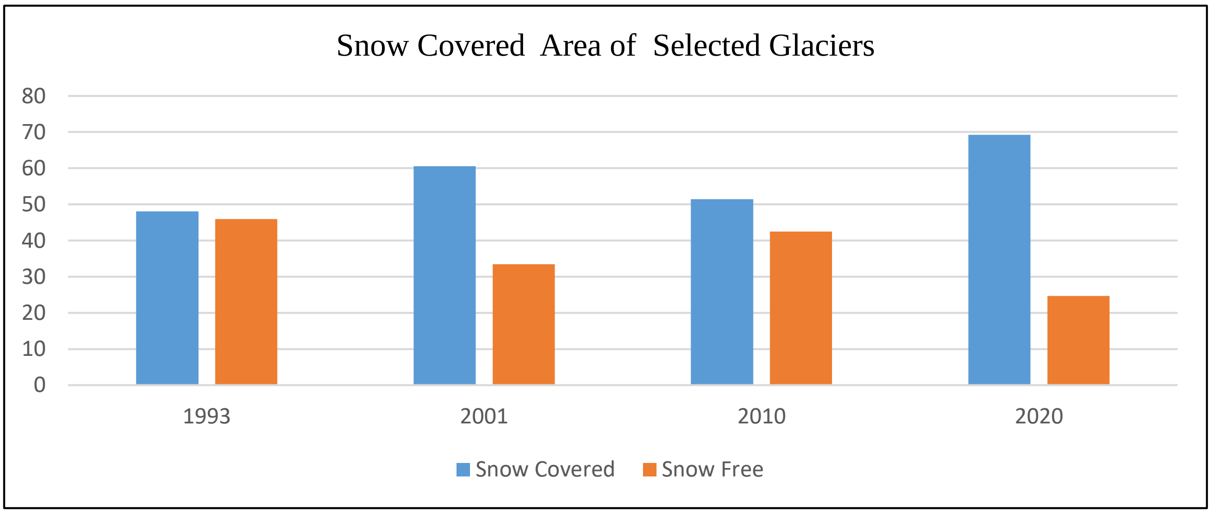

Figure 7: Total area of snow cover

Figure 7 shows the total snow-covered and snow-free areas of the three selected glaciers from 1993 to 2020. Relatively, the snow-covered area was maximum in 2020, approximately 69.26 sq. km, and minimum in 1993, approximately 48.06 sq. km. Further, the Snow-free area was maximum in 1993, approximately 45.91 sq. km, and minimum in 2020, approximately 24.69 sq. km.

5. Conclusion

This study provided a comprehensive picture of the status of glaciers and their decadal change (1990-2020) in the Hunza valley, Northern Pakistan, based on multi-temporal Landsat images. The Landsat images were effectively utilized to evaluate the temporal dynamics of the glaciers. NDSI was effective in demarcating snow extent, and the study identified that snow-free areas increased from 1993-2010. NDGI was effective in identifying the glacierized area and differentiating the ice from debris cover. As identified in the study, the glacierized area had decreased in the study area from 1993-2010. However, a slight increase was observed in 2020, and debris cover also increased. NDWI was effective in identifying water bodies. The study found that waterless areas increased from 1993-2020.

Further, LST was effective in checking the influence of temperature on glacial behavior in the study area. The air temperature mainly controls temporal variations in retreat rate. LST of Hunza valley increased from 1993-2010 but again decreased in 2020 due to the spread of the coronavirus. The glacial retreat was also calculated for selected years. Results concluded that retreat had increased from 1993-2010, but again in 2020, glaciers showed some advancement. The findings of the study can be used as a model for monitoring the glaciers significant for causing significant contribution to glacial lake formation so that the damages related to future GLOF events can be minimized.

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Climate Change Impacts on Coastal Regions in the UK: A Review

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Keywords: Climate change impact, coastal region, disaster risk

1. Introduction

The climate change impact highly threatens coastal regions globally. This paper covers a literature review conducted on the climate change impact on the built environment in coastal regions in the UK. This research is conducted as a part of BEACON (Built Environment leArning for Climate adaptation), a collaborative research project co-funded by the EU Erasmus+ programme of the European Union.

The UK is a maritime nation. According to the statistics, 10-15% of the UK's coastline comprises 10 km long stretches below 5 m elevation, and from these 3009 km (16%) is endangered due to coastal erosion. Consequently, 69% of GDP in the UK is located within 50 km of the coast and that 78% of the country's population are residents in these coastal regions(CCA, 2021). Accordingly, coastal zones are socially, economically, and environmentally indispensable to the UK as a country. Over the last decade, the UK has experienced several severe natural hazards associated with climate change events in the coastal regions resulting in significant economic and human impacts on communities, properties, and infrastructure networks. Climate change will cause sea levels to rise continuously throughout the 21st century. Sea levels have already risen around most British coasts during the 20th century, inducing rising flood levels. This tendency will develop in the 21st century, and by the 2080s, global sea levels could be between 18 and 99 cm. Due to coastal erosion, long-term morphological change is also evident in coastal areas, including extensive salt marsh losses (Nicholls et al., 2021). While these problems have various causes, climate change due to the anthropogenic greenhouse effect will worsen them (Nicholls, 2000). Around £150 billion of assets in the UK are at risk from coastal flooding. Damages to the UK from coastal flooding are estimated to be £500 million per year (Howard & Palmer, 2020). In 2007 summer floods affected 55,000 properties(Dale, 2021) and cost around £3.2 billion. In 2013–2014 the floods cost approximately £1.3 billion in insurance claims(Smith, 2013). In addition, increased storminess and more giant waves have contributed to an increased risk of storm damage and flooding in coastal areas(Nicholls et al., 2021). Coastal and offshore infrastructure is also vulnerable to changing patterns of storm conditions(Poo et al., 2021). In December 2015, during Storm "Desmond", wind gusts of up to 81 mph and record-breaking volumes of rainfall were logged across Northwest England(Hemingway & Gunawan, 2018). The storm, and its associated rainfall, is estimated to have flooded 8900 properties with over 100,000 properties left without power, with a cost estimated at £1.3 billion.

Many studies relate how climate change negatively affects the ecosystem functioning, agriculture and food security, durability of infrastructure, water resources, human health and causes many other impacts (Hossain et al., 2019). On the other hand, the existing studies mainly focus on a specific type of impact such as physical, economic, environmental etc. However, the diversified climate change impacts are correlated and interdependent, and identification of diversified impact categories in a holistic approach is not much seen in the existing studies. Therefore, this study identifies and summarizes the climate change impact categories in the coastal regions into four main categories: physical, economic, social, and environmental.

2. Methods and Materials

In this study, the existing literature and studies relating to the climate change impacts in the coastal regions in the UK are studied and synthesized. Establishing a holistic set of climate change impacts in the coastal regions can be an instrumental tool for policymakers, practitioners, and researchers in provisioning a solid basis for developing climate change adaptation plans in the coastal regions. The method adopted for this study is a mapping review which is alternatively named as descriptive review, and it is mainly used for the studies based on literature surveys. The secondary sources published during the last 20 years were used in this study. This specific methodology is mainly adopted to map out and categorize existing literature on a selected area, contextualize in-depth systematic reviews, and identify gaps in evidence-based research(Grant & Booth, 2009). The Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre), Institute of Education, London, further developed and refined this methodology. As a result of drawing overall conclusions about the existing conceptualizations, propositions, methods and findings at the end of this descriptive review, the study will derive state of the art in the particular domain of climate change impacts in the coastal regions (Paré & Kitsiou, 2017). This set of climate change impacts could be further validated through empirical research as a basis for practitioners and decision-makers in developing tangible climate adaptation measures, which will be the next phase of this project.

The desk review is framed around three areas; the climate change evidence in the coastal regions in the UK, the associated disaster risk due to climate change in the coastal regions in the UK, and as a result, what will be the climate change impacts in the coastal regions in the UK. The main findings are demonstrated under the critical research questions in the following section.

3. Results and Discussion

The evidence of climate change in coastal regions in the UK

The physical characteristics of the UK coastal areas are highly threatened due to the impacts from the climate change scenarios. The long term observations show that air and sea warming, sea ice melting or precipitation changes, sea-level rise, coastal erosion and ocean acidification are the most severe issues in the UK scenario(MCCIP, 2020).

It is recorded that parts of Southwest England are sinking at a rate of 0.6 millimetres, and on the other side, certain parts of Scotland are rising by 1 millimetre per year(Bob & Georgina, 2021). UK's vulnerability to sea-level rise is at the top level amidst European countries to sea-level rise(CCA, 2021). At present, in the UK, 414,000 people are exposed to sea-level rise (CCA, 2021). Historical trends in vertical land movements will introduce significant regional differences in relative sea-level rise around the UK(Hogarth et al., 2021). Accordingly, much of southern Britain sinking and much of northern Britain rising will take place.

Additionally, sea level extremes, storm surges and large waves will increase height and frequency(Gawith, 2005). In the long run, waves would be affected by seabed evolution. In particular, sea-level rise increases the annual maximum significant wave height over the long narrow sandbanks. Meanwhile, the seabed features and beach profiles will also evolve, resulting in increased wave energy, increasing the potential damages(Chini et al., 2010).

In the absence of proper adaptation, the UK could experience significant impacts on coastal flooding from sea-level rise. The impacts of sea-level rise mainly occur during the high tides and storms, leading to coastal floods(Bob & Georgina, 2021). According to the predictions in 2018, by 2080, up to 1.5 million properties, including 1.2 million residential developments, are exposed to a high level of risk due to coastal flooding(Bob & Georgina, 2021). Furthermore, sea-level rise impacts changes in tidal range, storm surges, vertical land motion(Gehrels & Long, 2008). As a result, coastal erosion is also increasing, specifically in East England. Accordingly, the coastal communities and their livelihoods are endangered, which has also affected the socio-economic status of the coastal regions' populations.

Overall the changing weather patterns for the UK suggest that higher temperatures, combined with changing precipitation patterns, will lead to hotter, possibly drier summers and milder, wet winters (Gawith, 2005; Nicholls et al., 2021). Over the last three decades, the UK seas have shown a pattern of increasing temperatures continuously. 2014 has been demarcated as the warmest year on the record, and 8 of the ten warmest records are found after 2000(MCCIP, 2020). Amidst the surrounding coastal lines, the North Scotland sea is recorded to have the most increase in seawater temperature, which records an increase of 0.24°C per decade(MCCIP, 2020). In terms of the weather change patterns due to the climate change impacts in the UK's coastal regions, the direct links to wind, wave and storm activity are not adequately established. However, changes in the ocean and atmospheric circulation in the North Atlantic are identified to impact extreme weather events in the coastal regions in the UK(MCCIP, 2020). It can be clearly seen that the majority of the climate change impacts in the coastal regions in the UK are directly and indirectly linked to the sea level rise. Furthermore, temperature variations, precipitation together with sea level rise create multiplier effects on the changing weather patterns in the coastal regions in the UK.

The disaster risks associated with climate change in coastal regions in the UK

Recently, there has been growing concern about escalating sea levels and their influence on storminess to increase the likelihood of coastal flooding worldwide (Saroar & Routray, 2010). In the UK, the coastal regions frequently experience numerous natural hazards such as coastal flooding and storms. These natural hazards cause significant damage to coastal communities and their economic, environmental and infrastructure (Stock & Wentworth, 2020). These range from small-scale local occurrences and regional incidents to significant high impact, low probability events. According to the latest studies, in 2020, the upper level of the sea level rise in the UK is much greater than anticipated, implying an increased risk of coastal floods. The magnitude and severity of the coastal floods are further exacerbated by the tidal changes and rainfall increases due to climate change(MCCIP, 2020). Furthermore, there is an increase in the short term events such as marine heatwaves and storms along the UK coastal regions lately(MCCIP, 2020). Therefore, the most common coastal hazards driven by climate change in the UK are identified to be coastal floods, storms, increased wave impacts, tidal changes, and heat waves.

Coastal hazards can lead to differential levels of impacts such as loss of life, impairment to the built and natural environments, or disruption to the coastal livelihoods due to varying extents of physical and socio-economic vulnerabilities (Percival & Teeuw, 2019). The vulnerabilities include a set of socio-economic challenges such as ageing populations, youth outmigration and inward migration of older people, high proportions of retirees and people receiving benefits, transitory populations, physical isolation, poor-quality housing, an over-reliance on tourism, seasonal employment, low income and pressure on services during the summer months (Mary Zsamboky et al., 2011). Accordingly, coastal communities are exposed to significant threats due to sea-level rise and other coastal hazards, mainly because their residents' economic and social activities are concentrated around the coast.

Climate change impacts in coastal regions in the UK

Climate change impacts and the associated disaster risks can affect the coastal regions and coastal communities in multiple ways. These impacts have been studied in detail, and the results are categorized based on the findings under the four main categories physical, social, economic, and environmental.

Physical Impact -UK

There is growing consensus that cities' populations, infrastructure, and ecology are at risk from the impacts of climate change(Wilby, 2007). Damages to coastal infrastructure are key physical impacts due to climate change and the associated disaster risks in coastal regions. The extreme events associated with climate change will disrupt the functionality of critical infrastructure such as health and emergency services, transportation(Mary Zsamboky, Amalia, et al., 2011). Roughly 1,600 km of major roads, 650 km long railway lines, and 55 historical landfills are at risk of coastal flooding or erosion by the end of the century. A further 100,000 properties located on complex cliffs could risk coastal land sliding (CCC, 2018).

Coastal flooding and coastal erosion have placed the coastal properties, roads, ports, and railways in the UK coasts at considerable risk. For example, Thames's estuary is densely populated, where many critical infrastructures are exposed to coastal climate change impacts(Bob & Georgina, 2021). Sea level rise causes an impact on coastal infrastructure assets. Some urban areas in the coastal regions and their infrastructure are already below average water levels(Dawson, 2015; Esteban et al., 2020). The UK consist of 2300 km of artificially protected coast, the longest in Europe. Yearly damages due to coastal erosion are expected to increase by 3-9 times, costing up to £126 million per year by the 2080s (Stock & Wentworth, 2020). According to the predictions in the 2080s, up to 1.2 million residential properties will experience a 0.5% or greater annual level of flood risk, and over 100,000 properties may be at risk from coastal erosion(CCC, 2018).

Flooding of infrastructure assets can lead to service disruptions. In addition, it can have knock-on implications for the movement of goods and people (Pregnolato et al., 2017). However, on the other hand, extended periods of low rainfall can lead to the failure of public water supplies, and impermeable surfaces in urban areas disrupt natural drainage processes. Additionally, it increases surface water flows and intensifies the risk of flooding(Dawson, 2015). These circumstances will create increased pressure on drainage systems, a potential increase in winter storm damage, and an increased risk of subsidence in subsidence prone areas (Gawith, 2005). Accordingly, many heritage sites along the UK coasts are subjected to increased erosions, inundation, weathering and decay(MCCIP, 2020).

Meanwhile, windstorms, lightning, humidity, solar radiation also causes damage and disruption to all infrastructure services in coastal regions. High winds lead to bridge closures and pose problems for high sided vehicles, and wind turbines cannot operate at very high wind speeds. Windstorms can disrupt infrastructure systems: directly by damaging infrastructure assets and indirectly by toppling trees or blowing other debris around. Degradation of building materials and structures are quite frequently seen in the coastal region in the UK. This is because corrosion is more severe in humid environments than in dry ones, and coastal zones inherit this environment (Dawson, 2015). Furthermore, temperature changes will affect the energy consumption patterns due to heating and cooling needs in indoor environments on the coastal built environment. Maintenance and construction activities are disrupted in very hot or cold temperatures, which impacts the reconstruction activities after extreme weather conditions (King & van den Bergh, 2017).

Economic Impact -UK

One of the significant economic impacts of climate change is attributed to the losses due to infrastructure damages in coastal regions. The UK consist of 2300 km of artificially protected coast, the longest in Europe. Annual damages due to coastal erosion are expected to rise 3-9 times, costing up to £126 million per year by the 2080s (Stock & Wentworth, 2020). In addition, approximately 1,600 km of road infrastructure, 650 km of the railway infrastructure, including nearly 55 historic landfill sites, are under the threat of coastal flooding or erosion by the end of the century. On the other hand, a further 100,000 properties on complex cliffs could be at risk from coastal land sliding (CCC, 2018). Housing quality and property values of 3.1 million properties across the UK are affected by the risk of flooding, and, as a result, the cost of insurance is high (Mary Zsamboky, Amalia Fernández-Bilbao, David Smith, & Allan, 2011).

Meanwhile, the natural hazards and the associated disaster risks will affect the community access to critical infrastructure and resources. In restoring these functions, the costs of emergency action, prevention and recovery may be a considerable burden to coastal populations and their public funds (Zsamboky et al., 2011). On the other hand, extreme weather, sea-level rise, and coastal erosion will increasingly affect the marine-based industries in terms of their functionality and make direct losses to the industry capital. Increased erosion and sea-level rise will affect beaches which in some places could disappear altogether, obviously affecting seaside tourism (Becken, Whittlesea, Loehr, & Scott, 2020). In addition, an over-dependence on tourism for employment could also worsen the economic vulnerability of coastal communities if coastal erosion or high temperatures discourage people from visiting the beach. However, regional scoping studies suggested that tourism, leisure, and recreation would benefit from the warmer summers expected with climate change (Gawith, 2005).

Climate change impacts will consequence the UK marine industries such as commercial fishing, which is the primary livelihood and source of employment for coastal communities (Peck, Pinnegar, & aquaculture, 2019). Another key industry in coastal suburbs is agriculture. Climate changes, including increased temperature and precipitation variability, could negatively affect UK agriculture. Additionally, weeds, pests and associated diseases will expand as temperatures rise, and farmers will struggle to adapt to new climate conditions also, the increased incidence of saltwater intrusion in irrigation systems (Harrabin, 2019).

Overall, UK coastal areas face deprivation and associated socio-economic challenges that make them particularly vulnerable to climate change. From an economic standpoint, coastal areas constitute fragile economic conditions. Low incomes, high unemployment rates, high numbers of people claiming benefits, cyclical employment, and seasonal economic activities such as tourism contribute to the predicament(Mary Zsamboky et al., 2011). However, these regions attract economic activity and human settlements due to the coastal belt that led to urbanization, infrastructure extension, and other land-use changes. Increased urban pressure ultimately results in further increases in disaster risks and vulnerability of coastal communities over time(Percival & Teeuw, 2019).

Social Impact -UK

The highest societal impacts are felt mainly by the coastal communities that reside and rely on their neighbourhoods for their economic activities(Mary Zsamboky, Amalia Fernández-Bilbao, et al., 2011). One of the primary social impacts of climate change in the UK coastal regions is temporary and permanent displacement and loss of neighbourhoods. For example, the UK's estimations of future flood risks show that nearly 2 million properties in flood plains along rivers, estuaries, and coasts are potentially at risk. (Munro et al., 2017). Furthermore, the seasonal effects of climate change will also alter tourism demand around the UK and its coastal and marine environments impacting coastal livelihoods and local income sources (Coles, 2020).

Another significant social impact is the threat to human life due to climate change scenarios. Direct health effects of flooding include drowning, electrocution, accidental deaths, and other injuries. Furthermore, contamination, loss of water supply, and loss of access to transport, electricity supply, and communications will also impact the coastal communities in the affected areas (Curtis, Fair, Wistow, Val, & Oven, 2017). Heat-related excess deaths occur primarily because of respiratory and cardiovascular illnesses. Climate change is expected to increase the annual mean temperature by 2–5°C and increase the frequency and intensity of heatwaves, especially in the UK's coastal regions by 2100 (Paavola, 2017).

Additionally, climate change can directly impact human wellbeing by affecting health and social care systems and facilities. Food and freshwater security impose challenges on human wellbeing. Yorkshire, Lincolnshire, and East Anglia are hotspots where temperature increases, and lower precipitation levels have imposed extra pressure on water availability. It has affected the local farmers sustained agricultural production (Zsamboky et al., 2011). Accordingly, UK s agriculture productivity and livestock productivity is also threatened by climate change impacts. Agriculture is a crucial industry in many districts along the UK coast. However, climate changes, including increased variability of temperature and precipitation, could negatively affect UK agriculture.

Environmental Impact -UK

UK climate is changing and will continue to change as a result of greenhouse gas emissions. For example, the Met Office's central England temperature series shows that the 21st century has so far been warmer than the previous three centuries(EA, 2018). Amidst those, the environmental systems in the UK coastal regions are also under serious threat. For example, the UK marine water's oxygen concentrations are far above the global average(MCCIP, 2020). Furthermore, the temperature of the UK seawater is rising. As a result, coastal ecosystems, such as salt marshes and coastal grazing marshes, will also respond to climate change. For example, significant saltmarsh losses have been widely reported in parts of Britain over the last few decades, including North Kent and Essex (Nicholls et al., 2021). Moreover, sea-level rise will alter wetland habitats, in some cases changing them into entirely different environments.

The impacts on the marine ecosystems are said to have multiplier effects on the food webs, seabed dwelling species, and plankton, fish, birds, and mammals in coastal regions (MCCIP, 2020). Additionally, the pressures of climate change are already beginning to impact agriculture and forestry in England(Pace, 2021). Additionally, climate change will further affect river flows directly through changes in rainfall and evaporation and indirectly through changes in vegetation and soil structure. These climate change implications further create severe threats to the coastal biodiversity as well. There are four threats to the biodiversity in the UK: competition from exotic species; the squeeze on salt marsh habitats from rising sea levels; the effect of drought on wetlands, and the changing phenology of different species as earlier springs occur more frequently (Britton et al., 2017; Ennos et al., 2019; McKinley et al., 2018). Accordingly, the key environmental impacts due to climate change in the coastal regions in the UK can be summarised as damages to the coastal ecosystems, impact on biodiversity and environmental pollution.

4. Conclusion

The most prominent climate change evidence in the UK coastal regions are sea level rise, air and sea temperature variations, precipitation changes, and coastal erosion. These climate change evidence mainly induce coastal flooding, intensity and frequency of the storms and the wave climate in the UK coastal regions. Additionally, the demographic characteristics of the UK coastal populations induce some socio-economic vulnerabilities. The ageing populations, youth outmigration and inward migration of older people, high proportions of retirees and people receiving benefits, transitory populations, physical isolation, poor-quality housing, an over-reliance on tourism, seasonal employment contribute to these factors.

The physical impacts include damages to coastal infrastructure, seaports, buildings, transport, water stormwater management infrastructure, access interruption to emergency facilities and critical infrastructure, degradation of building materials and structures, increased energy consumption. The analysis under the economic impacts highlights losses due to damages in the coastal infrastructure; loss of coastal income and economic depression; loss of employment; impact on marine-based industries such as tourism, fisheries, aquaculture; impact on planning economic development; depletion of resources and cost of adaptation and reconstruction. The social impact category identifies decreased agricultural / livestock productivity; displacement and loss of livelihoods; voluntary and involuntary human migration; food and freshwater insecurities; risk of increased human conflicts resulting in human unrest; increased human health risks; the need for social protection programmes and threat to human life, casualties, loss of human life. Finally, the environmental category includes damages to ecosystems, such as salt marshes, mangrove forests, seagrass beds, biodiversity, and environmental pollution.

5. Acknowledgement

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Technical Session 2

Geographies of Health and Education

Integrating Environmental and Demographic Factors in MaxEnt Modeling to Predict Dengue Cases Distribution: A Case Study in Kolonnawa Divisional Secretariat

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Keywords: Dengue, MaxEnt, Kolonnawa, Hotspot

1. Introduction

Dengue fever is a mosquito-borne viral disease. Even though it is caused by a virus, the mosquito is the disease's vector. Dengue fever, dengue hemorrhagic fever, and dengue shock are the three stages, and it affects over 60 million individuals each year (World Health Organization, 2016).

Dengue disease mostly threatens developing countries. Among them, tropical and sub-tropical countries stand out and are more likely to be impacted.

Dengue fever, which threatened only nine countries in 1970, has already spread to more than 100 countries in the last decade (WHO, 2016). The socioeconomic changes of the world over the past 50 years have created the path for dengue disease to spread rapidly. Major causes include rapid population increase and unplanned urbanization and insufficient use of mosquito control methods, and poor personal health, all of which contribute to the spread of dengue fever (Gubler D et al., 1998). In addition, according to WHO (2016), global climate change contributes to an increase in Dengue risk.

Dengue disease poses a significant threat to Sri Lanka as a developing country in the tropical region of the world. Dengue fever is the most common mosquito-borne disease that Sri Lankans confront now that Malaria has been eradicated (Lucas, 2017). Dengue fever is spreading at an uncontrollable rate around the country. Dengue illness progresses from infectious disease to an outbreak posing a direct threat to the community soon after the Monsoon periods in the country. Dengue incidence has increased rapidly in various provinces of Sri Lanka in recent years, owing to population growth, human migrations, urbanization, and mosquito dissemination, with numerous large outbreaks occurring in Colombo, Gampaha, and Kalutara districts (Tissera, 2020). The fact that the dengue disease spreads in different places for various reasons is an exceptional characteristic in investigating the nature of its spread. Climate change and human activities have both had an impact on the spread of the disease. Because of this variation, it is critical to identify the major causes of dengue disease in each area to eradicate the disease from Sri Lanka.

Ecological niche models (ENMs) have a lot of potential for assessing the spatial distribution of species based on their interaction with their surroundings (Peterson et al., 2002; Carvalho et al., 2017). They could be used to understand species' ecological requirements, explain elements of their biogeography, and predict habitat appropriateness in a specific location (Peterson et al., 2002; Arboleda et al., 2009; Li et al., 2017; Ma and Sun, 2018). Currently, ENMs are being utilized to investigate environmental appropriateness and high-risk areas of infectious disease incidence (Arboleda et al., 2009; Hsu et al., 2017; Mweya et al., 2016; Altamiranda-Saavedra et al., 2017). Qiao et al., for example, identified the elevated risk of dengue in China's Pearl River Delta on a fine scale (Li et al., 2017). However, the impact of putative environmental risk factors for dengue and the prediction of high-risk locations for dengue transmission in Sri Lanka remain unknown. As a result, micro-scale evaluations employing ENMs in these areas are still required, particularly in developing nations like Sri Lanka. The main objectives of this research were to identify the micro-level spatiotemporal clusters of dengue cases, examine the major environmental and population characteristics, and predict the high-risk area for dengue occurrence in Kolonnawa divisional secretariat.

2. Methods and Materials

Analyses of ecological niche models ENMs are algorithms that include maximum entropy and genetic algorithms in a rule-set production (GARP) (Ma and Sun, 2018; Liu et al., 2014). Maximum entropy can use existing meteorological elements and environmental data to compute their relationships with specific biological phenomena and suggest optimal habitats for species and high-risk areas for biological phenomena. This approach was frequently utilized in infectious disease detection and risk prediction (Arboleda et al., 2009; Altamiranda-Saavedra et al., 2017; Dom et al., 2013).

This study used Maxent software (version 3.4.1) to create dengue ENMs based on the maximum entropy technique. The model was set to regularisation multiplier 2. Each model was built by ten subsample replicates modeling data, with 75 percent of the dengue cases serving as training data and the remaining 25 percent serving as testing data. The effectiveness of the model prediction was assessed using the receiver operating characteristic (ROC) curve and the Area under the Curve (AUC), which is a measured value of the model predictive ability. AUC follows: 0.50–0.60, model insufficient; 0.60–0.70, model poor; 0.70–0.80, model average; 0.80–0.90, model good; and 0.90–1.00, model excellent (Li et al., 2017; Ma and Sun, 2018).

The present study aimed to assess the relative importance of environmental variables and population factors in predicting *Aedes aegypti* presence in Kolonnawa divisional secretariat using the Maximum Entropy Modelling Model (MaxEnt version 3.4.1). Dengue occurrence data were gathered from May to September in 2019, reported in the Medical office of Health (MOH) in Kolonnawa. Terrain data, i.e., the land use, aspect, and elevation data, were collected from the Survey Department data sharing services and Google Earth software. Also, the land cover and land use data were collected from the United States Geological Survey (USGS). The normalized differential vegetation index (NDVI) data were obtained through the calculation on ArcGIS 10.1 software. The value of NDVI ranged from -1 to 1, with NDVI > 0 indicating the coverage of vegetation; the larger the value, the higher vegetation coverage. NDVI = 0 indicates the coverage by rocks or bare soils, whereas NDVI < 0 reflects the coverage by others landscapes, such as land use, water and snow. The population size in every Grama Niladhari division was obtained from the Department of Census and Statistics in Sri Lanka.

Performance of the MaxEnt software was evaluated through model fit statistics, such as AUC, omission, and commission, as well as individual variable contributions through the Jackknife tool. Species occurrence data collected from May to September 2019 was used together with five environment variables, including land use and land cover, altitude, and population. Arc GIS 10.1 software has been used for hot spot analysis and interpolation of MaxEnt prediction value and the preparation of maps for the study area.

3. Results and Discussion

Due to the monthly climatic variations, a total of 498 dengue cases were reported in Kolonnawa divisional secretariat, with a generally increasing trend from May to September in 2019. Results show that mosquito species are currently widespread across the region, with a particularly higher incidence in the western part of the region. In addition, these cases were heterogeneously distributed across the division with five spatiotemporal clusters (Hotspots), namely Megoda Kolonnawa, Salamulla, Welewaththa, Kuruniyawaththa, and Madinnagoda (Figure 1).

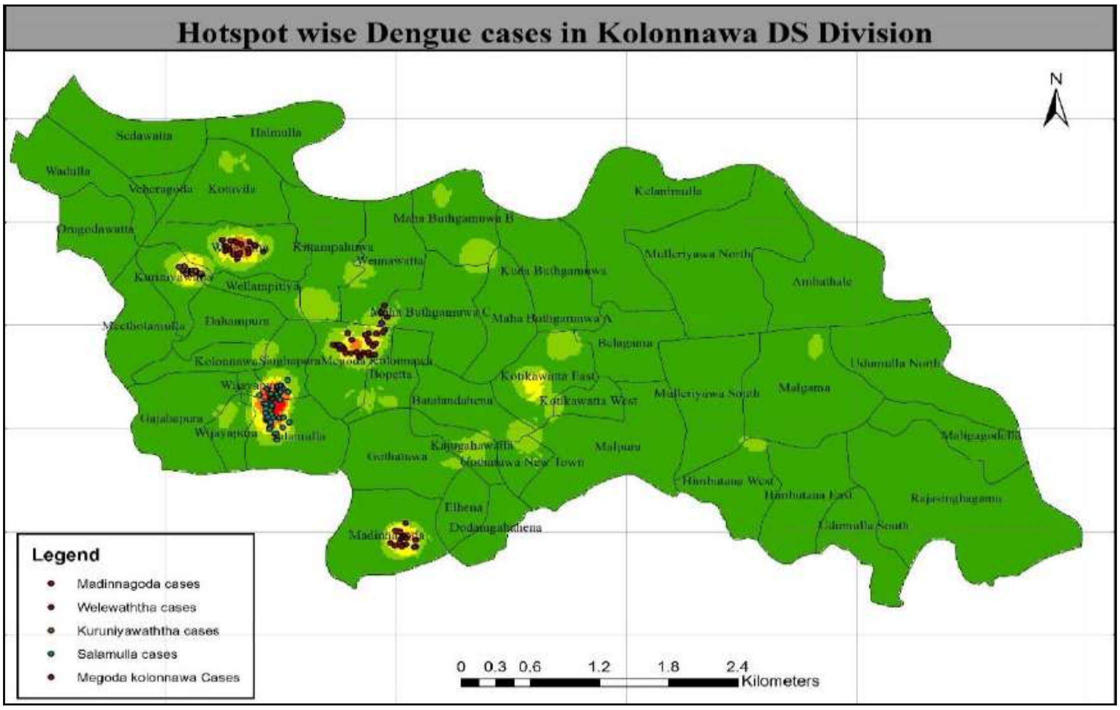

Figure 1: Dengue hotspots in Kolonnawa DS division-2019

Source: Prepared by the author using Arc GIS 10.1,2021

Also, the results of ecological niche modeling with the Jackknife tool showed that the land cover, land use, and Population density were the dominant environmental factors of dengue occurrence in 2019. Models that included population density and Normalized Difference Vegetation Index (NDVI) for land cover exhibited better predictive power and produced more precise distribution maps. Furthermore, the population density also accounted for much of the model contribution—more than terrain variables such as altitude and slopes. As per Figure 2, there was no significant association between aspects, slopes, and dengue incidence.

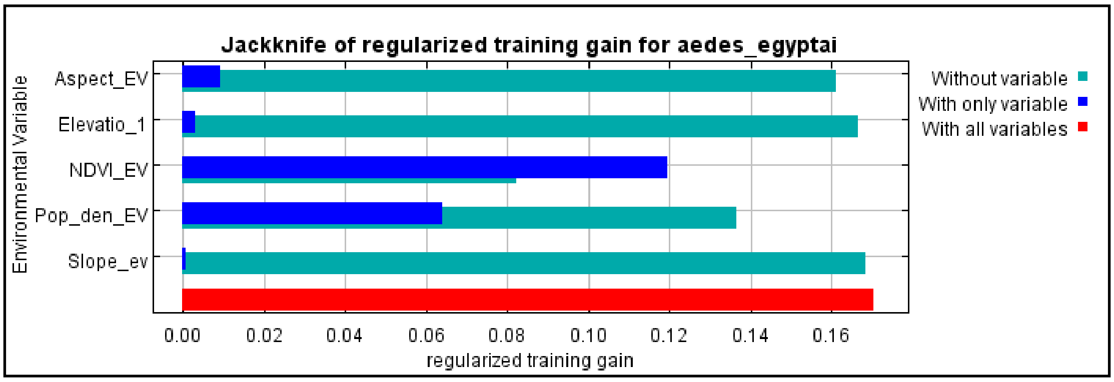

Figure 2: Jackknife method results for the contribution of environment variables in Dengue cases

Source: Prepared by the author using MaxEnt Software, 2021

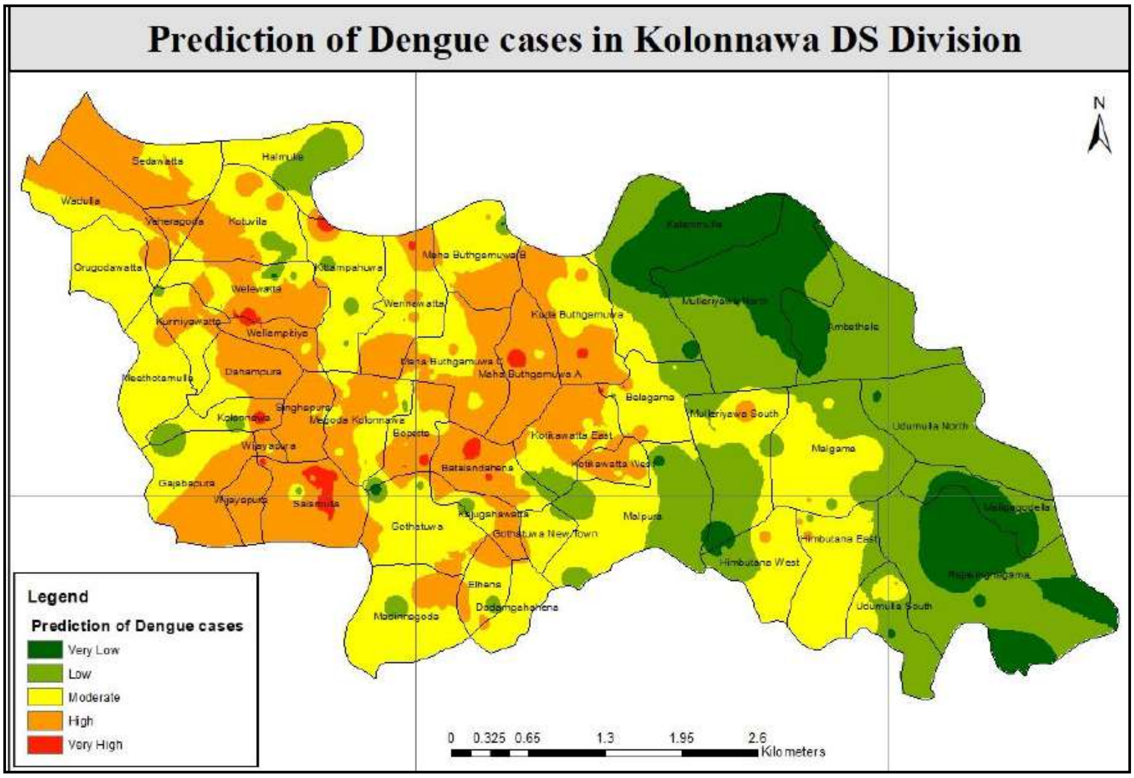

Figure 3: Prediction of Dengue cases in Kolonnawa DS division through MaxEnt Software values

Source: Prepared by the author using MaxEnt data and Arc GIS 10.1,2021

In addition, the predicted high-risk regions of dengue incidence were mainly in the western part of the Kolonnawa Divisional Secretariat, such as Welewaththa, Kuruniyawaththa, and Sedawaththa, which were highly urbanized with high population densities. Therefore, the corresponding AUC value further validated the model prediction, which ranges from 0.89–0.96 depending on the factors.

4. Conclusion

In this study, with the divisional secretariat-level dengue data in Sri Lanka, spatiotemporal distribution patterns of dengue were analyzed at a finer scale, environment-incidence associations were investigated, and potential risk regions were predicted across the Kolonnawa DS division. The results of the study indicated that dengue was spreading rapidly all over the division. In the analysis, Land use, land cover, population, and terrain data were used to predict the environmental suitability areas for dengue. The results of the model indicated that high-risk areas for dengue were mainly located in the highly urbanized western parts of the region, which includes the breeding habitats for the mosquitoes with urban land use, land cover, and population density. This result was in accordance with previous studies focusing on Brazil and Malaysia, where urbanization and highly populated regions among the hotspots for Dengue outbreaks (Carvalho et al., 2017; Mweya et al., 2016; Li et al., 2018; Freitas et al.,2003 and Hazrin et al.,2016). In urban than rural areas, the higher population densities provide a higher exposure risk to these dengue mosquito bites. Specifically, the appropriate temperature in urban regions and sources for polluted water with containers for laying eggs could influence the reproduction of vector mosquitoes and dengue viruses, which subsequently impacts the dengue risk (Teurlai et al., 2015). Land cover has an impact on mosquito density (Sarfraz et al., 2012). A lack of more important potential variables such as climatic variables and mosquito density in the model could explain the results. In conclusion, the discovered considerable spatial clustering pattern of dengue illnesses in 2019 shows the importance of targeting high-risk locations to maximize controls' cost-effectiveness. This study also revealed the most important environmental and population factors influencing dengue dispersion.

MaxEnt modelling may be used to make Dengue predictions and detect dengue vulnerability and possible risk. These findings will help to prevent and control programmes allocate needed resources to high-risk divisions.

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COVID-19 Pandemic Preparedness in Upcountry Tea Estate

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Keywords: COVID-19, preparedness, health guidelines, estate community

1. Introduction

The COVID-19 pandemic has posed an immediate threat to many people worldwide. The COVID-19 outbreak is a unique and unprecedented scenario for people, health care workers, and the government. The disease currently doesn’t have pharmaceutical treatment (Hevia & Neumeyer, 2020). The preparedness could also be a prime approach to overcome the pandemic crisis. Pandemic preparedness could even be a continuous process of designing, exercising, revising, and translating into action national and sub-national pandemic preparedness and response plans. Furthermore, the key influences on preparedness include outcome expectancy, self-efficacy, collective efficacy, previous experience, perceived responsibility, responsibility for other's coping styles (WHO, 2020). Sri Lanka is documented globally for its robust, efficient, and effective health system that eliminated many infectious diseases in the past.

Sri Lanka has been practicing many essential preparedness strategies against COVID-19 control, including lockdown, face mask ordinances, quarantine, PCR and antigen tests, and vaccination. The country's prime economic sector is tea export, and the people who work in the tea sector face many economic and social challenges in the long term. The current COVID-19 outbreak is a significant barrier to their future development. With this background, this paper identifies the COVID-19 pandemic preparedness in the upcountry tea estate.

Objective

The main objective of this study was to identify the COVID-19 pandemic preparedness in upcountry tea estate people and make suggestions on overcoming challenges in it.

Study area

The Bogawantalawa-south GND is selected as the study area, located in the Nuwara Eliya district, Sri Lanka. The coordinates of the study area are $06^0$47’56.43” N Latitudes and $80^0$40’19.3” E longitudes (Figure 01).

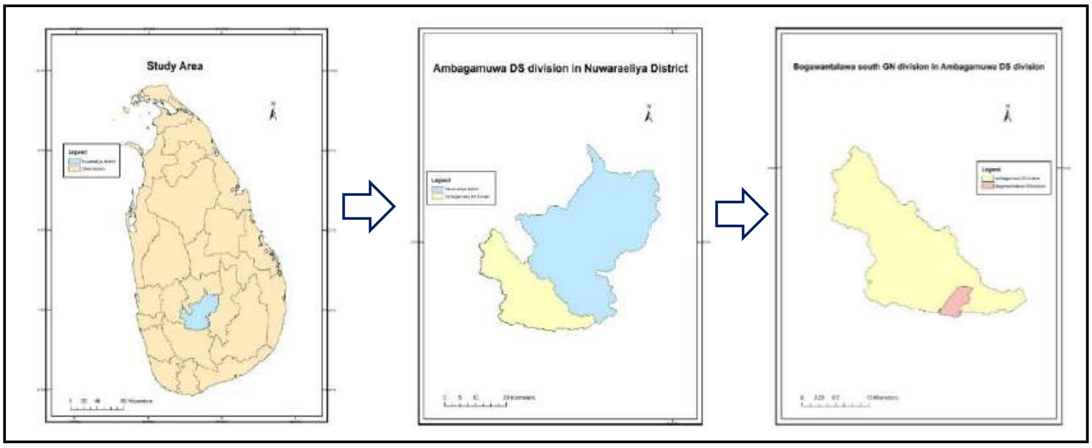

Figure 1: Study area
Sources: Prepared by author, 2021

2. Methods and Materials

The qualitative approach was used as the research design in this study, and the random sampling method was used to select the sample population. Fifty (50) families were selected from the Bogawantalawa-south GND. Further, discussions were held with the sample population, and notes were taken where necessary. Finally, narrative analysis was used for data analysis.

3. Results and Discussion

To identify the COVID-19 pandemic preparedness in upcountry tea estate people

The upcountry tea estate people follow several pandemic preparedness during the COVID-19 pandemic following traditional and modern methods. For example, they practice wearing masks, washing hands, social distance, vaccination, quarantine, frequently disinfecting their homes, and using herbal medicines.

The Nuwara Eliya District has recorded 3,240 COVID -19 positive cases and 15 deaths till 09 May 2021 (Health Ministry, 2021). It shows that, the COVID -19 disease is increasing gradually in the whole district. According to the findings, approximately 30 % of participants have been adhering to wearing masks in public places. On the other hand, most participants (70 %) had not followed health guidelines in public places and engaged in tea estates. According to the participants' idea, wearing a mask is an inconvenience. They strongly believe that their immunity level is high and therefore no need to panic about COVID-19. This factor could be identified as the major reason for avoiding the health guidelines including wearing a mask, among tea estate society. Social distancing is the best way to curb the spread of COVID 19. Keeping a distance of two meters between each person in public places has been minimized. The study found that tea estate people are maintaining social distancing in banks, hospitals, and other organizations. However, in groceries, bus stands, and markets, they do not keep up with the proper maintenance of the social distancing. Study further identified that the lack of awareness and knowledge about the Covid-19 pandemic, motive of traders to prosper their business in whatever means they could, the conventions and thoughts of the traditional tea estate community to not adhere to suddenly imposed health guidelines due to poor literacy rate are reasons for not maintaining precautions.

Sinopharm vaccines are being commonly given to the residents in the Nuwara-Eliya District. The Elderly community in the study area has received both doses. Moreover, according to the participants' response, 50% of those above 30 years have received their 1st dose of Sinopharm. Further, the other half of the participants (above 30 years) stated that they are not interested in getting the Sinopharm vaccine. Due to the fear of side effects, very few people have chosen other Covid-19 vaccines over the Sinapharm vaccine. The population below 18-years of age in the upcountry tea estate did not still receive any dose of the vaccine. Despite this, nearly all working adults below 30-year-old have received both vaccine doses. (From June, 2021 to September, 2021).

Quarantine in the case of Covid-19 essentially means, the 14-day incubation or isolation period of a person who is believed to have been contaminated with or exposed to the coronavirus. When a person is affected by COVID-19 in the tea estate, the Public Health Inspector (PHI) quarantines that particular family for 14 days.

For a long time, upcountry tea estate people use traditional medicines for curing and prevention of diseases. Especially, they use turmeric liquids, Neem extract, and lemon extract as disinfectants their homes. Inhaling steam infused with lemon leaves and basil leaves and drinking herbal drink are practices done by these people. Upcountry tea estate people mostly take Paspanguwa herbal drink when there is fever. *Paspanguwa* herbal drink consists of five ingredients, namely Ginger (*Zingiber officinale*), 'Pathpadagam' (*Hedyotis corymbosa*), 'Katuwalbatu' (*Solanum xanthocarpum*), 'Veniwalgata' (*Coscinium fenestratum*), and Coriander (*Coriandrum sativum*). In some instances, other herbs such as 'Thippili' *(Piper longum*), Thai eggplant (*Solanum melongena*), Black pepper (*Piper nigrum*), Wishnukranthiya (*Evolvulus alsinoides*), and Pawatta *(Justicia adhatoda)* may also be included. It is considered to contain the highest ability to prevent ailments such as coughs, colds, fever, and body aches (Zoysa et al., 2017). During the current pandemic period, tea estate people used this traditional method against COVID-19.

4. Conclusion

According to the participants' response (85%) upcountry tea estate community's COVID-19 preparedness and safety measurements are not at a satisfactory level. Specifically, their poor health practices against COVID 19, social irresponsibility, and lack of government support affected the modern preparedness in the study area. Further, health awareness programs, continuous evaluation, and research are key elements for the current and future pandemics preparedness among the tea estate people.

5. Recommendations

- Government should implement strict punishment for the people do not follow COVID-19 health guidelines.
- Conduction of awareness programs among the tea estate community about the importance of getting the vaccine.
- The government should provide enough vaccines to tea estates.
- Scientific research needs to evaluate the effectiveness of traditional methods against the COVID-19 pandemic.
- The tea estate community should regularly follow their responsibilities against COVID-19.

6. Acknowledgment

The author expresses special thanks and gratitude to the people from the selected tea estate who participated in the research.

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Mapping Ecosystem Services Supply for Selangor, Malaysia

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Keywords: Ecosystem services, Ecosystem services mapping, Sustainable development, Urban planning, Malaysia

1. Introduction

Ecosystem services (ES) is an important concept that intermingles both humans and nature. It is defined as components of nature that contribute to human wellbeing (Boyd & Banzhaf, 2007). In recent times, ES has become a more popular theme of research within sustainable development as it connects environmental and social-economic elements through intangible and interdisciplinary characteristics (Müller & Burkhard, 2007).
Integrating ES into the sustainable development process must be valued. Daily and Matson (2008) stated that ES mapping is a major element in the valuation and implementation process of ES. Although the primary valuation of ES is monetary (Vandewalle et al., 2009), it fails to understand the spatial differences and traits of ES and forces a narrow perspective of ES. Therefore, researchers are now focusing on biophysical metrics to guide ES mapping in the form of proxy mapping (Burkhard et al., 2009).

A proxy map will identify potential indicators that will represent the ES needs to be valued. For example, the valuation for crop production can be Plants/ha, where a study can be conducted to count the number of different crop types in the study area (Burkhard et al., 2012). This valuation is done using expert elucidation as it is the most optimal method to secure the best available knowledge (Burkhard et al., 2015). In addition, expert opinion provides a relatively fast technique and is more attuned to the decision-making process as it enhances communication leading to a scientific consensus (Jacobs et al., 2015). Although this method may have assumption uncertainty, it allows higher feasibility of ES mapping.

In the context of Malaysia, the use of the ES concept and ES mapping in sustainable development can be a vital tool. Malaysian urbanization has been increasing from 54.3% to 65.4% from 1991 to 2000, respectively. It is expected to reach 75% at the end of 2020 (Yeo et al., 2016). In addition, Malaysia has rapid landcover change with a large amount of forest cover loss, where Malaysia had the highest percentage of forest loss from 2000 to 2012 in the world (Butler, 2013). This has led to an overall loss of services and made the development unsustainable. Therefore, it is vital to integrate ES in decision-making regarding sustainable urbanization and development in Malaysia.

However, the lack of ES integration in Malaysia is apparent (Uni Kamlun & Arndt, 2019). Even in the state of Selangor, which is the economic hub of Malaysia. ES has only been acknowledged, but there has not been an attempt to quantify it. This study will follow work done by Burkhard et al. (2009) to map the ES supply capacity of Selangor Malaysia based on its landcover using expert elucidation and a matrix model assessment. This study will discuss the importance of ES mapping and its possible use in sustainable development.

2. Methodology

The study area is the state of Selangor, Malaysia (Figure 1). Selangor has long been the economic hub of Malaysia, containing the capital, Kuala Lumpur, and the administrative capital, Putrajaya. However, it has seen considerable changes in land use over the past decade with the introduction of commercial crops, i.e., plantations, which has drastically changed the composition of the ES. The methodology for this study follows two major steps which are:

1. Development of the landcover map
2. ES mapping with a matrix model

The processing of the landcover map was undertaken using ARC GIS Pro. The landcover map was created by expanding on work done by the University of Nottingham Malaysia in 2019, which provided a classified landcover layer for Greater Klang, which resides inside the state of Selangor and includes the majority of the urban space. In this study, ancillary data from open sources were used to complete the landcover map for the state of Selangor (Table 1).

Table 1: Ancillary data used to create the landcover map

Data Name	Year(s) obtained	Source
Water	2019	Open street maps
Plantation	2013-14	Global Forest watch and World resources institute
Impervious including roads	2018-19	Open street maps
Forest reserves	2019	Open street maps

The landcover layers were combined using the union tool to obtain the final land cover map (Figure 1).

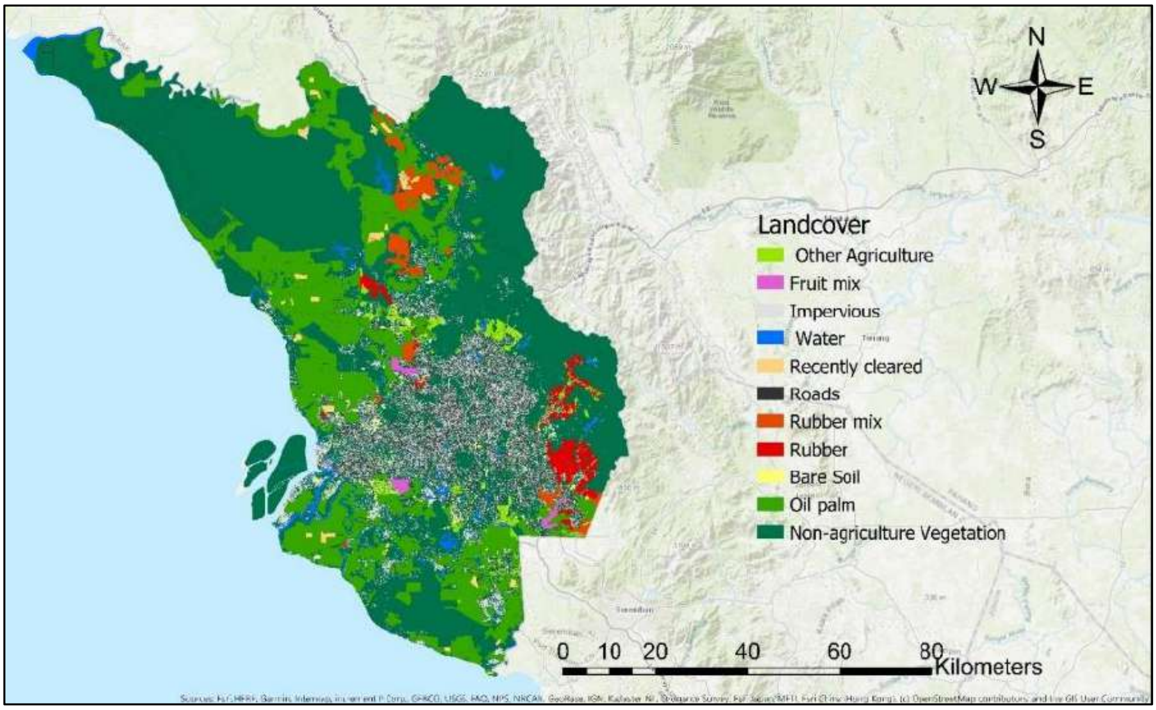

Figure 1: Landcover map of Selangor Malaysia for 2019

This study used a matrix model driven by expert elucidation (Burkhard et al., 2009) for ES proxy mapping and shown in Figure 2.

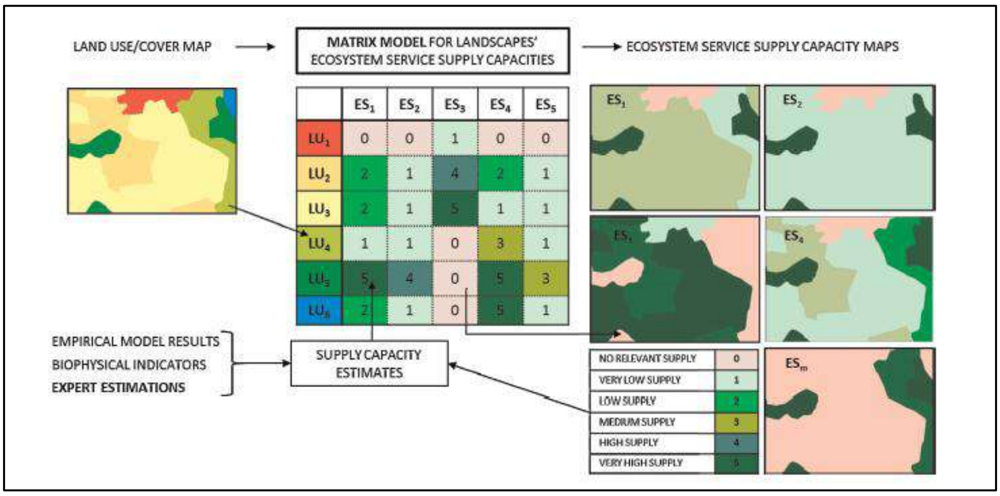

Figure 2: Proxy mapping process using matrix model. Adopted from Burkhard et al. (2009)

The process to score each ES was slightly adjusted from the method proposed in figure 3 by Burkhard et al. (2009) as this study did not have a large panel of experts. The step-by-step process of the Matrix scoring is shown in figure 3. Each expert took part in the filling-in process and used their expert elucidation to give scores. The scores were based on a scale of 1-5, where 1 represented very low capacity to supply and 5 represented very high capacity to supply.

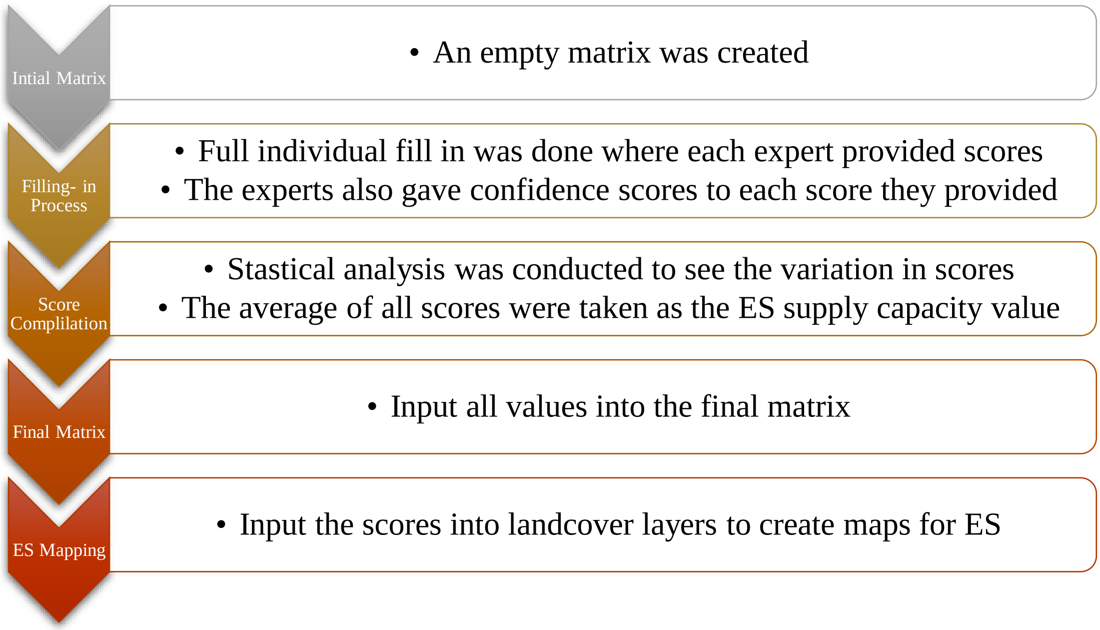

Figure 3: Creation of the matrix and ES mapping methodology

3. Results and Discussion

The final matrix shows all the scores for each landcover to supply each ecosystem service (Table 2). Natural resources such as water and non-agricultural vegetation show relatively high capacity to supply

ES. The commercial crops also show a high capacity to supply ES, with Crop production being at very high capacity. The vegetative landcover can be seen to have the highest capacity to provide ES.

Table 2: Metrix

	Provisioning Services			**Cultural Services**			**Regulating and Supporting Services**					
Water bodies	3.4	4.25	3.3	4.3	3.5	2.75	2.1	1.75	3.25	3.5	3.05	3.8
Bare soil	0.6	0.35	1.85	1.25	0.35	0.25	0.7	0.35	0.5	0.4	1.2	1.1
Impervious	0.3	0.25	0.25	1.65	1.65	0.8	2.5	0.45	0.35	0.35	0.35	1.55
Recently cleared	1.2	0.35	1.4	0.45	0.35	0.35	1.45	1.45	0.85	0.85	1	1.15
Roads	0.25	0.2	0.2	0.35	0.45	0.35	0.4	0.4	0.25	0.25	0.25	0.25
Oil palm	4.5	3.4	4.25	2.25	3.4	2.25	3.9	3.7	4	4.1	3.1	3.75
Rubber	4.5	3.2	4.4	3.2	3.25	3.8	3.9	3.8	4	4	3.4	3.5
Rubber mix	4.4	3.15	4.35	4.1	4.1	4.3	4	3.5	4	4.2	4	4.1
Fruit mix	4.4	3.1	4.3	4.15	4.4	3.6	4	4.35	3.8	4.1	4	4.3
Other agriculture	4.3	3.1	4.05	3.65	3.9	4	4.05	4.15	4	4.2	3.7	3.9
Non-agriculture vegetation	0.8	0.9	4.1	4.4	4.35	4.4	4.3	4.05	4.5	4.2	4.4	4.45

The distribution of Provisioning, Cultural and Regulating & Supporting services can be seen in Figure 4. This distribution was created by calculating the total average of each corresponding ES category using the individual ES scores. It is seen that agricultural landcover's provisioning services are mostly supplied, and non-agricultural vegetation can supply regulating and cultural services at a very high capacity.

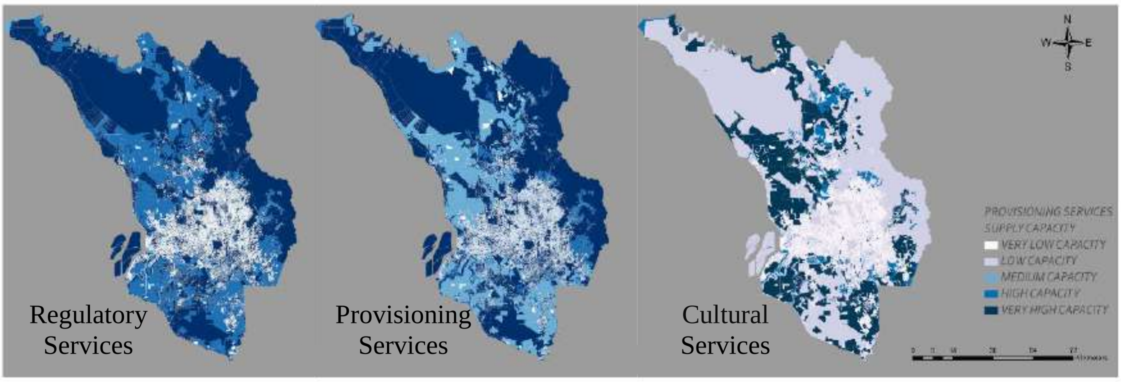

Figure 4: ES maps with average scores for regulating, provisioning and cultural services

We could observe the spatial trend of increasing ES supply capacity as we move away from the urban center of Greater Klang as Vegetative (green spaces) landcover and Water (Blue spaces) are more abundant. However, the ES supply is mostly influenced by anthropogenic landcover such as agriculture, impervious spaces, and roads. Therefore, it is vital to consider when incorporating the ES concept in decision-making for Selangor's development plans.

The urban development is expanding radially and envelopes the green and blue spaces, as seen by the concentration of impervious landcover at the center of Selangor. This expansion is unfiltered and the lack of the ES concept in policy in Malaysia is exacerbating the environmental damage, thus is unsustainable (Yeo et al., 2016). The degradation of blue and green spaces results in a large loss in ES supply as they have the highest capacity to provide ES. To achieve sustainable urban development, urban planning should have a framework governed by ES. This is because ES plays a critical role mediating the balance between ecological integrity and human wellbeing, which governs the supply and demand of ES. Urban spaces exert the highest demand for ES from all landcover (Burkhard et al., 2012). Not maintaining a balance can lead to long term economic cost for the state and compromised the ecological integrity (Gómez-Baggethun & Barton, 2013).

The spatial distribution of ES supply from this study, with additional data on population, can identify areas of ES scarcity or ES surplus, prompting more focused and evidence-based sustainable urban planning. Utilizing the ES concept in sustainable urban planning can be advantageous for Selangor in meeting National goals of increasing tourism and improving land value, in addition to improving citizen wellbeing. Moreover, services such as stormwater retention, erosion control can greatly help Selangor, which has many flood prone areas. Selangor already has some green and blue spaces within the urban sprawl of Greater Klang providing mostly Cultural and Regulating services (figure 5). These spaces are mostly urban parks and green patches that were developed without ES concept guidance but do provide some services, unintentionally. However, these spaces are important in future urban plans as they provide a unique opportunity to expand the supply of ES within a highly concentrated urban area.

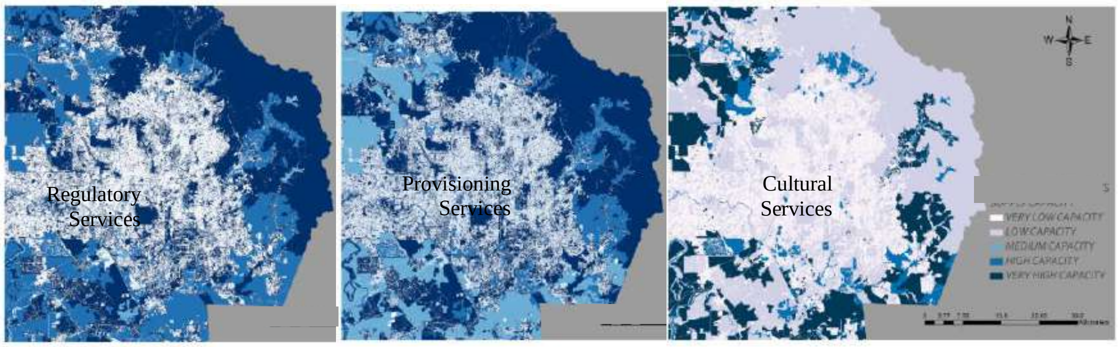

Figure 5: Focus on the ES supply of Greater Klang, which host majority of the urban development

Urban and agricultural development in Selangor drive a shift in ES as it involves landcover change. The basis of this shift is represented through the green-loop to red-loop transition concept (Cumming et al., 2014). It depicts a sustainable cycle (green loop) of human and ecosystem harmonizing where the demand for ES remains similar to its supply at first. It showcases population as a driver that introduces a new cycle (red loop) that begins to grow, changing socioeconomic values and increasing demand. This new red loop exerts immense pressure on the green loop until it consumes the green loop. Cumming et al (2014) portrays how this new red loop results in alienation of people and ecosystem, leading to environmental degradation and economic loss. Therefore, a better understanding of ES is vital to maintaining a balance and sustainable development path.

4. Conclusion

The ES concept is an important factor to include in humanity's goal to achieve sustainable development. For a country such as Malaysia, which hosts great natural resources and are rapidly developing, sustainable development is optimum pathway. The outputs from this study act as the foundation to understanding the complexities of ES and its effects on human well-being. The clear high capacity of vegetative landcover as seen in the results is a clear indication that green spaces provide many intangible benefits. Extending the ES supply maps into understanding ES surplus and deficit through parameterizing ES demand, Selangor can see which areas need more resources allocation. Considering the red-loop to green-loop concept proposed by Cumming et al (2014), the low capacities that is synonymous with urban areas indicate an unsustainable development path for Selangor. To avoid pressure from the red loop, the understanding of ES distribution is vital.

The complexity of applying ES into decision-making is one of the great limitations. It can be difficult to understand the connections especially when assessing many ES at the same time. The many factors from individual ES to their relationships increases the number of factors to be considered, which in turn increases uncertainty in general. This is true in the valuation of ES as, ideally, there would be many individual studies collecting data for each individual ES to be assessed. However, this carries a lot of uncertainty and are often difficult to standardize. This study follows expert elucidation to gather data following work done by Burkhard et al (2009) which states it is the most optimum, although it has some limitations regarding the reliability of it. Nevertheless, the growing technology from high resolution satellite imagery to using artificial intelligence to run models, propose a bright future for ES mapping and the general incorporation. These technologies will be able to remove the difficulties of valuation, uncertainty and scale and help focus more on the application and decision-making process.

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How Does Geography Success as a Strong and Practicable Discipline in Secondary Education System?
Case Study in Nivithigala Education Division, Sri Lanka

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Keywords: Geography, Secondary Education, Practicable subject, Teachers Qualifications

1. Introduction

Geography is the study of locational and spatial variations in physical and human phenomena on earth (Balasubramanian, 2014). Which mainly focuses on the places and the relationships between people and their environments. Geography seeks to understand where things are found, why they are there, and how they develop and change over time (Vernon et al., 2000). The Study of Geography in the world has grown along with human evolutions and revolutions. Today, it is a vast subject involving scientific information derived from other subjects like geology, biology, anthropology, economics, physics, sociology, demography, and environmental sciences. Moreover, it has diversified into several branches of study over the last century (Murray, 1969).

The world-wide Geography is developing very fast. But unfortunately, in Sri Lanka, Geography became a neglected field at all levels in school curricula following the educational reforms in 1972 (Katupotha, 2007). Human and Physical Geography are the two traditional divisions of the subject area in the secondary education system in Sri Lanka (National Institute of Education, 2018). It is important that learning and teaching techniques in Geography also need to be revived and revised to meet the emerging needs. Most students are afraid to select Geography as a subject for their Ordinary Level (OL) and Advanced Level (AL) examinations. Even they don't have a strong motivation to select Geography as a subject. Not only students, teachers who are teaching Geography in schools, they also don't have much knowledge about the subject and subject background. Sri Lanka needs human resources with strong geography knowledge who can visualize, conceptualize, explain, analyze and find solutions to issues in different contexts (Nimal, 2021). Secondary education level is essential to provide qualified entrants for higher education. Teacher training and other courses in tertiary and post-secondary education and training and understanding the behavior of the nature of the subject is necessary. The main objective of this research is to find out whether Geography is successful as a practicable and robust discipline in the secondary education system by considering a case study in Nivithigala Education Division. The research findings will be beneficial to develop Geography as an interesting and robust subject in the secondary education system in Sri Lanka.

2. Methods and Materials

Nivithigala Education Division was selected as the research study area, and 17 schools were selected to collect the information and data for the analysis. Out of 17, both AL and OL classes are available in 7 schools. The remaining ten schools are conducting classes up to grade 11 (OL). Both primary and secondary data have been collected for the study. The Primary data was collected by conducting interviews through phone calls based on purposive sampling under the non-probability sampling method. For instance, the principals and geography teachers in the 17 schools were interviewed. In addition, a sample of 34 students was also interviewed.

Secondary data was collected from the Zonal Education Office in Nivithigala from 2010 to 2019. The computer software of the map analysis, Arc map 10.4, was used to examine the changes of pattern in the availability of Geography in selected schools. In addition, MS Excel has been used in this research to display the final results.

3. Result and Discussion

Studying Geography gives meaning and awareness of places and spaces. It also helps students learn about spatial relationships and changes in the globe. Geography is growing as a firm and practicable discipline in the tertiary education system in Sri Lanka. But it is hard to find a similar trend in the secondary education system.

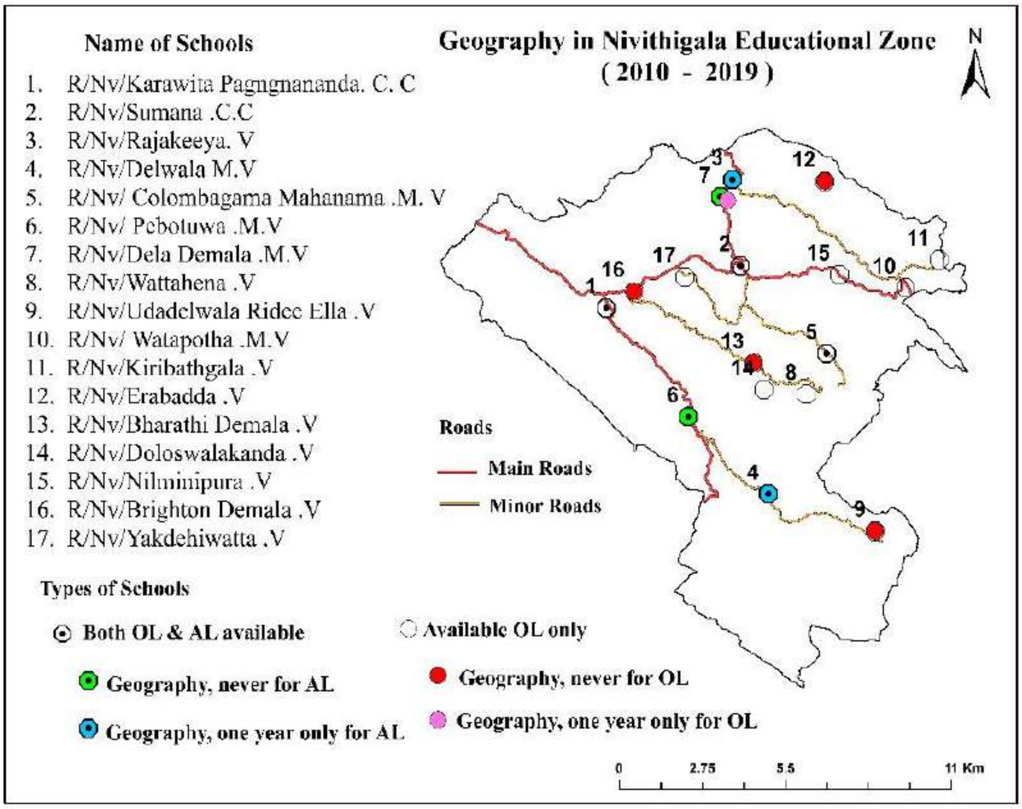

Figure 1: Students' selection of geography as a subject
Source: Created by author

When considering the secondary data, which represent the students who sat for the OL and AL examinations under the subject of Geography in Nivithigala Education Zone from 2010 to 2019, a very clear spatial pattern can be observed among the schools by using GIS technology, the spatial pattern is summarized into a single map (Figure 1). According to the results, out of 17 schools, both AL and OL classes are available in 07 schools only. From that, 03 schools are giving a chance for the students to select Geography for their AL examination. In those schools, the students also have great motivation to select Geography as a practical discipline. But in two schools out of 07, no one had selected Geography for AL within the period 2010 to 2019. And also, during this period, the records of R/Nv/Rajakeeya Vidyalaya and R/Nv/Delwala Maha Vidyalaya showed that only once students sat for the AL examination under the subject stream of Geography.

Table 1: Teachers' educational qualifications on Geography

No	School	Details about the teachers				
		DG	DNG	NT	OL	AL
1	R/Nv/Karavita Pagngnananda C.C		✓		av	av
2	R/Nv/Sumana .C.C	✓			av	av
3	R/Nv/Rajakeeya. V		✓		av	
4	R/Nv/Delwala M.V		✓		av	
5	R/Nv/ Colombagama Mahanama .M. V	✓			av	av
6	R/Nv/ Pebotuwa .M.V		✓		av	
7	R/Nv/Dela Demala .M.V			✓		
8	R/Nv/Wattahena .V		✓		av	
9	R/Nv/Udadelwala Ridee Ella .V			✓		
10	R/Nv/ Watapotha .M.V	✓			av	
11	R/Nv/Kiribathgala .V	✓			av	
12	R/Nv/Erabadda .V			✓		
13	R/Nv/Bharathi Demala .V			✓		
14	R/Nv/Doloswalakanda .V	✓			av	
15	R/Nv/Nilminipura .V	✓			av	
16	R/Nv/Brighton Demala .V	✓				
17	R/Nv/Yakdehiwatta .V	✓			av	

Source: Created by author by using the data of zonal education office of Nivithigala
description of the table

Symbol of Colours		Teachers Qualifications		Other short forms	
	Geography, never for AL	**DG**	A Degree in Geography	**av**	Geography available
	Geography, one year only for AL	**DNG**	The Degree is not in Geography	**OL**	Ordinary Level
	Geography, never for OL	**NT**	No Teacher	**AL**	Advance Level
	Geography, one year only for OL				
	Schools, both AL & OL available				

Significant patterns could be identified when considering the students who sat for the OL examination within the years 2010 and 2019. Out of 17 schools, in 04 schools, students had not chosen the Geography subject for their OL examination. According to the students, they were not interested in selecting Geography as a subject for the OL examination. Therefore, they had not chosen geography as a subject for the AL examination either. Some of the students stated that they thought it was a tough and futureless subject. According to the students' point of view, the main reason for rejecting Geography for OL and AL examination was students having a negative mentality about the maps and statistical part of the subject. The common answer of the students to reject the subject was that they didn't have good knowledge about the practical sessions, and most of the teachers also roughly went through the practical parts. Students were further stated that some teachers were also not interested in teaching practical sessions of the subject.

In that sense, teachers' qualifications on the subject are essential. The study identified that, in the study area, some teachers who are teaching Geography for the OL and AL students do not have the necessary

qualification (A Degree or Diploma in Geography) of the geography subject. For example, one of the geography teachers in the sample has obtained a degree in Commerce. As revealed in the research, there is only one National school in the Nivithigala Educational Zone. In that school, most of the students had selected Geography for their OL and AL examinations, and more than 20 students sit for the OL examination each year. Since the geography teachers do not have at least a basic degree in Geography, the problems come up with teaching-related knowledge and students' interactions with the subject.
Another important factor could be identified in Table 1. There are 03 Tamil medium schools in the Nivithigala Educational Zone. But none of the students in those schools are taking up Geography for AL and OL examinations, and they stated that they don't have much interest in selecting the subject. The study revealed that most Tamil medium students would like to select Sinhala as a subject as their second language. According to the students, teachers and their parents force them to follow Sinhala. Therefore, students believe that they have more advantages in taking Sinhala as a subject for OL and AL examinations than geography. In addition, some students stated that though they are willing to study Geography for OL and AL, they do not have Geography teachers in their schools.

4. Conclusion

Geography is studying the human-environmental inter relationship according to the spatial and temporal aspect. Although the global demand is high, through the secondary education system in Sri Lanka, Geography is not growing as a practicable and robust discipline. Most students are afraid to select Geography for their OL and AL examinations. The main reason is that many students do not have good practicable knowledge of maps and cartographic techniques. On the other hand, some teachers who teach geography are not qualified in the same field. Students feel that Geography is one of the most difficult subjects they have ever seen. Therefore, the problem comes up with the teacher's subject-related knowledge and students' interactions with the subject. Another important factor identified in the research is that most Tamil medium students don't have much interest in selecting Geography, and they have been given priority to study the subject Sinhala. Considering all the facts, this study recommends that proper encouragement and guidance are necessary for both students and teachers to develop Geography as a very strong and practicable subject in the secondary education system in Nivithigala Education Division.

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Technical Session 3

Disaster Resilience in Sustainable Development

The Importance of Building Resilience in Tropical Agro-ecosystems for a Sustainable Future

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1. Introduction

Agriculture has made positive and negative impacts on lives and the natural environment. For example, agricultural lands damage natural vegetation, habitats, and ecosystems (Darkoh, 2003). Moreover, agrochemicals cause environmental degradation and harm human well-being (Arthur et al., 2000; Moncaster et al., 2000; Wimalawansa & Wimalawansa, 2014). In contrast, agriculture provides the lifeline for humans and the environment (Altieri et al., 1983; Cervantes-Godoy & Dewbre, 2010; Dubey et al., 2021; Wezel et al., 2014). Tropical agro-ecosystems are specifically important since tropics have optimum conditions for agricultural production with large verities of products. Furthermore, with the increasing population growth, tropical agro-ecosystems have become a vital element to assure global food security (Vermeulen et al., 2012).

However, within the context of climate change, tropical agro-ecosystems have become specifically challenged due to changes in climatic conditions, weather patterns, rainfall changes, temperature changes, and extreme weather events (Andres & Bhullar, 2016). Furthermore, the rapid population growth leading to increasing food demand, urbanisation, and clearance of agricultural lands further challenge tropical agriculture (DeFries et al., 2004; Liebman et al., 2015; Peterson et al., 2018). In this context, achieving Sustainable Development Goals becomes a challenge since preserving agriculture sustainability while fulfilling human and environmental sustainability (Dubey et al., 2021).

Hence, agro-ecosystem resilience, including tropical agro-ecosystems, has become a key priority in many international agendas (Andres & Bhullar, 2016; Dubey et al., 2021). For example, the 2030 Agenda for Sustainable Development and the Paris Agreement promote sustainable agricultural practices which minimise environmental damages while maximising agricultural output for communities. Furthermore, governments and other local and international stakeholders have introduced many initiatives to provide sustainable agricultural solutions. For example, sustainable agro-ecosystem practices have been implemented as a measure of building resilience through agriculture (Folke et al., 2010).

Thus, BRITAE, a project funded by the European Commission, aims to build resilience in tropical agro-ecosystems by building higher education institutions' capacities. At the initial stage of the project, a systematic literature review was conducted to:

1. Emphasise the importance of agro-ecosystems resilience
2. Explore the importance of tropical agro-ecosystems in building resilience

Accordingly, the following section describes the methods and the materials adopted in the study.

2. Methods and Materials

An extended literature review was conducted as a combination of both systematic and snowball methods. A systematic literature review helps to identify concepts related to the study scope in a systematic way (Ferrari, 2015; Laufs & Waseem, 2020). The snowball method is a way of finding literature by using one or two key documents on the subject as a starting point and then consulting the bibliography in the key document (book or journal article) to find other relevant titles of the subject area.

Keywords and the search string used to conduct the systematic search are presented below.

Keywords	***Related terms***	
• Agro-ecosystems	Tropical agro-ecosystems	Rice based agro-ecosystems
• Resilience	Ecosystem resilience	Agro-ecosystem resilience

Search String

("Agro-ecosystems" OR "Tropical agro-ecosystems" OR “Rice-based agro-ecosystems”) AND ("Resilience" OR "Ecosystem resilience" OR “Agro-ecosystem resilience”)

Figure 1 presents the PRISMA flow diagram which describes the process involved in conducting the extended literature review. First, the papers were screened based on predefined inclusion and exclusion criteria as presented below.

Inclusion Criteria

- Research papers, book chapters, journal articles
- Key terms are included in the title, abstract, or keywords
- Papers are written in English
- Related to one or more domains of agro-ecosystems and higher education

Exclusion criteria

- Reviews, meta-analysis and commentaries
- Papers not written in English
- Any repetitive articles in the database

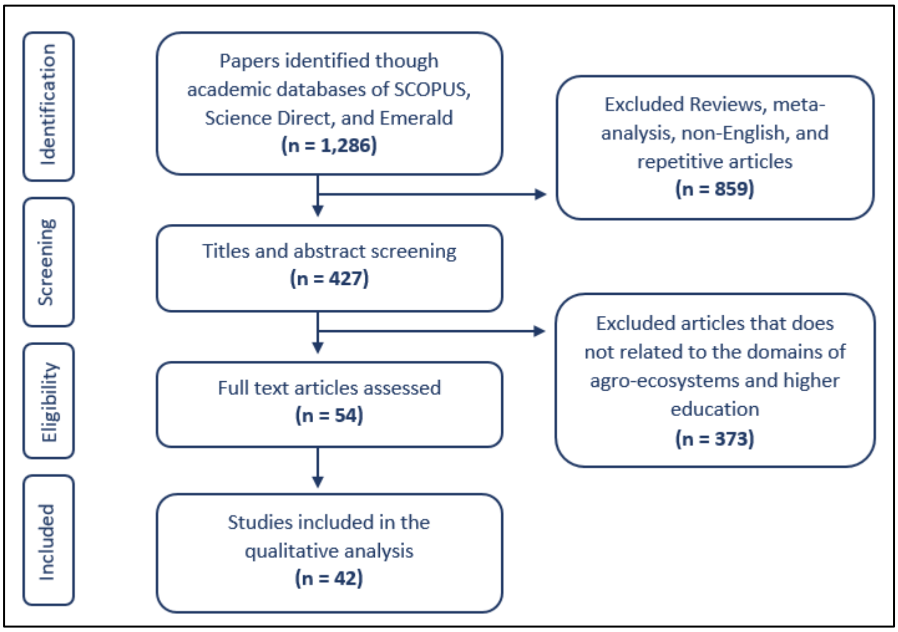

Figure 1. Prisma follow diagram adopted in the systematic literature review

Source: Prepared by the authors

The study conducted a qualitative analysis in answering research objectives. The data extracted from the papers were thematically analyzed to identify the key thematic areas related to the study objectives. Accordingly, the following section presents the outcome of the analysis under the two research objectives.

3. Results and Discussion

Importance of agro-ecosystem resilience

Agro-ecosystems are diverse. There are long-term crops where the ecosystem functions are maintained for years, and some short-term crops where the land use is changing more frequently with harvesting seasons. Due to climate change and more frequent natural hazards, agro-ecosystems have become more vulnerable, especially in tropical regions (Bhaskar et al., 2018; Cogato et al., 2019). Floods, extreme rainfall events, reduction of the number of rainy days, droughts, and changing temperature have adverse effects on agricultural production by destroying the harvest or declining the yield (Várallyay, 2007). Losing species diversity is another key factor in declining an agro-ecosystem's resilience capacities (Kindt et al., 2006). Nevertheless, many agro-ecosystems are reluctant to incorporate diversification of crops, especially when it comes to large-scale farming. However, many tropical agro-ecosystems are maintained as intermediate and small-scale agricultural lands where crop diversification is possible to apply.

Therefore, the concept of resilience agro-ecosystems has gained attention in agro-ecosystems planning (Walker & Salt, 2012). Hence, practitioners propose different approaches across the world. Crop diversification is a commonly used strategy in agro-ecosystems resilience (Weibull et al., 2003). Crop diversification increases the number of species in agro-ecosystems resulting in increasing the yield. It also provides a sustainable platform for managing agro-ecosystems (Smith et al., 2008) (Ratnadass et al., 2012). Crop diversification has been recognised as an effective practice in agro-ecosystems where diversified crops have different tolerant capacities for natural and man-made scenarios. For example, a pest infestation among some crops may not harm other crops. This results in securing farmers by allowing them to harvest a certain amount of yield from their agricultural lands.

Moreover, some crops are highly sensitive to extreme climatic conditions, whereas some crops are less resilient. Therefore, by incorporating both verities within the crop diversification, farmers can make their agro-ecosystems more resilient. This is vital for food security, especially in tropical regions since many developing countries belong to the tropical region. Hence, agro-ecosystems resilience has become vital.

Under the resilience approach, agro-ecosystems are expected to withstand and recover from disturbances, such as pests, weather, and other biophysical factors (Liebman & Schulte-Moore, 2015). However, a well resilient agro-ecosystem is susceptible to fluctuations in production costs and market prices (Kremen & Miles, 2012; NRC, 2010). Furthermore, due to commercialisation, the main purpose of agro-ecosystems has become to increase the producers' profits. Therefore, increasing the resilience of agro-ecosystems has also become one major concern of the producers.

In order to utilise agro-ecosystems as a mechanism of increasing community resilience, the resilience of the particular agro-ecosystems should also be considered an important factor. Therefore, preservation of biological diversity is significantly important to maintain the services delivered by that particular ecosystem (Feledyn-Szewczyk et al., 2016).

Another benefit of agro-ecosystems resilience is the ability to preserve agricultural biodiversity. Agricultural biodiversity will ensure the crops pollination process (Richards, 2001), the biological crop protection (Gurr et al., 2003), the maintenance of proper structure and fertility of soils (Bender et al., 2016), the protection of soils against erosion (Mkanda, 2002), the nutrient cycling (Hendrix et al., 1992), and the control of water flow and distribution (Mijatović et al., 2013). Therefore, conservation of agro-ecosystems and natural ecosystems with high richness and diversity of species will increase the agro-ecosystem resilience.

With the advancement of technologies, agro chemicals and genetic modification have become more common practices for agro-ecosystems resilience. Different agrochemicals are used as insecticides, herbicides, fungicides, and nematicides (Hartley & Kidd, 1987). However, researchers and scientists have highlighted that it disrupts the agro-ecosystems' natural environmental processes (Bhandari, 2014; Kabir et al., 2010). These agro-chemical destroy the essential organisms, especially in soils which also disrupt the natural process of soil nutrients. Once agrochemicals are used as pesticides, farmers may also need chemical fertilisers since there are no organisms to make soils nutrients for the plants. Moreover, as the side effects of using agro-chemicals contributed to contamination of groundwater (Sunitha et al., 2012), contamination of soils (Rodríguez-Seijo et al., 2019), eutrophication (Khan & Mohammad, 2014), and acting as toxic agents for all living organisms (Kungolos et al., 2009). Moreover, genetic modification seems to have promising results when facing the adverse impacts of climate change (Singh et al., 2017). For example, drought tolerance crops have been successful in many parts of the world under extremely dry conditions (Gosal et al., 2009; Lightfoot et al., 2007). However, again there are discussions about the health impacts of genetically modified agro-products (Dona et al., 2009). Therefore, current practices for making agro-ecosystems resilient are more focused on organic farming practices and incorporating the natural environment process into agriculture.

Under agro-ecosystem resilience, the focus is given to crisis and disaster risk, monitoring and early warnings, community vulnerability, preparation, and response (FAO, 2016). Moreover, it is essential to be aware of such practices for both decision-makers and practitioners, where the role of higher education institutions can play a vital role in enhancing the knowledge.

To improve resilience through agro-ecosystems, it is essential to maintain the agro-ecosystem resilience in all agriculture sectors. According to Food and Agricultural Organization (FAO), the livelihoods of 2.5 billion people depend on agriculture. Furthermore, one out of nine people does not receive enough food across the world. Furthermore, more than half of the agro-ecosystems are threaten by disaster risk (FAO, 2016). Therefore agro-ecosystem resilience becomes a vital element in achieving sustainable development success.

The role of tropical agro-ecosystems in building resilience

Resilience refers to recovering from any downfall (Herrman et al., 2011) caused by natural and man-made incidents (Rose, 2007). Resilience could be perceived from individual and community perspectives. In terms of disaster resilience, decision-makers and practitioners focus on community resilience (Cutter et al., 2010), economic resilience (Rose, 2007), and cultural resilience (Crane, 2010).

In addition, resilience in agro-ecosystems support building individual and community resilience. For example, well maintained and managed sustainable agro-ecosystem contribute for increasing economic and social resilience of farmers as individuals and hence the society. Therefore, agro-ecosystem can play a vital role in building resilience in both community and individual perspectives. Furthermore, tropical agro-ecosystems resilience is specifically important in building resilience. This is because tropics have optimum conditions for agricultural production with large verities of products.

With increasing population growth, the demand for food increases. Hence, tropical agro-ecosystems is significant towards global food security (Anderson et al., 2011; Vermeulen et al., 2012). Without agricultural products, communities will not have sufficient resilient capacities for their survival. Therefore, sustainable agro-ecosystem practices for food production have been introduced for building resilience through agriculture (Dubey et al., 2021; Folke et al., 2010).

Moreover, within the urban resilience context, tropical agro-ecosystems help to restore natural cycles, ecosystems and ecosystem services (Ferreira et al., 2018). One of the key reasons for declining community resilience is the disturbances in the natural environmental process. The natural environmental process happens due to the destruction of ecosystems in urban settings for settlements and other anthropogenic constructions. Current practices and policies have highlighted the importance of ecosystem based adaptation in building urban resilience (Faivre et al., 2018; Wood et al., 2018). Therefore, incorporating agro-ecosystems under the ecosystem-based adaptation will bring multiple benefits for communities while improving climate and disaster resilience and increasing food security. For example, promoting organic farming can increase community resilience in different aspects (Döring et al., 2015). As highlighted earlier, merging agricultural plants with ecosystem based approaches will have multiple benefits as increasing food security among urban communities.

Tropical agro-ecosystems can also implement as a mechanism for disaster resilience by using them as adaptation measures against climate change and its related disasters. For example, agro-ecosystem will function as carbon sequestration units directly linked with reducing atmospheric carbon dioxide levels

(Lal, 2010). This will be directly linked with reducing global warming and reducing urban heat (Oberndorfer et al., 2007). In urban settings and rural and semi-urban settings, the use of ecosystem-based measures for DRR is highly encouraged by the planners (Shah et al., 2019). For example, ecosystem-based initiatives have been introduced to prevent landslides (Sandholz et al., 2018), coastal erosion (Hale et al., 2009), riverbank erosion, and flooding (Daigneault et al., 2016).

Furthermore, cultivating permanent fruit-bearing plant species will enhance the agricultural production of these areas as well. The use of agro-ecosystems in reducing natural hazards is significantly important within development practices. These environmentally friendly agro-ecosystems provide multiple benefits in the current development agendas (Tanner et al., 2015).

In addition, urban agro-ecosystems further reduce societal vulnerabilities caused by food shortages. Urban agro-ecosystems can increase urban food production by diversifying urban food production (Müller, 2007). It will also provide income opportunities for the urban poor by making them more resilient while utilising the urban space more productively (Smit et al., 2006). This will also support the urban poor by uplifting their quality of life through making their economies more resilient.

Moreover, ecosystems, including agro-ecosystems contribute to preserving and restoring natural environmental processes and functions in the urban and rural context (Zellmer & Gunderson, 2008). It will increase environmental resilience by reducing the adverse impacts of extreme weather events.

Despite the above-stated benefits of agro-ecosystems in building resilience, tropical agro-ecosystems face several challenges when preserving resilience in tropical regions. For example, the shifting cultivation or the chena cultivation contributes towards deforestation in many parts of the developing world (Ickowitz, 2006; Zhang et al., 2002). Though governments declare permanent agricultural lands and forest conservation practices, rural communities still practice land shift methods for cultivation. Moreover, the deforestation caused by land shifting directly impacts global climate change, which reduces community resilience. Therefore, tropical agro-ecosystems resilience should be well-managed to achieve multiple aspects of resilience in societies.

4. Conclusion

Agro-ecosystems, including tropical agro-ecosystems, function as the lifeline for both humans and the environment**.** Nevertheless, they face significant threats caused by changing climate, population growth and urbanisation. Due to such reasons, agro-ecosystem resilience has become a global priority when meeting development agendas. Agro-ecosystems resilience could be introduced through sustainable farming practices, crop diversification, urban agro-ecosystems, and organic farming are some examples of resilient agro-ecosystem practices.

Through resilient agro-ecosystems, food security can be established across the world. Due to the rising population, food security has become a major challenge for development planners. Hence, through resilient -agro-ecosystems, the global challenge of food security can be established. In addition, agro-ecosystem resilience also helps to reduce environmental pollution through organic farming and crop diversification. Finally, through agro-ecosystem resilience, disaster risk can also be reduced. Hence, agro-ecosystem resilience should be preserved by minimising possible challenges for a sustainable future.

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Challenges of Urban Planning in The Context of Multi-Hazard: A Systematic Literature Review

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Keywords: Multi Hazard, Urban Planning, Systematic review, COVID-19

1. Introduction

Addressing the issues of urbanization is soon becoming a global priority as the world progressively urbanizes. Indeed, 54 percent of the world's population was urban in 2014, and that figure is expected to rise to 66 percent by 2050(United Nations, 2018). Natural disasters offer a significant issue in these urban areas, where the urban population is constantly exposed to the risk of these calamities. Nearly three out of every five cities with a population of at least 500,000 people are at high risk of being hit by at least one of six types of natural disasters, namely cyclones, floods, droughts, earthquakes, landslides, and volcanic eruptions. (United Nations, Department of Economic and Social Affairs, 2018). Poorly planned urban environments, ineffective urban administration, and outdated and brittle infrastructure can all put pressure on the urban environment and expose it to disaster risk. They are related to the magnitude of the vulnerability of urban areas rather than the magnitude of the hazard. As Rus (2018) points out, the need for these cities' maintenance and upkeep makes safety measures for their residents critical in these conditions. As a result, urban design for multi-hazards and risk reduction has been identified as a critical aspect in building resilient urban communities to severe calamities.

Urban planning, which is concerned with improving the plans, functions, and management of cities and places, clearly plays a role in catastrophe mitigation. According to León and March (2014), there has been a long-standing commitment, at least theoretically and in policy, to further improve urban planning's ability to reduce disaster risk and damage. Proper planning allows communities to govern land use and habitation, which is critical in preventing tsunamis and flooding. However, several countries have employed various urban planning tools to monitor land usage and mitigate the effects of tsunamis. These include resettlement, the development of no-build zones, land use restrictions, tsunami-safe building standards, and the preservation of natural buffers, including forests, compacted dunes, and wetland areas.

The emergence of the COVID-19 pandemic underscored the importance of proactive urban planning in a global context where the threat to cities was a major worry. It has been reported that 90% of COVID-19 infections have started in cities, making pandemic preparedness more critical than ever (UN-Habitat, 2021). Unfortunately, natural disasters and related disasters do not halt for a virus, and the pandemic created cascading impacts in urban areas. Only a few months after the COVID-19 pandemic began, various natural disasters such as earthquakes and floods, as well as their primary and secondary impacts, occurred (Čivljak et al., 2020). They affected the pandemic's evolution in a variety of direct and indirect ways, affecting different aspects of daily life. The interaction of the evolving pandemic and natural hazards has a high potential for causing compound disasters, complex emergencies, and multiple crises, all of which endanger human life and well-being and involve a variety of effects and challenges for authorities at all administration and governance levels (global, regional, national, and local) not only in developing but also in developed countries (Lau et al., 2020; Phillips et al., 2020).

Even though a considerable body of research on various multi-hazard methods connected to urban planning in metropolitan regions has been published, there appears to be a lack of consensus or best practice on what measures to implement in these locations. Furthermore, most previous research does not address the combined and cascading consequences of multi-hazard scenarios. Furthermore, the COVID-19 pandemic has generated new concerns about disaster preparedness and response, requiring physical separation and hygiene protocols to be followed in preparing for healthy evacuation from other disaster situations. As a result, it is important to consider whether existing urban planning strategies in multi-hazard environments support disaster preparedness efforts in dealing with concurrent hazard threats, such as a pandemic. A systematic review of the research literature using systematic and explicit accountable methods could address this by deploying an explicit, rigorous, and transparent approach to reviewing the literature on urban planning strategies while answering specific research questions. As Gough (2013) highlighted, systematic reviews provide an unbiased picture of the literature on urban planning. In contrast, traditional literature reviews attempt to summarize what is "known" about a topic, but without explaining how included studies have been identified and why other studies have not been reviewed and discussed.

2. Methods and Materials

This systematic review aims to answer the following questions about the state of the academic literature on urban planning strategies around the globe: 1) what other hazards (including COVID-19/pandemics) have been addressed through urban planning? And 2) what are the existing strategies for urban planning in tsunami-prone areas? Are these multi-hazard strategies, for example, addressing cascading hazards, COVID-19/pandemics? A systematic review of the literature on urban planning strategies is therefore presented.

After the literature search, this study employs a frequency analysis to identify and categorize the applied methods from the literature to better frame the urban planning strategies. Because this study of urban planning techniques was primarily based on academic literature, the database search was limited to peer-reviewed publications published in English. First, the search terms were "urban planning*" AND "Multi-hazard," and these terms were then searched in the Web of Science, Scopus, and Academic Search Complete databases to ensure the rigour and quality of the included materials. The search was limited to all public documents from 2000 to February 2020. Second, the exclusion criteria were developed,

- Urban planning is not the main focus
- Did not include any hazard
- Did not include urban planning strategies or mechanism

These criteria were applied to the remaining articles during the abstract screening stage to determine whether they are relevant to the assessment of urban planning. Lastly, the 56 filtered articles were then carefully reviewed to answer the two research questions (Figure 1). A frequency analysis was conducted to record the characteristics and dimensions of urban planning as well.

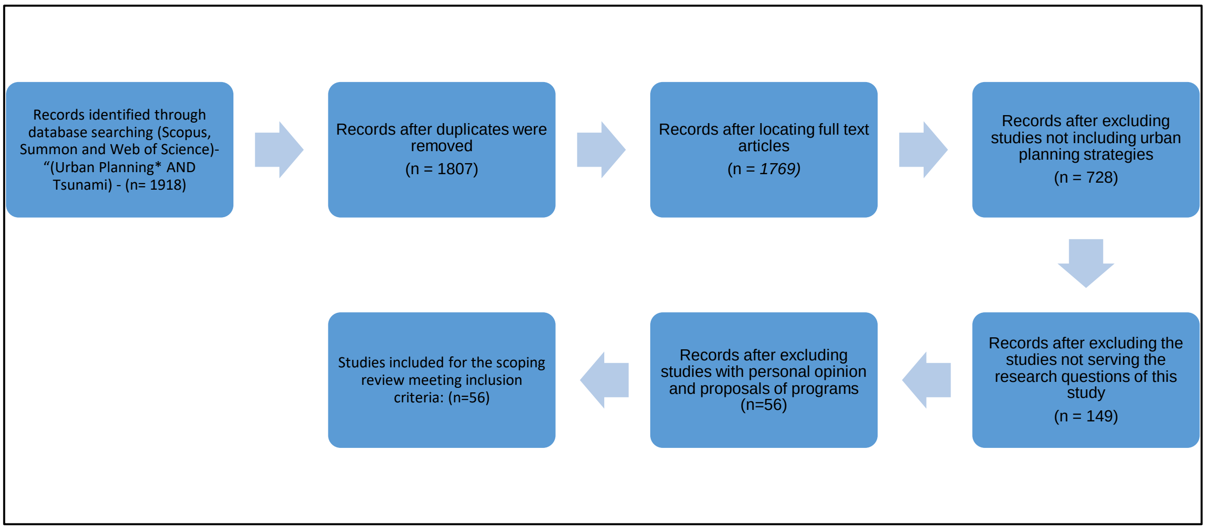

Figure 1: Flow diagram of the systematic review

3. Results

As revealed through the review, urban communities are also vulnerable to catastrophic events such as hurricanes, tropical storms, and even flooding and high winds. Among these hazards, floods, earthquakes, and coastal storms are prominent in the cities, and the association of landslides, volcanic eruptions, and wildfires were less frequent in these urban areas. Out of 56 reviewed papers, 28 were tsunami-based studies, and 7 were flood-based studies. Also, 17 of the reviewed papers have considered the multi-hazard context for urban planning. However, the tsunami and earthquakes were prominent in multi-hazard scenarios where both incidents could be occurred on the same occasion and same region, respectively. The recent outbreak of COVID 19 was not significant in the literature as studies did not adequately address the impact of the pandemic in a multi-hazard environment.

Due to the impact of hazardous events on urban regions, planner has developed various types of strategies and tools to meet these events. As identified through the review, evacuation planning and community participation are responsible for the majority of studies. Evacuation planning involves the movement of people to a safer location and their return which should be planned carefully and implemented for better results. Most of the studies tend to focus on the evacuation sites, and secure sites for people as a significant concern in the all-hazards approach, which will maximize the efficiency and effectiveness of any evacuation that may be required. As identified through the review, public participation in the urban decision-making process can be implemented through a number of tools such as stakeholder analysis, city consultations, and working groups (Aoki, 2018; Hettige & Haigh, 2016; Lim et al., 2016).

Most cities across the world are exposed to more than one hazard event, as highlighted in the literature (Barría et al., 2019). However, most of the studies focused on single hazard event, whereas multi-hazard scenarios were relatively law in consideration. Among them, evacuation planning and stakeholder participation have been identified through some studies as the main concerns in a multi-hazard scenario.

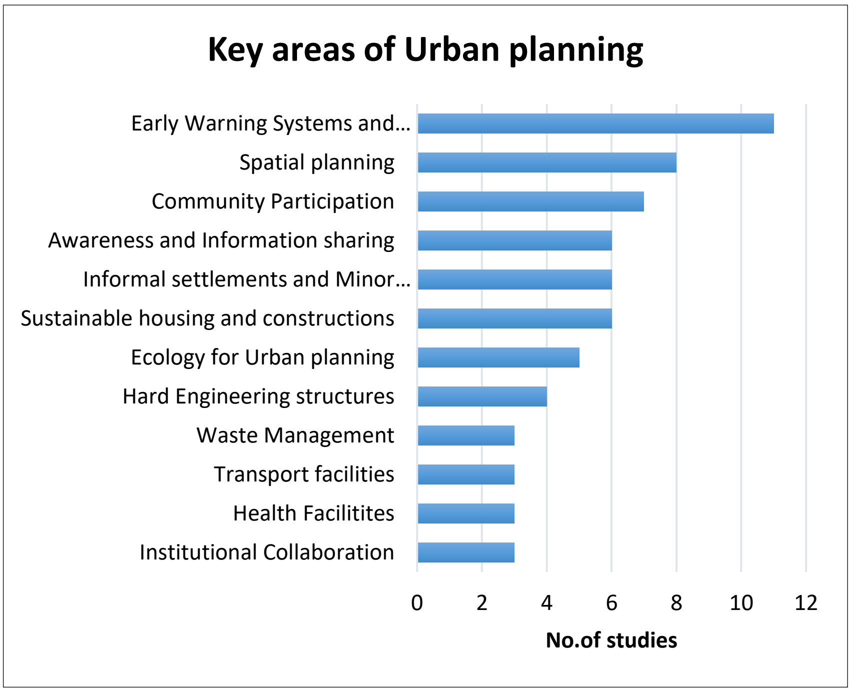

Figure 2: Key areas of urban planning

Also, most research has emphasized community engagement and other stakeholder participation as a beneficial technique for improving evacuation planning performance. Citizens' participation in recognizing their needs, determining priorities, and formulating strategies increase the likelihood of developing sustainable, practicable solutions that citizens are willing to adopt (UN-HABITAT, 2007). Further, the inclusion of digital-based technologies as multi-hazard strategies could enhance the accuracy and efficiency of the planning where Geographic Information Systems and Remote Sensing tools are more useful in such situations (Garcin et al., 2008; Ito et al., 2019; Lim et al., 2016 and Usha et al., 2012). Few studies also highlighted the contribution of environment-based planning for multi-hazard strategies such as the green city concept, which is more focused on sustainability in these situations (Arif, 2017). However, the pandemic-related urban planning strategies were yet lacking in the literature, although the challenges were highlighted in some studies (Sharifi & Khavarian-Garmsir, 2020).

4. Discussion

Biological hazards are not new to the world through the awakening that happened due to the current pandemic caused by the SARS-CoV-02 virus. The covid-19 pandemic has altered almost all resilience strategies in the world with the critical challenges faced by the global community during several crucial SARS-CoV-02 outbreaks. Therefore, the new development paradigm should be more concise, anticipating growing future challenges to establish build back better in DRR. Yet, the entire globe is facing many unresolved challenges in mitigating risks and vulnerabilities pertaining to present and future physical and social development.

The literature provides a variety of urban planning techniques, methods, classifications, and practices in multi-hazard scenarios. Furthermore, the majority of studies in the reviewed publications focus on tsunami-based urban design rather than other risks in metropolitan areas such as coastal storms, floods, and landslides. A severe threat in most cities, Tsunami, has prompted the different governments to embark on better risk-reduction strategies. However, the multi-hazard scenarios or the cascading impact of the disasters were not clearly discussed in these studies. Therefore, there is a clear need to explore the potential of adopting multi-hazard strategies for urban planning, making cities more resilient for such scenarios.

The most prevalent strategies for urban planning are found under the topics of evacuation planning and community participation. Most of the literature incorporated the innovative methods for evacuation planning which were highlighted as the main concern in a hazardous event (Munirwansyah et al., 2020). Furthermore, the introduction of digital-based technology to evacuation planning provides a new solutions such as web-based planning, emergency flying equipment, etc.(Januszkiewicz, 2019). On the other hand, community participation in both pre-planning and implementation stages yields superior results as an urban planning technique worldwide. Most studies have emphasized the necessity of broad stakeholder engagement in addressing difficulties in urban planning and providing a realistic image of disaster risk reduction at the grassroots level. However, there are discussions in the literature about integrating multiple types of stakeholders in the planning process during a pandemic crisis, which complicates the planning with different parties and opinions.

Spatial planning empowered by digital technologies creates new opportunities for urban planning in regions not just as a tool for pre-planning, but also to guide sustainability vision and strategies for urban planning. Using GIS, Remote sensing, and satellite-based technologies have guided urban planners and practitioners to monitor the progress of the existing urban planning strategies in a multi-hazard scenario (Guntur et al., 2017). Many developing nations struggle to enhance their social development stability, including public health, economy, poverty alleviation, and livelihood development. On the other hand, physical development programs have faced enormous repercussions in building resilient infrastructure that can robustly provide a healthy environment to combat future biological hazards in urban areas. This need is further emphasized when a country faces a multi-hazard scenario either due to a set of natural hazards or a mix of biological and natural hazards faced by several countries such as India, Sri Lanka, and Indonesia during the Covid-19 outbreak.

5. Conclusion

This paper analyzed the literature on multi-hazard urban planning techniques to identify the most prevalent methodologies, framings, and categorization of important areas that have been used to date. This paper concludes from a literature review that the most common methods and framings—organizing large indicator sets around the aspect of urban planning and other dimensions—may not be the best course for future urban planning tools for multi-hazard scenarios where emerging pandemics may disrupt existing strategies. Instead, a more integrative multi-hazard strategy for pandemics should be used, with basic sustainable urban design principles guiding a goal-based framework.

There are also differences in the literature about clear regulations and coordinating and implementing such regulations with corresponding institutions within an urban zone. Conflicts with parties arise as a result of the various structures in the implementing agency, making the implication process more complex. In addition, there is a lack of understanding of medical and mental health facilities in urban planning infrastructure, which is rarely incorporated into the planning process. As a result, a holistic approach with a multi-hazard scenario may result in more equitable access to urban planning with a wide range of urban planning options.

Depending on the expertise of others, the breadth of this paper is limited by their self-reporting of results from their investigations. As a result, studying the literature is dependent on this author's interpretation of other people's work, which is frequently ambiguous. Nonetheless, this study emphasizes new research that will advance urban planning and multi-hazard risk reduction. Future studies will largely need to formulate guiding planning concepts, build goal-oriented evaluation frameworks based on these principles, and empirically analyze the frameworks. This should be pursued in tandem with the development of a single framework for integrating urban planning literature.

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A Framework for Using Road Network Centrality for Tsunami Evacuation Planning Amongst a Pandemic Outbreak

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Keywords. COVID-19, emergency management, rapid onset hazards, risk assessment, weighted centrality

1. Introduction

The COVID-19 pandemic, which transmits as a contagious respiratory disease (Coronavirus 2 SARS-CoV-2), made a rapid transformation in the daily functions required to adhere to health and safety guidelines, especially with regards to the physical distancing measures. During this period, the emergency management tasks, especially for rapid onset hazards, are left with ambiguity or confusion when adapting to the physical distancing measures. The present pandemic preparedness guidelines for Tsunami issued by the Indian Ocean Tsunami Information Centre (ICG/IOTWMS, 2020) exemplify this matter as the guidelines state that a tsunami evacuation order should prioritize over covid-19 stay-at-home advice when evacuations are required. Many countries where the COVID-19 general reproduction rate (R) is high are found highly susceptible to other natural hazards, including earthquakes, cyclones, floods, wildfires, etc. (Ashraf, 2021). However, as the present disaster management guidelines, including tsunami evacuation, are not integrated with pandemic preparedness guidelines, the risk of sudden spikes of COVID-19 cases and fatalities following the incidents of other natural disasters during a pandemic is identified to be significantly high (Hariri-Ardebili, 2020). Accordingly, the COVID-19 pandemic outbreak has caused the emergency management services in the disaster management discipline to be prepared with extra precautions regarding health and safety and physical distancing measures (Ishiwatari et al., 2020). Especially during the rapid onset hazards, the fast and mass movements can cause to accelerate the transmission of the COVID-19 disease and develop post-disaster pandemic clusters in the relief centers. Therefore, identifying a novel approach to manage community evacuation and relief services for rapid onset hazards during a pandemic outbreak is considered as an urgent need in the present emergency management plans.

Physical distancing is one of the major preventive measures introduced in the world to contain the transmission of the COVID-19 pandemic (WHO, 2020). However, emergency response activities, especially for rapid onset hazards, are left with no guidelines to incorporate physical distancing for a compound hazard amongst a pandemic outbreak (Nande et al., 2021). Consequently, the compound hazardous situations amongst a pandemic are commonly recorded with the sudden spike in the COVID-19 cases and related mortalities (Ashraf, 2021). The lack of linkage and knowledge on the convergence of the guidelines provided for natural disaster management, including evacuation and pandemic management, can be considered as significant causes of the above situation (Ibrahim, 2020). Most of the disaster evacuation guidelines, including tsunami evacuation, are equipped with a comprehensive risk analysis that enables all affected persons to reach designated assembly facilities along the designated evacuation routes (Scheer et al., 2011). However, as the likelihood of COVID-19 exposure and vulnerability is not measured in these guidelines, the contagious disease can easily transmit across the communities being evacuated (Sakamoto et al., 2020). However, as the likelihood of COVID-19 exposure and vulnerability is not measured in these guidelines a contagious disease can easily transmit across the communities being evacuated (Sakamoto et al., 2020). The transmission of COVID-19 which is measured using the Reproduction (R) rate depicts that the COVID-19 virus is most likely to spread within the regions belonging to a single cluster where strong and dense connectivity within a group is shared (Koh et al., 2020).

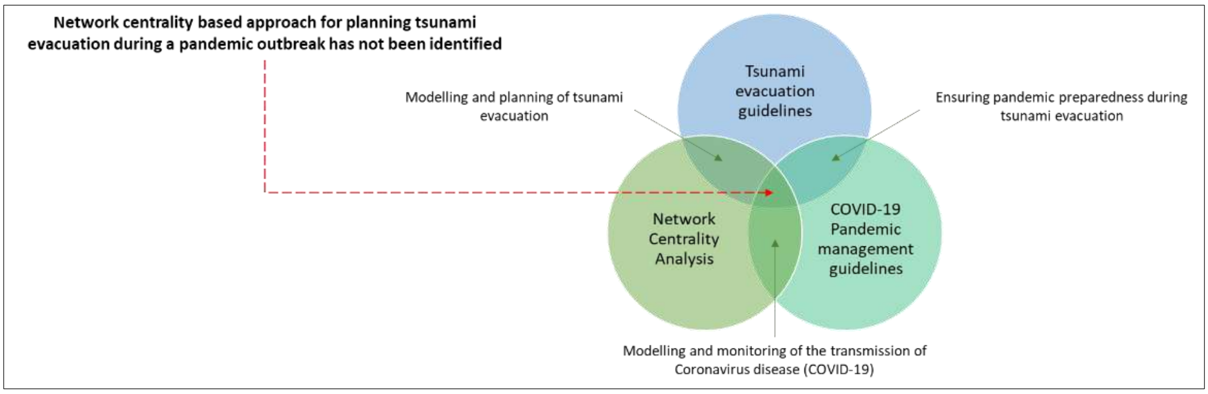

Figure 5, Research gap

The above pattern is further identified to be correlated with the road network connectivity where large community movements and physical contacts are generated. On the other hand, evacuation models, including tsunami evacuation, use the simulation of population mobility across connected geographical areas during disasters to analyse the capacity and consistency of infrastructure for evacuation plans (Dong et al., 2015). Accordingly, road network connectivity can be a common feature for pandemic management and disaster evacuation planning disciplines for determining safe evacuation routes and relief locations. However, there is insufficient knowledge about considering connectivity as a common factor in identifying safe evacuation routes for rapid onset hazards among pandemic outbreaks (Figure 1). Therefore, identifying the above research need, this research aims to use a connectivity approach to analyse the risk of transmitting a contagious disease (COVID-19) during a rapid-onset disaster evacuation.

The Aim of the Research

The research aims to develop a framework for planning a clustered tsunami evacuation strategy to minimize the transmission of a contagious disease during evacuation. The research outcome will be a road network connectivity led evacuation strategy for the tsunami hazard during a pandemic outbreak.

The Objective of the Research

To formulate the framework for identifying the spatial relationship between tsunami evacuation and the transmission of coronavirus disease (COVID-19).

2. Methods and Materials

Centrality Analysis

Connectivity analysis is an explanatory tool that can be used to describe the dynamics underlie road networks (Candeloro et al., 2016). In connectivity analysis, the centrality measure is an important aspect to quantify and prioritise the importance of nodes and links. The centrality measures can quantify the importance of nodes based on their location, links to other nodes, or any other structural or geographical property associated with the respective node (Singh et al., 2020). Centrality as an analytical method of connectivity represents a given node's relevance and risk based on the geometric positioning and the properties (Lin, 2017). This analysis can be widely adopted into the scenario evaluation of tsunami evacuation, assessing the system-wide response for internal-external impacts (Brandes, 2001).

Degree centrality can be considered the primary centrality measure indicating the network nodes' interconnectedness based on the number of direct contacts. Based on the degree centrality, several other global network analyses have been developed (Borgatti, 2005). The closeness and betweenness centrality measures, which are two main global network analyses, identify the length of the shortest paths in the given network. Betweenness centrality indicates the number of shortest geodesic paths that a node serves when connecting any two other nodes of the graph. During an evacuation, the crowd flow always takes the shortest possible geodesic path towards safe destinations. Thus betweenness centrality can be used to study the fraction of distance and the origin-destination pairs (Opsahl et al., 2010). The closeness centrality provides a clear interpretation of locations on the road network that are central and distinct in terms of the global network context.

The closeness centrality of a node in a network represents the node's average distance, the expectation of time, flow of information from any node to another node, or vice-versa (Bucur & Holme, 2020). A higher closeness central node is reached and updated easily as early warnings are issued. Nodes with low closeness centrality will take longer to get reached and updated with the information. These locations can be considered as relief centers in an evacuation plan as these are central in terms of closeness and provide convenient access combined with shortest paths. The eigenvector centrality can be considered as a more efficient analysis for planning evacuation routes and relief locations as this analyse both the number and the importance of its adjacent nodes (Agryzkov et al., 2019). The eigenvector centrality values of the nodes can be calculated by considering the disaster risk properties of adjacent nodes and developing a hierarchy of nodes considering the adjacency of a node to the nodes that are adjacent to more risk nodes. This pattern organises a sequence of the cluster where evacuation operations can naturally take place.

Weighted centrality analysis

In any network, all nodes with the same characteristics are highly unlikely to occur (Benzi & Klymko, 2014). Studies have proven that an unweighted centrality can exhibit limitations when identifying classifications and priority networks (Agryzkov et al., 2019). Specifically, when various forms of demography characterise the network and nodes, infrastructure capacity, disaster risk, etc. the characteristics of these forms should be incorporated in the centrality analysis to obtain efficient results. Especially when analysing the evacuation routes in a region, the disaster risk elements should be considered with high priority inputs to the centrality analysis. These characteristics of the nodes and the links can indicate important information about the contribution of each node to the road network when determining evacuation and relief locations.

Therefore, an essential item in centrality analysis is considering weights on nodes in the process for a better analysis of fully weighted networks (Opsahl et al., 2010). There are two possible extensions of the weighted centrality measures for considering the weights on the nodes (Abbasi & Hossain, 2013):

- Node-weighted centrality - identify the node characteristics for the analysis while considering edge as equal.
- Fully weighted centrality - consider characteristics in both edges and nodes for the analysis.

Over the last decades, the evacuation for natural disasters has been improved in different perspectives, such as evacuees' behaviours, traffic coordination strategies, and evacuation route optimization (Lujak & Giordani, 2016). Conventional natural disaster evacuation plans often guide evacuees to pre-designed routes and destinations based on geographic proximity and natural disaster risk. Such approaches are identified as inefficient when the roads are congested, blocked, or becoming dangerous because of the cascading effects of the disaster that may be present (Fushimi et al., 2019). Therefore, the evacuation route planning should incorporate this variety of characteristics in the geography in the evacuation route calculation. The weighted forms of the network centrality is an efficient way of capturing the geographic properties of a network as it is calculated as the sum of weights assigned to the node's direct connections and node properties, such as disaster risk, demography, capacity, disease, etc. (Opsahl et al., 2010).

As centrality analysis can capture the parameters of central and peripheral nodes, it can be combined with tsunami and pandemic risk elements in a weighted analysis to develop a clustered tsunami evacuation strategy. Therefore, a fully weighted eigenvector centrality analysis can capture both characteristics in the risk of natural hazard and the transmission of COVID-19 disease. However, the relationship between these two disciplines has never been addressed. Accordingly, in this work, a fully weighted eigenvector centrality analysis is planned to be used to develop an evacuation strategy for the rapid onset disasters during a pandemic outbreak.

Use of weighted centrality for planning evacuation amongst pandemic outbreaks

As recent studies have proven that the risk of occurring pandemic clusters is high following a natural disaster evacuation during a pandemic outbreak, analysing the evacuation movements concerning the transmission of diseases is identified as a significant need (Quigley et al., 2020). The weighted centrality analysis has been identified as an effective method to identify and optimise an outbreak situation via novel evacuation strategies (Ashraf, 2021). These works showed the eigenvector centrality measure to have a high capacity to detect the central role of holdings in the network, which is significant for evacuation movements. In this paper, a disease spread will be simulated through the evacuation movement network, testing how weighted centrality led to a better estimate of nodes' natural disaster vulnerability and risk of infectious disease transmission.

The nodes with a high eigenvector centrality value will indicate the frequency of travels across the respective path (Ando et al., 2020). These paths can be identified as critical paths with a high risk of transmitting a disease across the high number of evacuees. Moreover, nodes with a high eigenvector centrality are network hubs, and their presence is crucial in maintaining the paths among all network nodes. However, a high eigenvector centrality value of a node might be a root to panic and highly contagiousness in the case of a high traversing rate via the node. Therefore, classifying the eigenvector centrality values can be potentially used to determine the routes of contagious disease transmission during evacuation. When a hazard occurs on the evacuation route, the evacuation routes get unsafe and sources of disease transmission. Therefore, in the computation of evacuation routes, the related possibility to identify the contagious routes and rerouting towards safe areas should be considered while considering the isolation of identified contagious routes.

The classified eigenvector centrality measures permit the recognition of the evacuees' behaviour to identify their position and flow with their risk situations (Lujak & Giordani, 2016). Furthermore, the evacuation flow is defined by the usage of infrastructure at their momentary positions compared to the evacuation destinations defined as the safe exits. In this aspect, weighted eigenvector centrality of the routes' constituent nodes can make the evacuation route sufficiently safe through time. Accordingly, a fully weighted eigenvector centrality analysis can be considered the most suitable analysis to model the natural disaster risk of the evacuation flow while calculating the risk of contagious disease transmission along the evacuation routes. Natural disaster risk components (Hazard, exposure/vulnerability, deficiency of preparedness) can be used to calculate the node weights while using the eigenvector centrality values for classifying the routes of potentially contagious disease transmission. The findings can be verified via the real data of COVID-19 transmission, which is measured in the Reproduction rate (R-value).

Methodology

This study used an integrative literature review approach to identify the key elements from tsunami response and evacuation and COVID-19 management for the weighted centrality analysis. Inclusion criteria were considered regarding aspects of disaster evacuation and contagious disease transmission, mainly associated with the centrality analysis, evacuation, and COVID-19. The publications older than 2015 were excluded from the search criteria. The literature review aimed to address how a rapid-onset disaster evacuation (tsunami) can cause to accelerate the transmission of contagious disease among the evacuees. Based on this research question, a content analysis was carried out to identify the key elements in the tsunami evacuation planning during a pandemic outbreak. Using the Gephi software (open-source network analysis), degree and betweenness meta-analyses were performed for 50 elements considering their relative importance in a pairwise comparison. According to the analysis the result was categorised into three different forms based on the highest and lowest values in the degree analysis and the highest values in the betweenness analysis. The results were incorporated into the conceptual framework to facilitate the pandemic risk analysis during an evacuation operation following the risk identification, risk assessment, and risk reduction phases as mentioned in the conceptual framework (Figure 2).

3. Results and Discussion

The results of the literature and content analysis of the study can be summarised as mentioned in the conceptual framework in Figure 2. The risk identification phase consists of deterministic tsunami hazard identification, weighted centrality analysis, and COVID-19 transmission monitoring. The centrality analysis for assessing disaster evacuation and transmission of contagious disease can provide significant information for identifying the relationship between neighbouring nodes. These parameters can be reflected as node and edge properties combined with the tsunami risk parameters such as exposure to natural hazards, vulnerability, and disaster response and preparedness measures (Table 1). The centrality analysis can characterize the probability and spatial hierarchy of contagious disease transmission across evacuation routes with reference to varying disaster risk scenarios. The fully-weighted eigenvector centrality of the case study area can simulate the tsunami evacuation while identifying the potential high-risk contagious routes. Finally, the actual COVID-19 R data from the case study area can be used to verify the findings and classify the spatial relationship to formulate the clustered evacuation strategy for the tsunami evacuation during a pandemic outbreak.

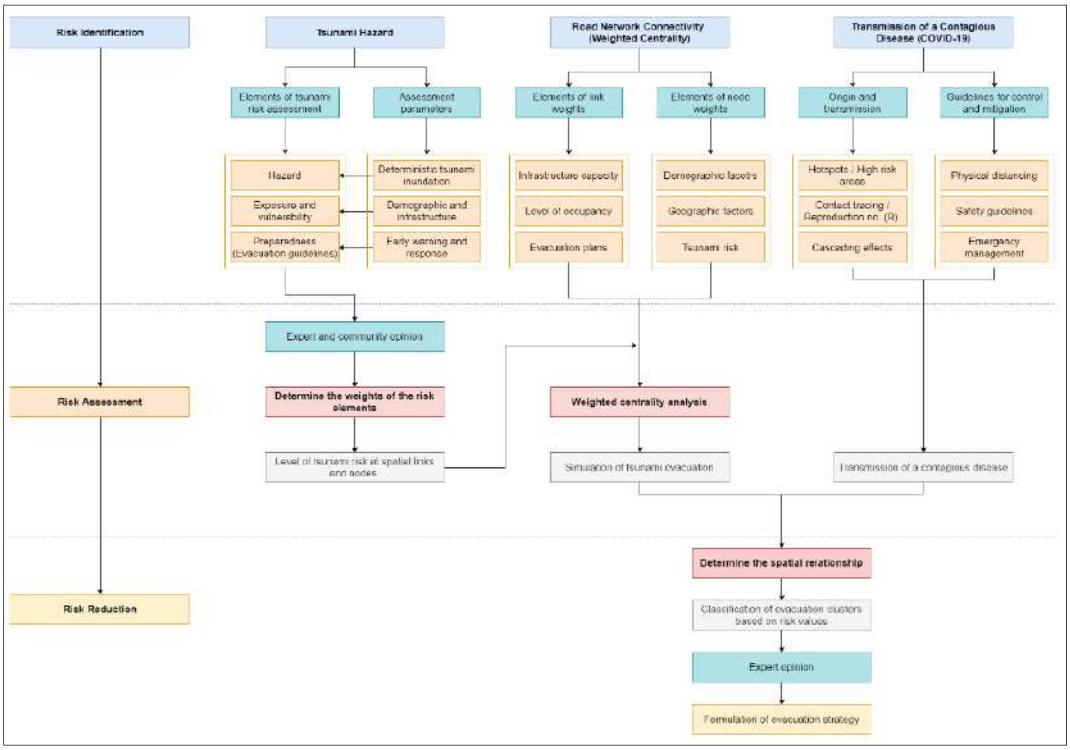

Figure 2, Conceptual framework

Table 1, Weighing criteria of risk elements for the weighted eigenvector centrality analysis

Element of Risk	Components of risk identification	
Deterministic hazard identification	Drag	
	Flooding extent	
	Inundation depth	
Exposure / vulnerability	People	Population density
		Sensitive age groups
		Literacy
		Extreme level of poverty
		Disability (physical/intellectual)
	Disease	Transmission of disease (COVID-19)

		Critical evacuation
		Isolation
	Ecosystem	Protection
		Singularity
		Services
		Degradation
	Socio-economic activities	Job generation
		Contribution to GDP
		Exposed activities
		Tourism
	Infrastructure	Road network
		Hazardous/dangerous industries
		Emergency/health infrastructures
	Buildings	Critical buildings
		Vertical evacuation
		Construction materials
Deficiency in preparedness	Information and awareness	
	Early warning and evacuation	
	Emergency response	
	Disaster recovery	

Case Study

Three cities in Sri Lanka have been identified as case studies for this research, considering the recent outbreak of COVID-19 in the worst affected cities in the 2004 tsunami. Accordingly, from the Sri Lankan context, the following 3 locations are identified to carry out the case study: (1. Galle, 2. Matara, 3. Batticaloa) (Figure 3). The case study mainly aimed to evaluate the clustered tsunami evacuation strategy during a pandemic outbreak in an urban context where road networks can be incorporated for alternative route designing and community self-evacuation can be considered as a significant approach.

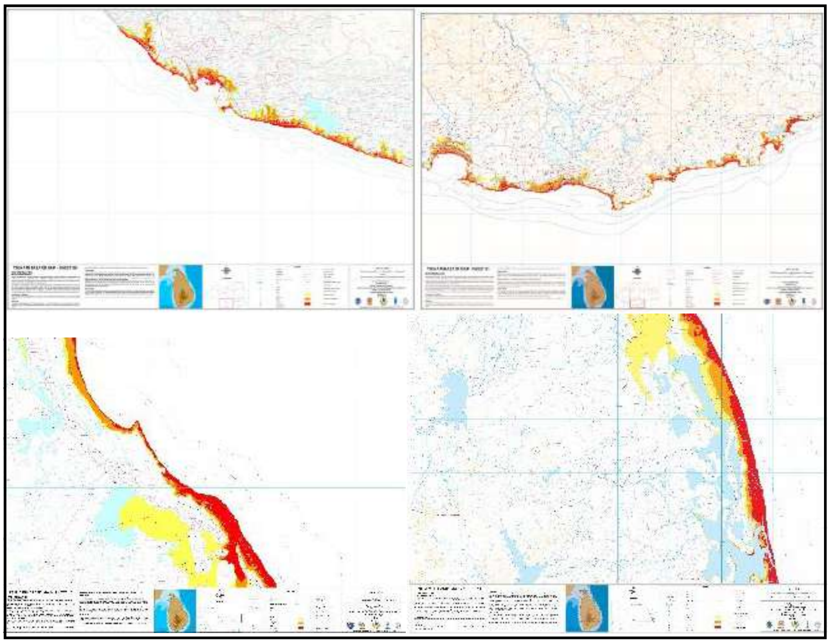

Figure 3, Tsunami hazard map - sheet 90/91/45/51 covering Galle, Matara, and Batticaloa coastal area (CCCRMD, 2012)

Limitations

One of the major limitations of the study is that the impact of tsunami evacuation amongst a pandemic outbreak is studied based on other similar instances since there are no empirical records available during the past COVID-19 pandemic period. In addition, the methods used in the research are still at the research stage for a pandemic situation; thus, there can be extreme scenarios that are not captured in the methods.

4. Conclusion

The weighted centrality-based risk analysis approach can be considered as a potential approach to identify the pattern of a contagious disease transmission during a disaster evacuation. The values of risk elements will be used to weight the centrality analysis, which will output a simulation of tsunami evacuation along with the road network. The simulated result will be used with the Coronavirus transmission (R) data to develop the relationship to identify the disease transmission hotspots. The evacuation mode is considered the by-foot evacuation, which can provide the maximum risk scenario of disease transmission. The risk elements are identified from the content analysis and verified via expert opinions. As the centrality analysis is highly effective when weighted with spatial elements, the spatial reference is considered as a priority factor when identifying the risk elements. The R data will recognize the transmissibility of the disease concerning the spatial locality. The individual-level disease transmission prevention measures (Ex: face masks, hand sanitizing) will not be included in the analysis considering the variables' high complexity and monitoring difficulties. The above-identified relationship will be used to classify the evacuation strategies based on the experts' opinions and spatial distribution of results. The tsunami evacuation strategies will be extended towards horizontal or vertical evacuation clusters based on the classified spatial values. The framework can be used to identify the dynamics of disease transmission hotspots based on the tsunami and pandemic risk scenarios. The recommendations section will consider linking the framework with an Early Warning System (EWS) for further research areas.

5. Recommendations

The main recommendation that can be drawn from the conceptual framework is that the weighted centrality analysis is a potential approach to address the lack of linkages between the guidelines for planning tsunami evacuation and pandemic management. Exploring the relationship between these two disciplines based on the weighted centrality analysis can provide inputs for identifying community clusters along the evacuation routes. The clusters of evacuation can be further explored to plan horizontal and vertical evacuation strategies to mitigate the further transmission of disease while ensuring the timely evacuation and monitoring of at-risk communities. Therefore, countries like Sri Lanka, which is most vulnerable to far-field tsunami, can better benefit from the research outcomes.

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Urban Evapotranspiration and Heat Island Effect in Colombo District

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Keywords: Evapotranspiration, Built-up Area, Urban Landscape, Land Surface Temperature, Vegetation Cover

1. Introduction

Urbanization has converted natural earth surface and land cover to more artificial in development perspective, but it should be sustainable. Urbanization has become an essential contributor to global warming [1]. The temperature difference between urban space and surrounding non-urban space is called the urban heat island effect (UHI) [2]. Moreover, urban heat islands have become an essential factor affecting human health. However, vegetation evapotranspiration has excellent potential to reduce urban and global temperatures [2]. The heat held in the water molecules leaves the plant as the liquid water turns to vapor, which cools the plant and the air around it. So plants cool the environment by providing shade and evaporative cooling [3].

This study aims to review the role of vegetation in terms of evapotranspiration on the urban heat island effect. The findings can be used for urban designing and planning.

2. Methods and Materials

Actual Evapotranspiration (AET), Normalized Deferential Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and the Land Surface Temperature (LST) have been carried out for 2000 to 2019. This study is mainly based on secondary data. MODIS temperature data and Landsat TM, ETM and OLI satellite images (Red, NIR, SWIR bands) were used. The year 2000, 2013, and 2019 images were downloaded from earth explorer; these three years were considered based on the available data with less than 10% cloud cover. The monthly temperature was extracted from the MOD11C3 satellite image, and sunshine hours were calculated using secondary data from timeanddate.com. Observed data set from Meteorological Department was used to verify the accuracy of the temperature data.

AET explains the exchange of water and energy between soil, land surface, and atmosphere, and this was calculated by multiplying the fraction of vegetation cover with the potential evapotranspiration. The whole method of calculating AET can be presented as below:

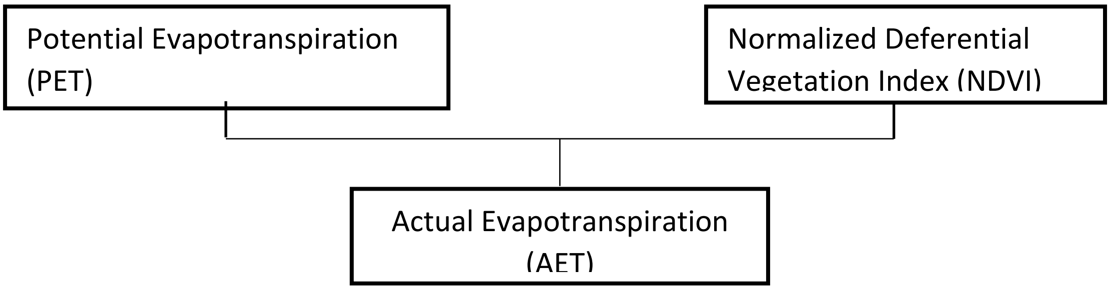

Figure 1: Methodology for AET

To calculate PET using the Thornthwaite method, first the Annual Heat Index (i) calculation is required, using the equation 01:

$$I = \sum_{i=1}^{12} (T_i / 5)^{1.514} \qquad (1)$$

PET estimation is obtained for each month using the formula below,

PET $_{\text{non corrected}}$ = 16 x (10Ti / I) a (2)

Where a is

a = (492390 + 17920 I – 771 I2 + 0.675 I3) x 10 -6 (3)

Obtained values are later corrected according to the actual length of the month and the theoretical sunshine hours for the latitude of interest, with the formula:

PET = PET $_{\text{non corrected}}$ x N x 30 (4)

Where T is the mean monthly temperature (c^0), N is the mean monthly sunshine hour.

The method of Brunsell and Gillies (2003) proposed to obtain the fraction of vegetation cover has been used in this study.

Firstly, NDVI was calculated using the below equation: TM, ETM, and OLI Landsat data for 2000, 2013, and 2019.

NDVI= (NIR-RED)/ (NIR) + (RED) (5)

Then, the fraction of vegetation cover using the raster calculator was done based on the equation:

Square (("NDVI" - 0.14) / (0.75 -0.14)) (6)

NDBI was also calculated for the above data period using equation 07.

NDBI = (NIR-swir)/(NIR+swir) (7)

Landsat Thermal and Visible bands were used to calculate LST. Radiometric and atmospheric errors were corrected by image preprocessing using Radiance Scaling Factors Provided in Landsat Metadata File. Red, Near Infrared, and Thermal bands of Landsat images and NDVI were used to estimate land surface temperature.

The following formulas were adopted from Wijeratne.S. et al., 2018 to calculate land surface temperature.

LST= (BT / 1+ W* (BT/P) * in (e)) (8)

Where:

BT = At satellite temperature

W = Wave length of emitted radiance (11.5 um)

P = h* c/s (1.438*10^-2mk)

h = Planck's constant (6.626* 10^ - 34)5)

e = Velocity of light (2.998 * 10^ 8 m/s)

Several formulas, such as brightness temperature and NDVI, were calculated for this formula. Landsat thermal band data has been converted from spectral radiance to brightness temperature using the below formula,

T = K2 / In ((K1/ Lλ) + 1) (9)

Where:

T = At satellite brightness temperature (K)

Lλ = TOA spectral radiance (Watts/(m2 * srad * μm)

K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

NDVI is used to calculate the velocity of light (e), and its formula is as follows,

e = 0.004 PV + 0.986 (10)

Where PV:

The proportion of Vegetation (PV) = (NDVI – $NDVI_{min}$ / $NDVI_{max}$ – $NDVI_{min}$) 2

Spatial analyst tool, spatial calculations tool, 3D analyst tool, calculate geometry, and field calculation tool in ArcGIS environment were used for analyzing data. And also, the hotspot analysis method was used to find the agglomeration of the built-up area.

3. Results and Discussion

According to the census data, the urban population has increased by 388,000 from 2001 to 2012 in the Colombo district. Furthermore, built-up areas are also has been increased over the years (Figure 2).

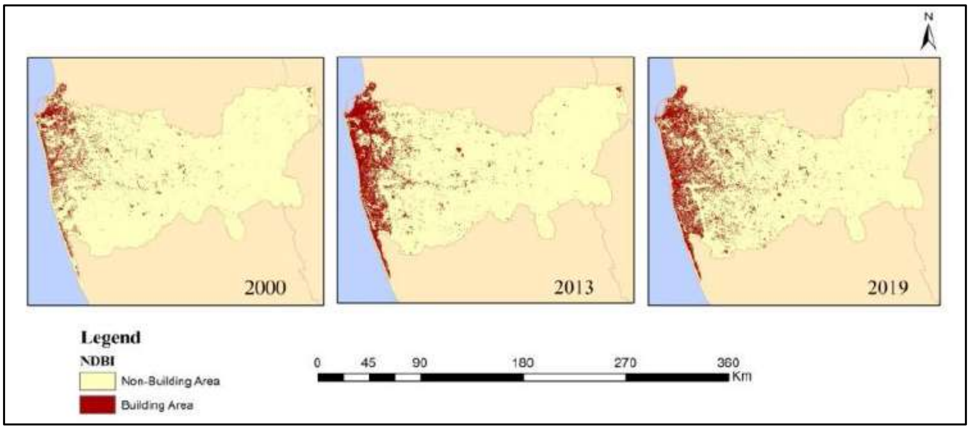

Figure 2: Built-up area

Building density covered 11% of the entire area in 2000, and it has been increased by 2% by 2019. Although the building density consists of low values when considering the extent of the entire district, building agglomeration in the western part of the Colombo district is very high (Figure 3).

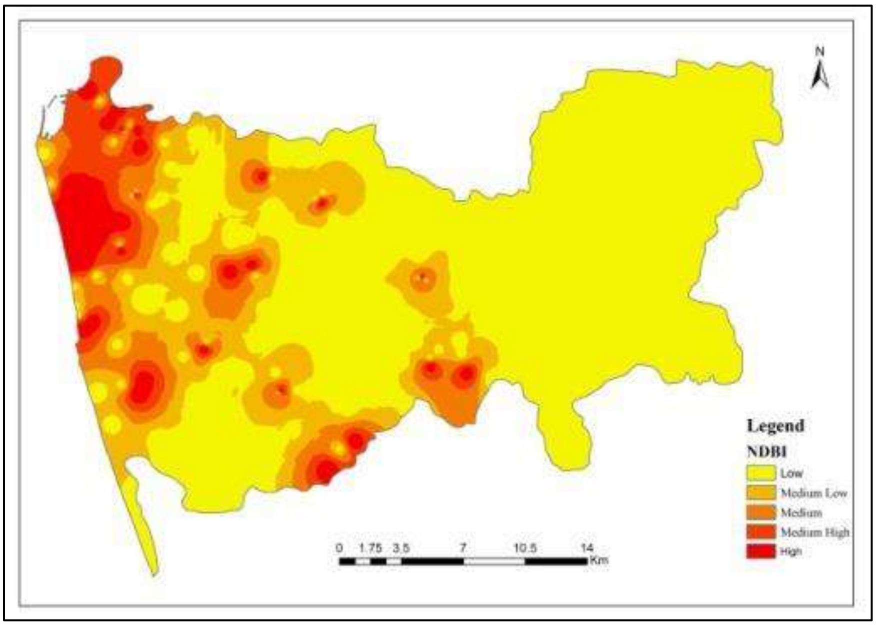

Figure 3: Agglomeration of the built-up area

According to the NDVI calculations, it is evident that vegetation cover has been reduced by 2019 (Figure 4).

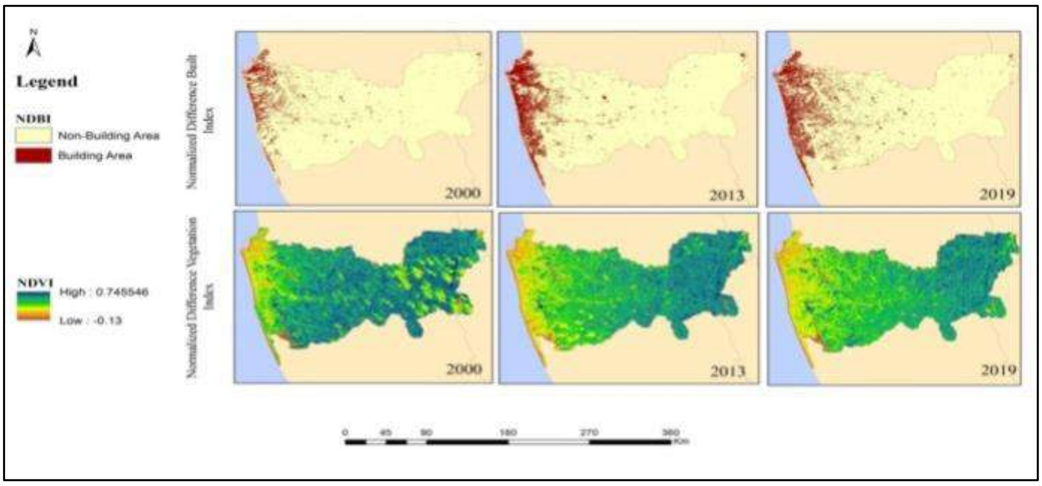

Figure 4: Built-up area and NDVI

However, reducing vegetation cover and increasing built-up areas have caused a reduction in AET (Figure 5), and there is a strong relationship between the vegetation cover and the AET (Figure 6).

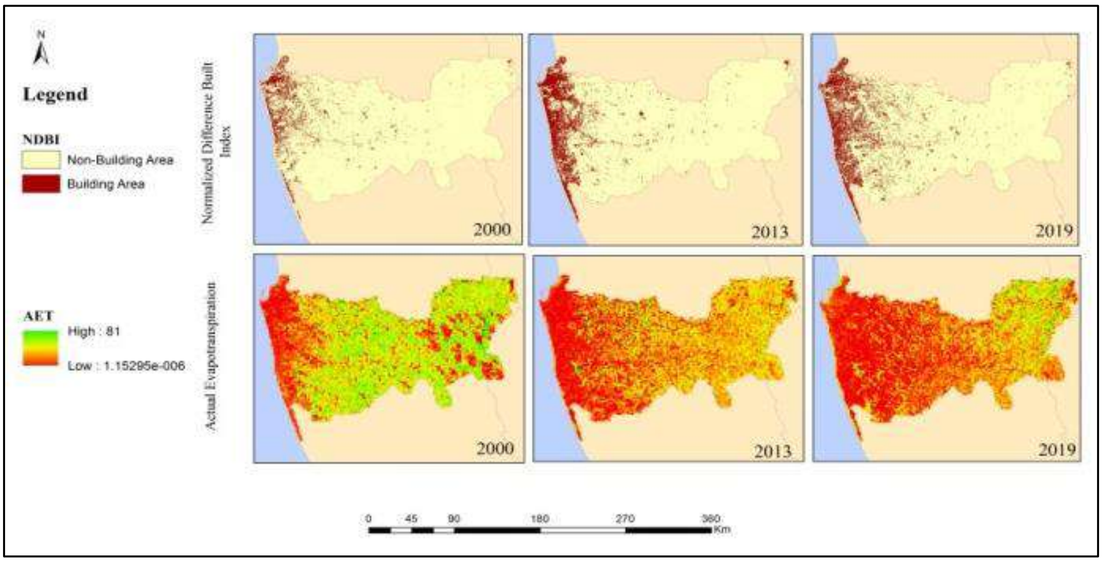

Figure 5: Built-up area and AET

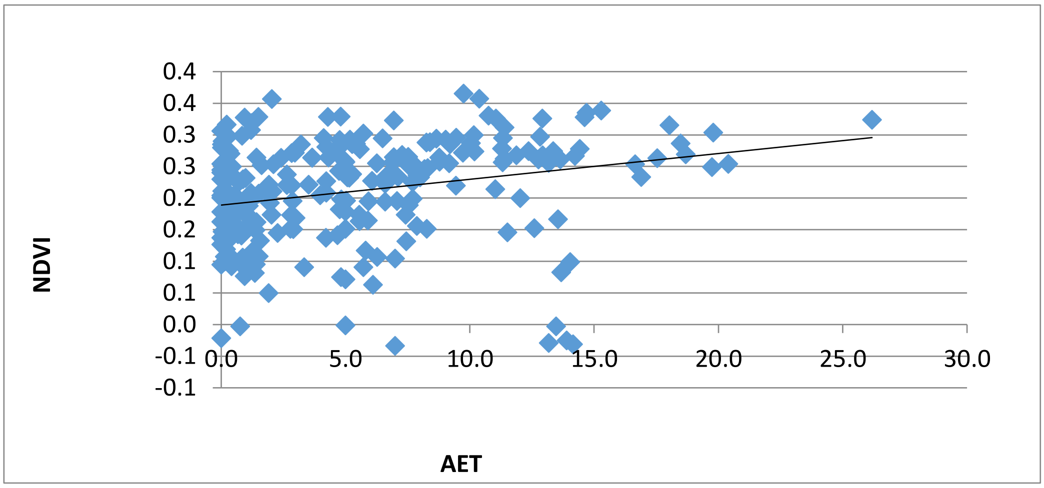

Figure 6: Correlation between AET and NDVI

Moreover, the result reveals a negative correlation between AET and the NDBI, however, the relationship between these two variables is moderate (Table 1).

Table 1: Correlation between NDBI and AET

Correlation	*NDBI*	*AET*
NDBI	1.0	-0.1
AET	-0.1	1.0

Built-up areas evaporate less water (Figure 7), contributing to elevated surface and air temperatures.

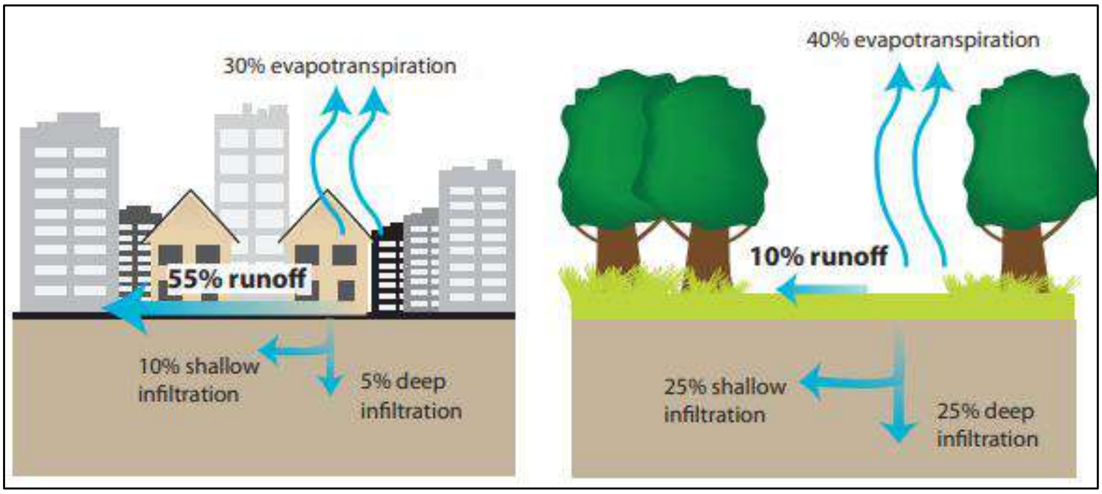

Figure 7: Impervious surfaces and reduced evapotranspiration

Source: Climate Protection Partnership Division in the U.S. (2014)

It is noticeable that land surface temperature is high with a high building density area (Figure 08), and there is a strong positive correlation between these two (Table 02).

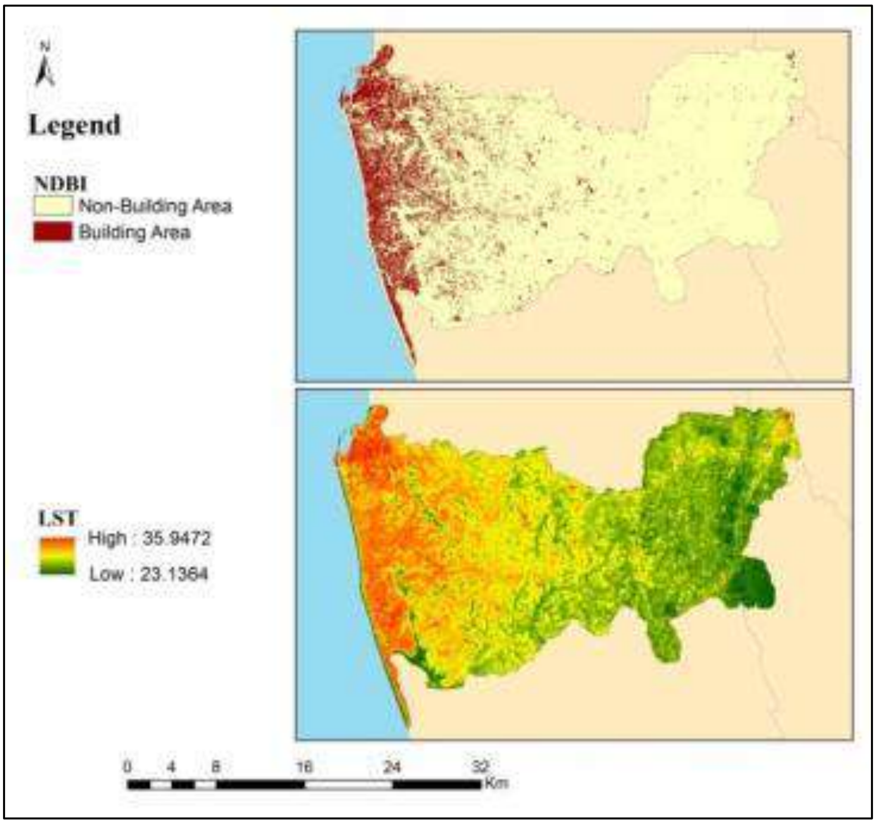

Figure 8: NDBI and LST

Table 2: Correlation between NDBI and LST

Correlation	*LST*	*NDBI*
LST	1	1
NDBI	1	1

Moreover, it shows that land surface temperature and evapotranspiration move in opposite directions. For a positive increase in land surface temperature, there is a decrease in evapotranspiration (Figure 9).

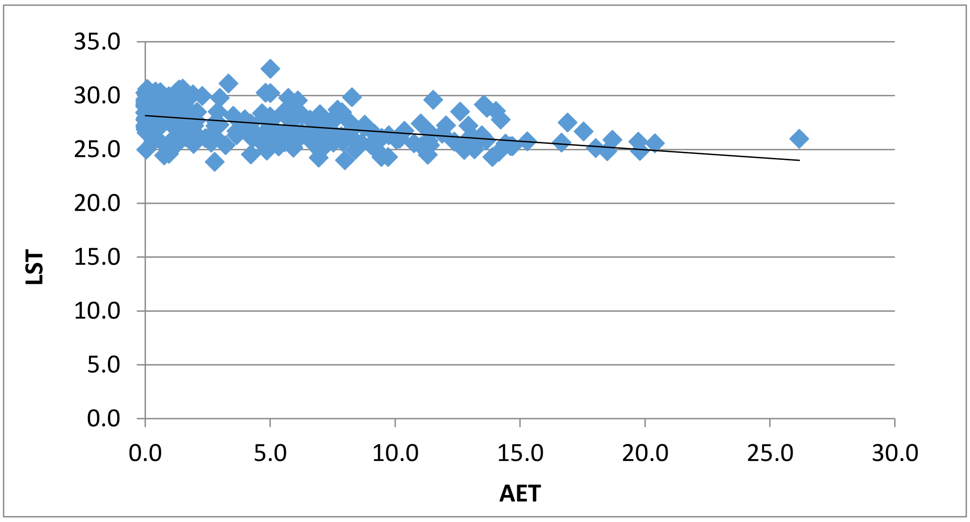

Figure 9: Correlation between AET and LST

When considering the AET, it takes very low values in 2019 compared to 2000, and the reducing evapotranspiration may cause the air and the land temperature to increase. Air temperature variations along with evapotranspiration can be studied for further understanding.

Global terrestrial evapotranspiration (ET) can consume 1.4803×1023 joules (J) of energy annually, which is about 21.74% of the total available solar energy at the top of the atmosphere, whereas annual human energy use is 4.935×1020 J, about 0.33% of annual ET energy consumption [1]. Therefore, vegetation ET has great potential to reduce urban and global temperatures. Vegetation and urban agricultural ET can reduce urban temperatures by 0.5 to 4.0°C [1].

4. **Conclusion**

Built-up area is increasing with urbanization. The results reveal vegetation cover and evapotranspiration have been decreased while the built-up area is increased. Furthermore, there is a positive correlation between built-up area and land surface temperature and a negative correlation between evapotranspiration and land surface temperature. The literature review shows the negative connection between evapotranspiration and UHI. It can be concluded an increase in evapotranspiration can effectively mitigate the effect of UHI.

Increasing canopy cover increases evapotranspiration, and it would affect decreasing land surface temperature. Therefore, urban greening can be suggested as a strategy for combating the ill effects of UHIs.

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Agroecology and Home Gardens in Geographical View: Case Study in Divisional Secretariat Nivithigala

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Keywords: Agroecology, Home Garden, Management Practices, Geographical View

1. Introduction

People are creating their cultural landscape on the physical landscape. The cultural landscape is the combination of humans and nature, where the natural landscape provides the materials, culture provides the shaping force, and the mind of the man creates culture. However, it is man's record of the landscape (Sauer, 1983). Home gardens are one of the basic units of the cultural landscape, since 1945 expanded human activities toward the biotic environment. People thought of the whole world as a resource for their daily consumption. Problems were arising from that point. But everything must be balanced, and the development should be sustainable. The concept of Agroecology is one of the most famous and practicable solutions for that.

Agroecology is an applied science that studies ecological processes used in agricultural production systems (Gliessman, 2007). Agroecology involves various approaches to solve the real challenges of agricultural production. Though agroecology initially dealt primarily with crop production and protection aspects, new dimensions such as environmental, social, economic, ethical, and development are becoming relevant in recent decades (Wezel & et al., 2009). It improves the adaptive capacity of the agroecosystems and reduces vulnerability to natural disasters, climate change impacts, new and emerging environmental and economic system stresses, and shocks (Miguel, 2015).

The concept development of Eco-friendly home gardens and home gardens management are raised through the terms of Agroecology and Agroforestry. The home garden can be defined as a farming system that combines different physical, social, and economic functions on the land area around the family home. It provides daily consumption necessities for all and gives healthy nutritional foods. On the other hand, it helps to maintain the economy in the family and sometimes it gives a chance to earn additional income too. Garden plants often help reduce erosion by holding the soil in place. The importance of gardening at home extends beyond human health physically and mentally. The main objective of this study is to analyze the spatial patterns and management strategies of the home gardens through the geographical view of the Nivithigala Divisional Secretariat (DS) of Rathnapura District.

2. Methods and Materials

Nivithigala DS is selected as a study area of the research, one of the divisional secretariats in Sabaragamuwa Province, Sri Lanka. For the study, both primary and secondary data have been collected. All primary data was collected from the field base interviews, questionnaires, and observations in the Nivithigala DS. The method of sampling is based on purposive sampling, which is under the non-probability sampling method. Thirty households have been selected as a sample of the research. To select the individuals in the sample, mainly considered their field-based experiences on home garden management strategies, and the age category should be greater than 30 years old. Grama Niladari Officers, Development Officers, and Agricultural Advisers were supported to select representative samples in Nivithigala DS. Questions mainly focused on identifying the spatial arrangements, agroecological land management strategies, and usual problems combined with the home gardens in a particular area. Under the secondary data collection method, Research papers, government and private institutions reports, municipal council reports, and websites have been used. The whole methods and steps are summarised in Figure 01.

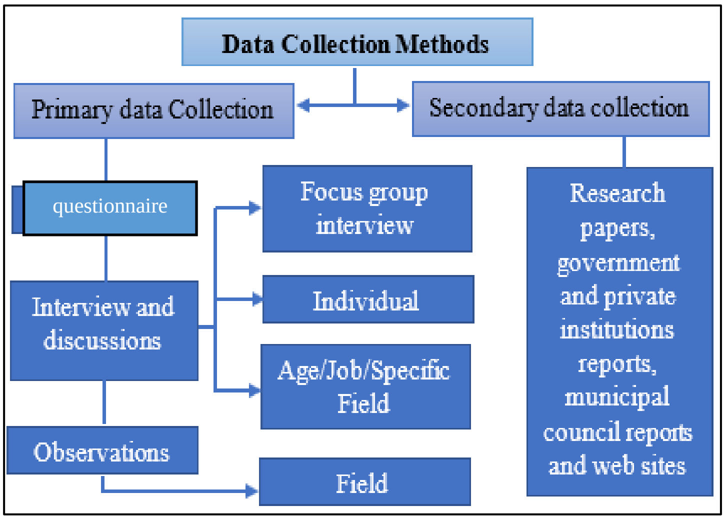


Figure 1: Methodology of the research

3. Result and Discussion

When considering the study area of the research, a clear geospatial pattern can be identified in the field. For instance, the spatial patterns of the home garden could be analyzed under the three sections, such as the front side, backside (close to the kitchen), and backside far from the house. Nivithigala DS is mixed up with suburban and rural characteristics.

Because of that, many traditional types of home gardens can still be observed as well as a few modern types of gardens. As usual in many gardens, the front side is reserved to maintain the beauty of the scenery. Commonly grow flowering plant species at the front, and some unique fruits items also can be seen (Table 1). For medicinal and cosmetic usages, *Aloe Vera* and *Turmeric (Curcuma longa)* bushes are also planted. The backside of the home garden is very special. Near to the kitchen, cooking necessities, such as some main spices, are available. But somewhat far from the kitchen, large-scale trees can be observed. Most of them are giving ecological as well as economic values to the home garden. Many people consider gardening to be a relaxing activity.

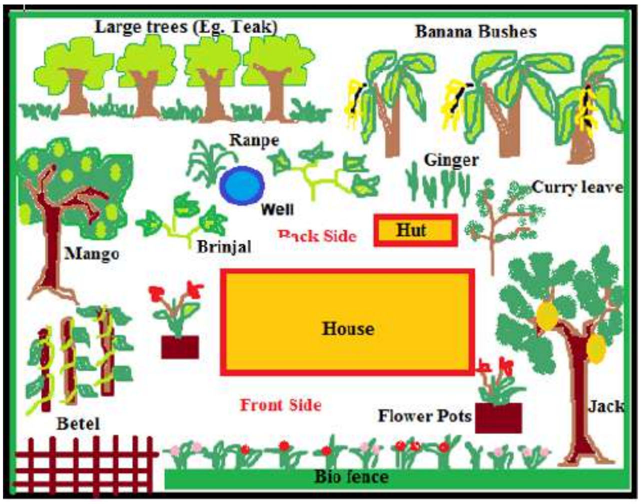


Figure 2: Spatial arrangement of home gardens
Source: Created bv author

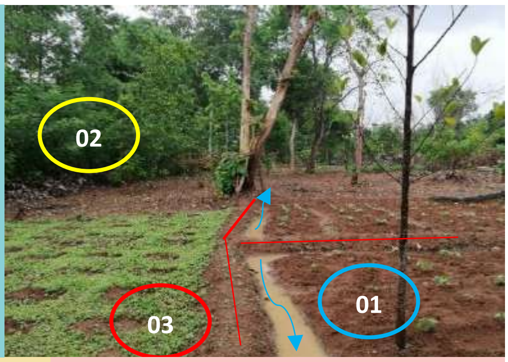
Table 1: Types of plant species

Front Side	Back Side (Close to Kitchen)	Back Side (Far to House)
Flowers	Small hut	Banana Bushes
Betel	Well	
Bio Fence	Kitchen Needs: -Rampe -Curry Leaves -Brinjal -Ginger -Chili -Lemongrass (Sera) -Lemon	Jack Trees
Fruits: -Mango -Passion Fruit -Guava -Java Apple -Rambutan		Coconut Plants
		Bread Fruit Trees
Herbs: -Kumarika -Turmeric		Other Kind of Large Trees

Source: Created by author

01. Water management (Channels)

- Managing water very well and circulate water around the land.
- Control over flow and release water through the channel.
- It will help to control the soil erosion in cultivation area.



02. Bio Fence (Girisiliya)

- Increase the fertility and productivity of the land.
- Working as a natural barrier for the wind, pest and diseases.
- Protect moisture and humidity level in the land.
- Natural divider of the land.

03. Soil dams (Niyara)

- Naturally land divide in to small pieces for the different cultivation types.
- Control soil erosion, protect soil fertility in the land.
- Easy to manage land and well planning system.

Figure 3: Eco-friendly land management practices for the cultivation
Source: Created by author

Small-scale cultivation strategies also can be seen in some home gardens. Land management practices for the cultivation are appreciable. All of these are eco-friendly and give advantages to both the ecosystem as well as the income of the home. Most people are earning economic value from their home gardens. Cultivated things are used for daily consumption, and other surpluses are sent to the market. Although they have small land, advanced and eco-friendly management practices can be seen. Those very simply can be applied to the land. Because of that, without having more cost, can easily be earned both economic and ecological benefits from the home garden. As shown in Figure 3, it is very clearly visualized how land management practices are applied to natural land.

Under the home, and garden management practices, crop protection strategies also can be identified. Normally the rural people are not trying to harm the animals. Their main target is protecting the harvest without having any injuries to the animals. Most of the biological methods are applied to control the harmful pests and insects on the land.

As usual, problems related to home gardens also can be seen in the Nivithigala DS. Usually, the area is very famous for gem mining, and most of the people are engaging in gem mining activities as their main occupation. Not only home gardens but earlier paddy lands were also used for gem mining activities. These are happening in both legal and illegal ways. As a result, soil texture, structure, and arrangement of the lands are damaged very fast. Not only had that, with time, the huge holes dug for the mining activities are filled with rainwater. It makes a very comfortable environment to grow for the mosquitos and other harmful insects. This common feature in the area adversely influences the eco-environmental balance in the lands. Figure 4 shows an unfilled mining hole filled with rainwater.

Figure 4: Holes of gem mining

Table 2: Crop protection strategies from the animals

 Source: Created by Author	**Pathok** Use as a natural fence to the areas which have more wild animals attack. Because of the thorns animals are afraid to move through the fence.		**Daspethiya** It has a very bad smell for some animals. Especially for the insects. They always try to get away from these plants.
	**Takaya** Using the sound, people identify the attack of wild animals. Other small animals are also afraid of the sound and they don’t try to damage the crops.		**Margosa** It has a good medicinal value and kills bacteria and other diseases in the atmosphere. Control the spread of insects in the home garden.

4. Conclusion

The concept development of eco-friendly home gardens and home gardens management is rising through Agroecology and Agroforestry. When considering the home gardens of Nivithigala DS, clear geospatial patterns can be identified. The different patterns of the species arrangement can be observed in the front side, backside (close to the kitchen), and backside, which is far from the house. As usual in many gardens, the front side is reserved to maintain the beauty of the scenery. But in the backside, near the kitchen, cooking necessities, such as some main spices, are available. Small-scale cultivation strategies also can be seen in some home gardens. In the study area, land management practices for cultivation should be appreciated. All practices are giving advantages to both the ecosystem as well as the income of the home. The main thing is that the target of applying crop protection strategies for the garden is to protect the harvest without injuring the animals. The research also found that a major problem in the study area is illegal gem mining activity, and it adversely affects the arrangement of the home gardens.

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Technical Session 4

Geospatial and Geotechnical Application in Sustainable Development

Delineation of Arid Areas of Sindh Using Different Vegetation Indices and Land Surface Temperature

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Keywords: Aridity, EVI, NDVI, PET, Aridity Index

1. Introduction

Aridity and drought have become a common occurrence in many parts of the world in the past few decades, especially in the subtropics and mid-latitudes, impacting an increasing number of biodiversity and habitats. Aridity is defined as a long-term climatic feature defined by a low average precipitation or water availability (IPCC, 2019). Governments, researchers, the media, and ordinary people worldwide have been paying increasing attention to recent global climate change, as tolerance to and mitigation of dryness and aridity are part of the evolution of various industries. Agriculture and water supply appear to have taken the worst of the destruction. (Croitoru, Piticar et al. 2013). Pakistan is a country in Southeast Asia with complex terrain and limited water resources. According to the IPCC, Pakistan lies in arid and semi-arid zone. Numerous attempts have been made to classify Pakistan's aridity and climate using a variety of climate variables and methods (Bharucha & Shanbhag, 1956). Pakistan's climate is characterized by aridity, and climate change aggravates this phenomenon and poses serious threats to the country's water and agriculture sector (Haider et al., 2021; N Mazhar & Nawaz, 2014). Pakistan is also afflicted by extreme aridity in regions of Sindh and Punjab. In Pakistan, decreasing precipitation is the main contributor to aridity. Aridity has been activated in Pakistan because of agricultural land loss and climate change (Haider & Adnan, 2014). The spatial analysis of the seasonal aridity trend in Sindh Province is not calculated yet. Therefore, this study focuses on determining seasonal aridity trends. This study also provides information about the arid zones of Sindh province.

Study Area: Sindh is in the western corner of South Asia (figure 1). It lies between 25.8943° N and 68.5247°E. It is the third-largest province of the country, stretching for about 579 km from north to south and 442 km (extreme) or 281 km (average) from east to west, covering an area of 140,915 square kilometers (54,408 sq mi) within Pakistani territory. With the Thar desert is in the east, the Kirthar mountains in the west, and the Arabian Sea in the south, the central part is covered by the fertile Indus plain.

This study revolves around whether aridity across Sindh province on a Spatio-temporal base, with the main objective to demarcate arid areas of Sindh using different vegetation indices and land surface temperature.

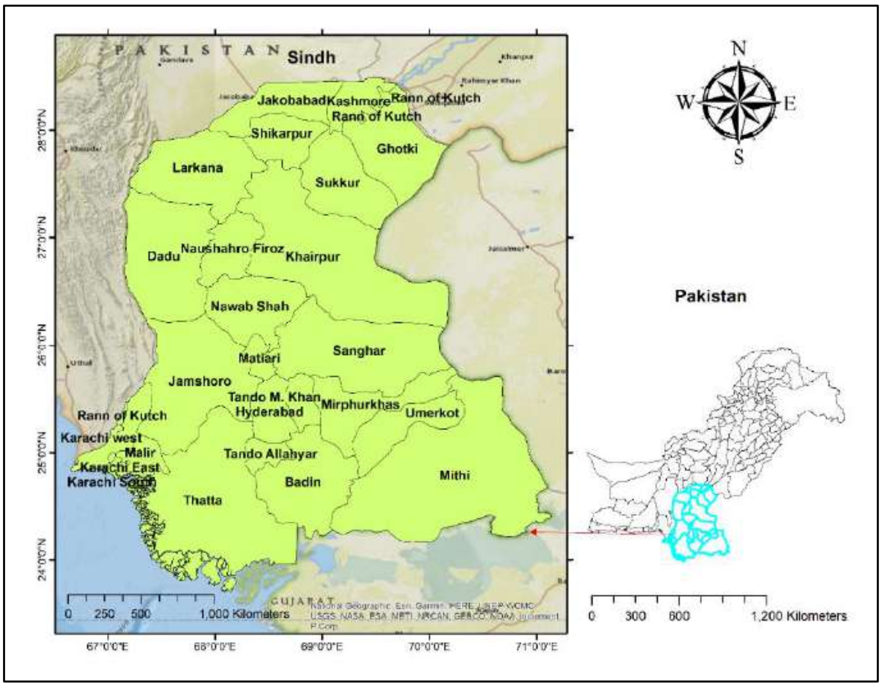

Figure 1**:** Location map of study area

2. Methods and Materials

This study takes NDVI, LST, PET, and EVI as variables affecting aridity. The relation between these variables for the aridity of a region might be written as: Aridity= low NDVI + high LST + high PET + low EVI

Scene Selection: The image selected in Aridity mapping is a Land Sat 5 for 1991 and MODIS Terra for 2000,2010,2020 of March.

The Landsat 5 TM was used to calculate LST, NDVI, and EVI through bands 1,3,4,6 for the year 1991.

The MOD11A1 was used to calculate Land Surface Temperature (LST) for 2000, 2010 and 2020.

The MOD16A2 was used to calculate Potential Evapotranspiration (PET) for 2000, 2010 and 2020.

The MOD13A1 was used to calculate Vegetation Index i.e. Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) for 2000, 2010 and 2020.

Table 2: Landsat 5 satellite data collection

Sr.No.	**Satellite Image**	**Year**	**Band**	**Path**	**Row**
1	Landsat 5	March 1991	1, 3, 4, 6	150	043
2	Landsat 5	March 1991	1, 3, 4, 6	150	042
3	Landsat 5	March 1991	1, 3, 4, 6	151	040
4	Landsat 5	March 1991	1, 3, 4, 6	151	041
5	Landsat 5	March 1991	1, 3, 4, 6	151	042
6	Landsat 5	March 1991	1, 3, 4, 6	151	043
7	Landsat 5	March 1991	1, 3, 4, 6	152	040

8	Landsat 5	March 1991	1, 3, 4, 6	152	041
9	Landsat 5	March 1991	1, 3, 4, 6	152	042
10	Landsat 5	March 1991	1, 3, 4, 6	152	043
11	Landsat 5	March 1991	1, 3, 4, 6	153	041

Table 3: MODIS Satellite data collection

Sr.no	Satellite Images	Year	Area	Scale Factor	Units
1	MOD11A1 (Land Surface Temperature)	March,2000to2020	Sindh	0.02	K, ºC
2	MOD16A2 (Potential Evapotranspiration)	March,2000to2020	Sindh	0.1	kg/m²
3	MOD13A1 (Vegetation Indices)	March,2000to2020	Sindh	0.0001	NDVI, EVI

Data Analysis: In this section, analyses applied to research are discussed below.

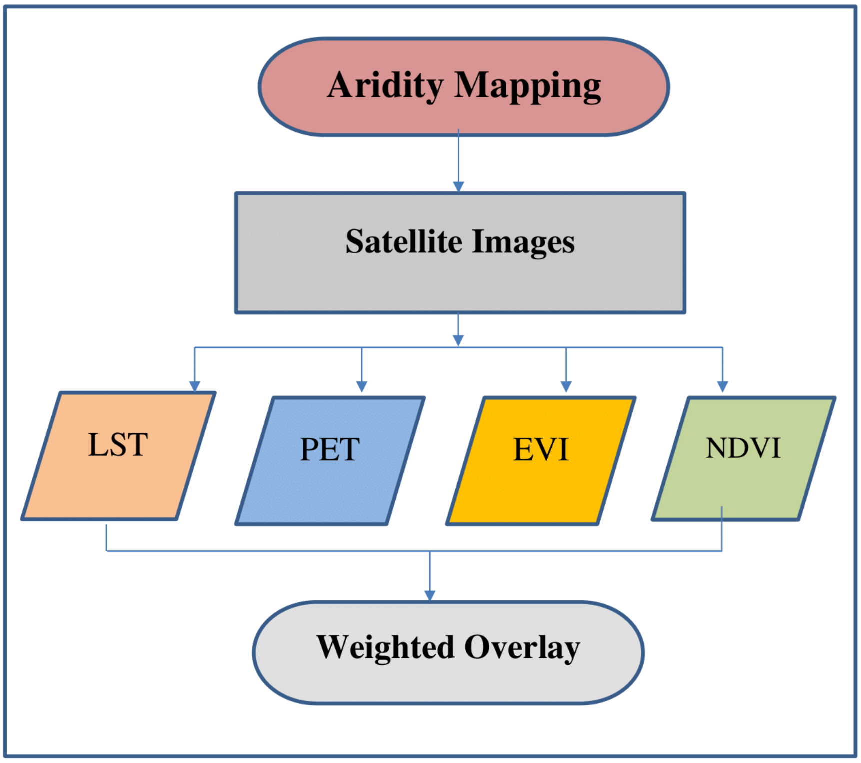

Figure 2- Method of data analysis

Delineation of Arid Areas of Sindh using Different vegetation indices and land surface temperature

Following analysis is used to check the delineation of arid areas of Sindh. Normalize difference Vegetation Index

NDVI has been widely used in semi-arid and arid regions for vegetation production, soil moisture estimation, crop yield assessment, and drought detection.

Normalize Difference Vegetation Index for Landsat 5 calculated as:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad \text{(Eq.1)}$$

NIR is Near-Infrared band value and red band value denoted with R.(Siddiqui & Javid, 2019)

NDVI for MODIS calculated as:

$$NDVI = MODIS \times 0.0001 \quad \text{(Eq.2)}$$

(USGS, July 28 - August 12, 2018)

Enhance vegetation Index

Enhanced Vegetation Index (EVI), For Landsat 5 is calculated as:

$$EVI = G \times \frac{(\text{NIR} - \text{red})}{(\text{NIR} + \text{C1} \times \text{red} - \text{C2} \times \text{blue} + \text{L})} \quad \text{(Eq.3)}$$

G is a gain factor (set at 2.5), C1 and C2 correct for aerosol resistance (set at 6 and 7.5), L adjusts for canopy background (set at 1) and NIR, red and blue are reflectance in the near-infrared, red and blue wavelengths (Jarchow et al., 2018).

EVI for MODIS Calculated as:

$$EVI = MODIS \times 0.0001 \quad \text{(Eq.4)}$$

(USGS, July 28 - August 12, 2018)

After calculating all the raster surfaces, i.e. NDVI, EVI, LST, and PET, according to the formulae provided above, weighted overlay analysis was performed in Arc GIS on all these rasters, using equal weight function.

Land Surface Temperature

Land surface temperature is one of the crucial problems faced globally. LST is highly accelerated by the loss of vegetation and soil moisture content, increased temperature and is activated with anthropogenic activities (Kang et al., 2010). LST is one of the global challenges directly involved with urban development activities and hinders sustainable development growth (Siddiqui & Javid, 2019)**.** LST of Landsat 5 is estimated using the following equation:

Thermal Image (Band 6) Of Landsat5

Conversion DN to Radiance

$$L\lambda = \left(\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right) \times (QCAL - QCALMIN) + LMIN\lambda \quad \text{(Eq.5)}$$

Convert radiance into BT and in Kelvin into Degree Celsius

$$T = \left(\frac{K2}{Ln\left(\frac{K1}{L}\right)} + 1\right) - 273.15 \quad \text{(Eq.6)}$$

Where,

Lλ= Spectral radiance

QCAL= Quantized Calibrated Pixel value in DN

LMAXλ= Spatial Radiance scaled to QCALMAX in (watts/(m2*sr* µm))

LMINλ= Spatial Radiance Scaled to QCALMIN in (watts/(m2*sr* µm))

QCALMIN = the minimum quantized calibrated pixel value

QCALMAX = the maximum quantized calibrated pixel value

LST for MODIS calculated as:

$LST = (MODIS \times 0.02) - 273.15$ (Eq. 7)

(USGS, July 8, 2018)

Potential Evapotranspiration

Potential evapotranspiration of MODIS is calculated as:

$PET = MODIS \times 0.1$ (Eq.9)

(USGS, August 13 - 20, 2018)

3. Result and Discussion

I. Land Surface Temperature (2000, 2010, 2020)

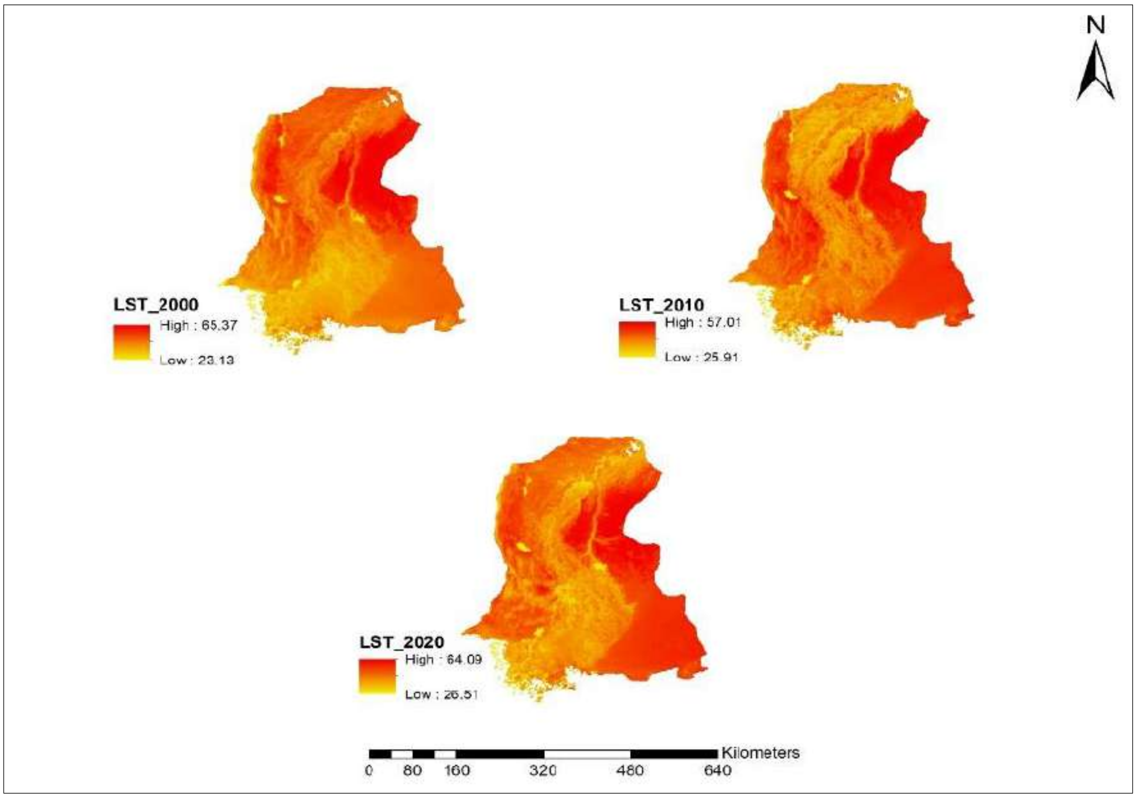

Figure3: Land surface temperature of Sindh for 2000, 2010, 2020

LST values for March 2000, 2010, and 2020 are shown in Figure 3. Land surface temperature is shown in 3 classes high, medium and low to Celsius. Areas of high-temperature values derived from LST primarily represent the eastern side of Sindh. However, the land surface temperature had decreased from 65ºC in 2000 to 57.01ºC in 2010, and then it had increased in 2020 up to 64.09ºC.

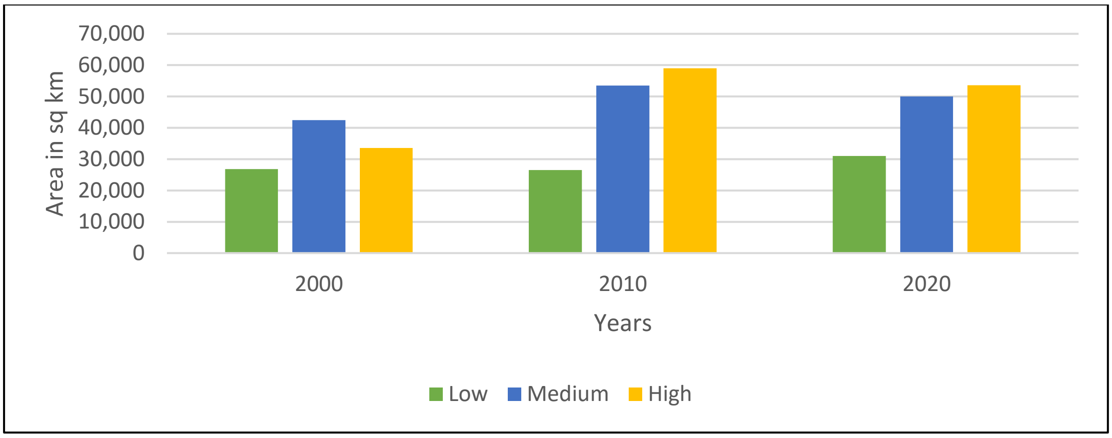

Figure 4: Area of land surface temperature of Sindh for 2000, 2010, 2020

The area of Land Surface Temperature of Sindh from 2000 to 2020 is shown in Figure 4. There is a 16% change in low LST, 18% change in the area of medium LST, and 60% change in the area of high LST from 2000 to 2020.

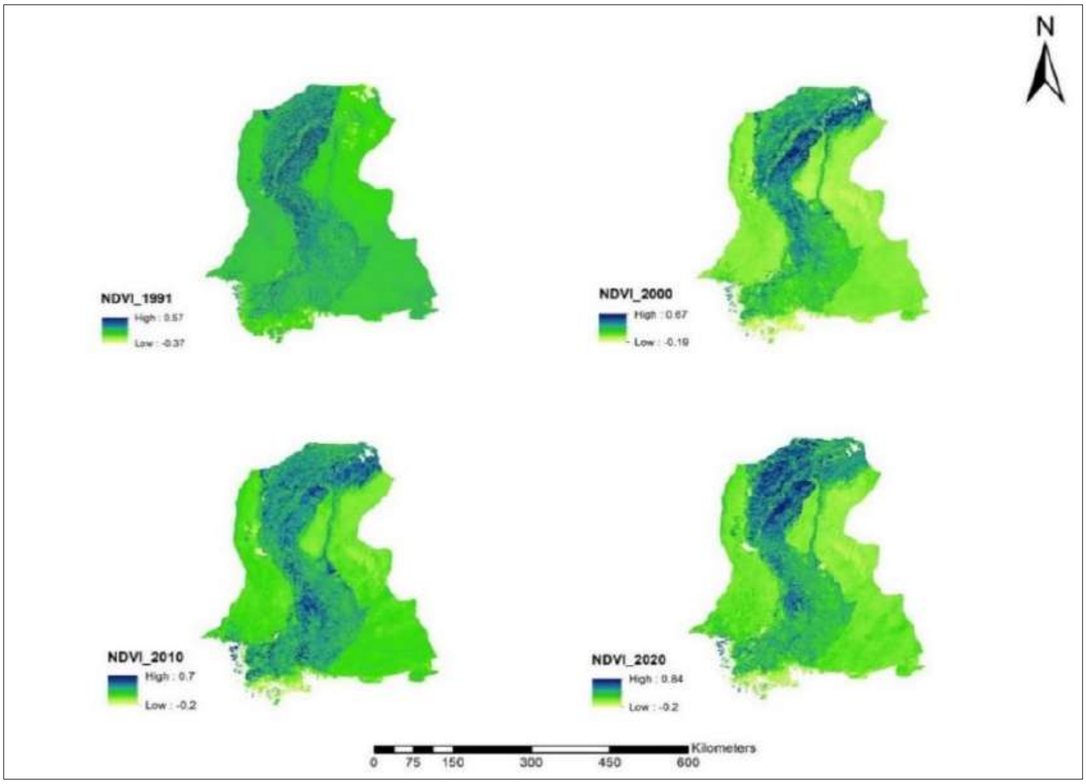

Figure 5: Normalized difference vegetation index of Sindh for 1991, 2000,2010, 2020

NDVI values in 1991, 2000, 2010, and 2020 for March are shown in Figure 5. Typically, Low NDVI values are related to arid areas, and high NDVI values are related to humid areas. Areas of low NDVI values (high aridity) are primarily represented in the eastern and western sides of Sindh, including areas of Tharparkar, Umerkot, Sanghar, Khairpur, Ghotki, Sukkar. However, some other areas of low NDVI values are located on the western side of Sindh, including Daddu, Karachi, Jamshoro, and Thatta. In addition, aridity distribution had decreased over time. As a result, the vegetation cover ratio increased in 2020 compared to recent past decades, particularly in the Indus belt of Sindh.

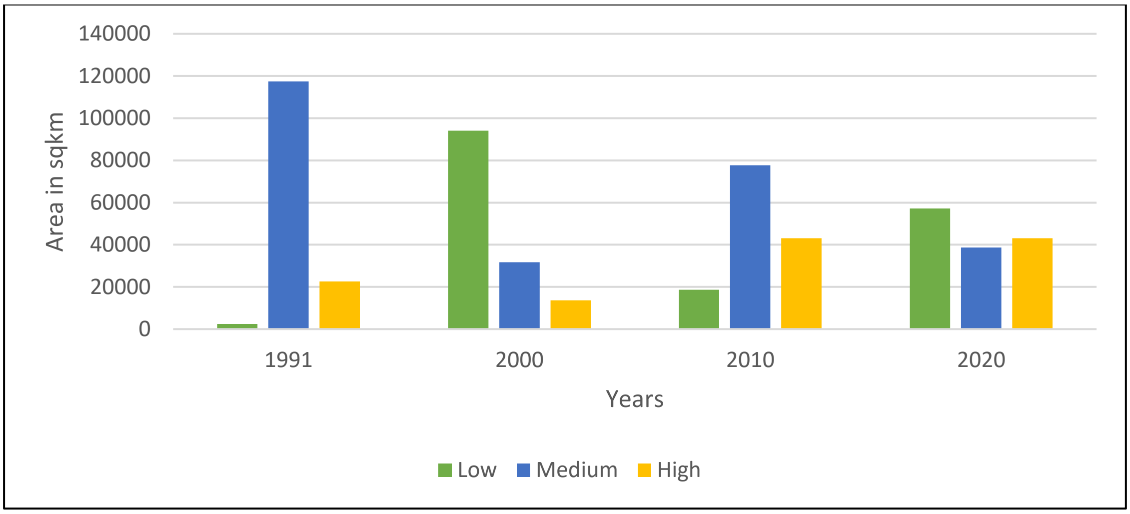

Figure 6: Area of normalized difference vegetation index of Sindh for 1991, 2000, 2010, 2020

In Figure 6, the spatial distribution pattern of Normalized Vegetation Index from 1991 to 2020 is shown. The low NDVI class witnessed a positive change of 2232%, while medium class underwent a negative change of 67%. However, the high NDVI class also witnessed a positive change of 91%.

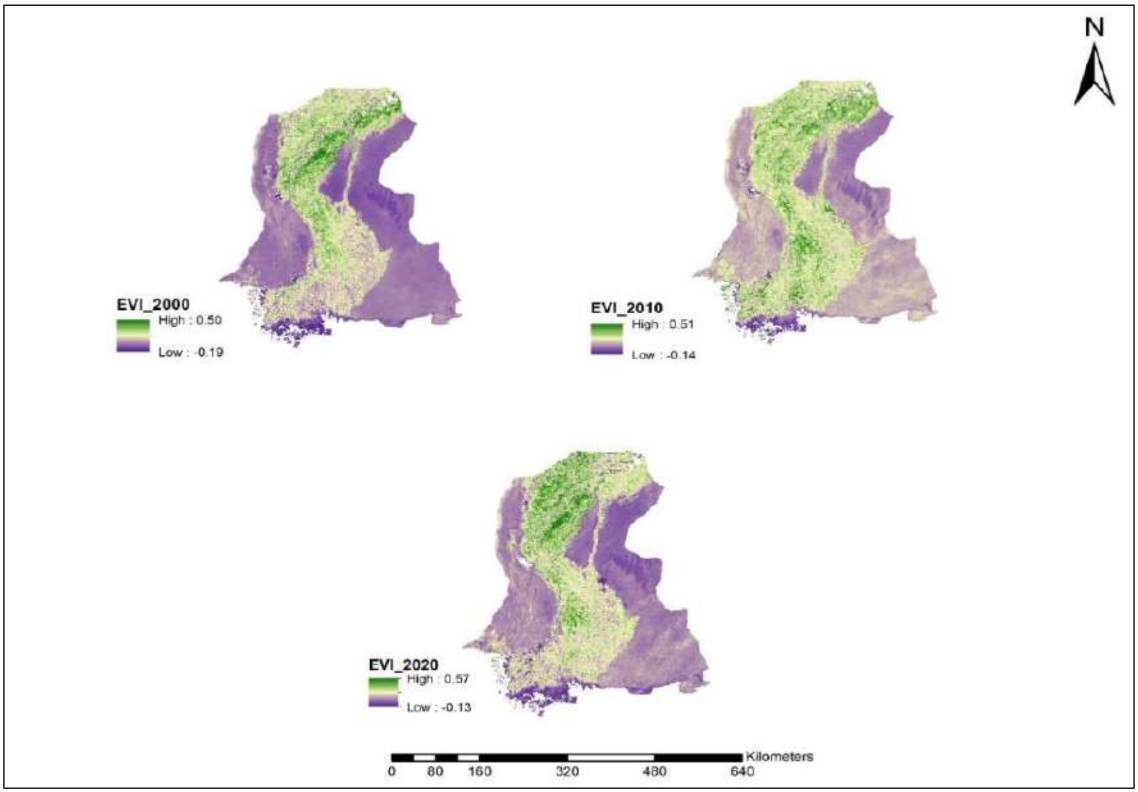

Figure7: Enhance vegetation index of Sindh for the years 2000, 2010, 2020

EVI values 2000, 2010, and 2020 for March are shown in Figure 7. Typically, low EVI values are related to arid areas, and high EVI values are related to humid areas. Areas of low NDVI values (high aridity) are primarily represented in the eastern and western sides of Sindh, including areas of Tharparkar, Umerkot, Sanghar, Khairpur, Ghotki, and Sukkar. However, some of the other areas of low EVI values are located on the western side of Sindh, including Daddu, Karachi, Jamshoro, and Thatta. Aridity distribution is decreasing from 2000 to 2010. However, it again increased from 2010 to 2020.

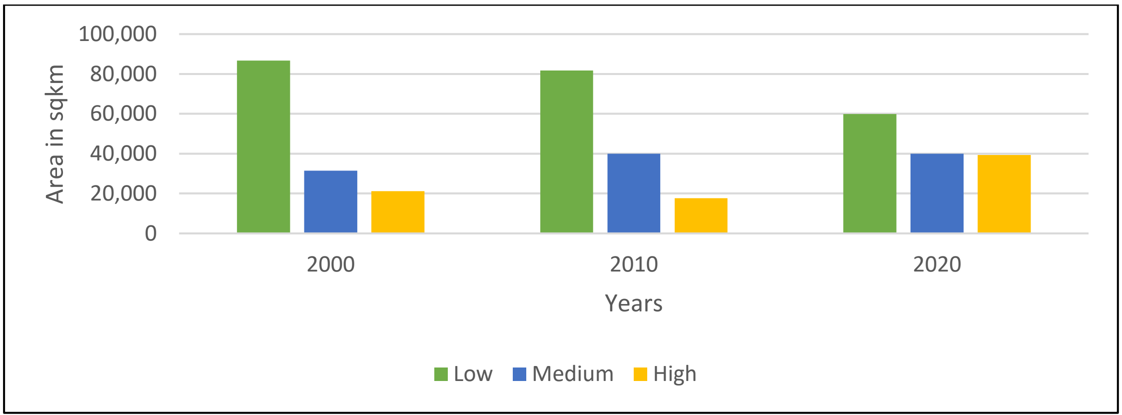

Figure 8: Area of enhance vegetation index of Sindh for 2000, 2010, 2020

The spatial distribution pattern of Enhance vegetation Index is shown in Figure 8. About 27% change in low **EVI**, 31% change in medium EVI area, and 86% change in high **EVI** from 2000 to 2020 could be identified in the study area.

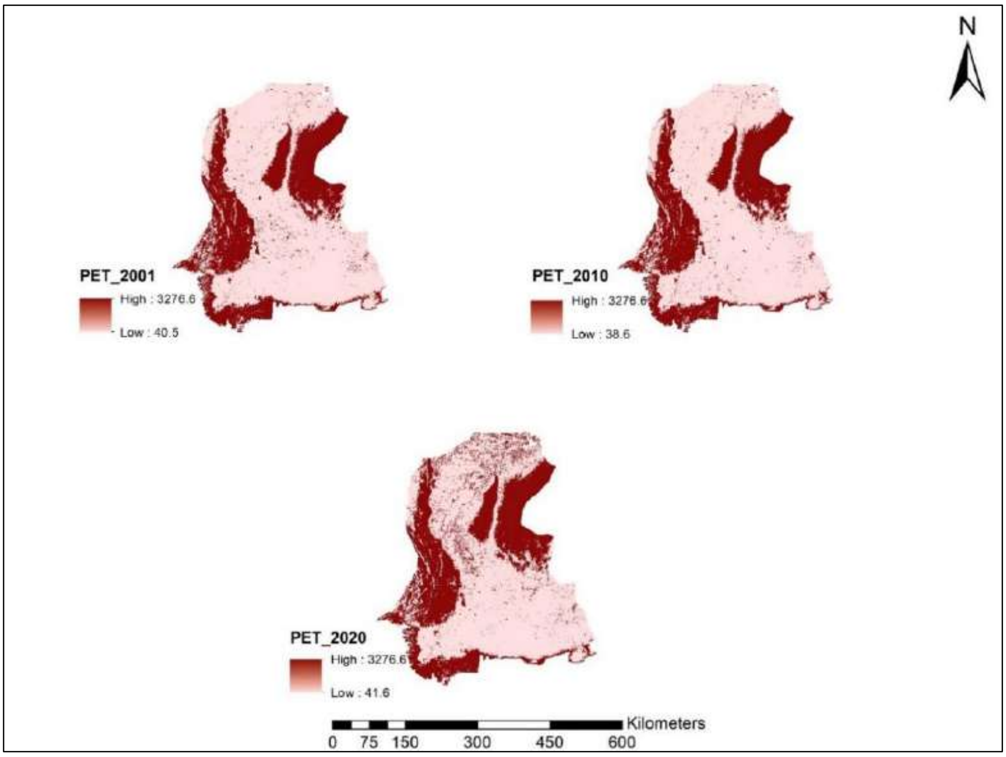

Figure 9: Potential evapotranspiration of Sindh for 2000, 2010, 2020

Figure 9 shows the Potential Evapotranspiration values of Sindh province for 2001, 2010, and 2020. Higher PET values in Karachi, Thatta, Dadu, Jamshore, Tharparkar, Sukkar, Umerkot, and Khairpur represent high aridity. While the lower values of PET represent Humid or sub-humid condition, as seen in Jacoabad, Shikarpur, Larkana, Naushera Feroz, Nawabshah, and Badin.

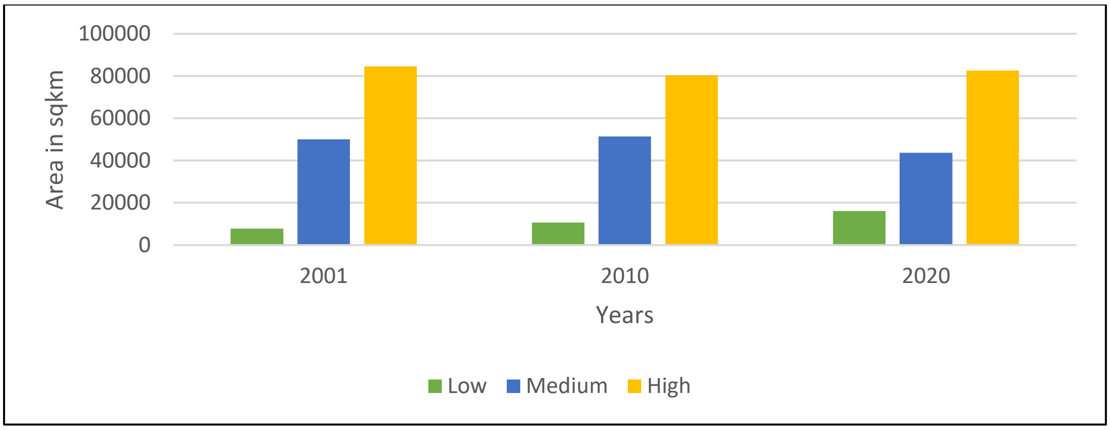

Figure10: Area of potential evapotranspiration of Sindh for 2000, 2010, 2020

The potential Evapotranspiration values for 2000, 2010, and 2020 are shown in Figure 10. There is a 13% change in Low PET from 2000 to 2020. Percentage change in Medium PET is 108%, and Percentage change in Low PET is -2%.

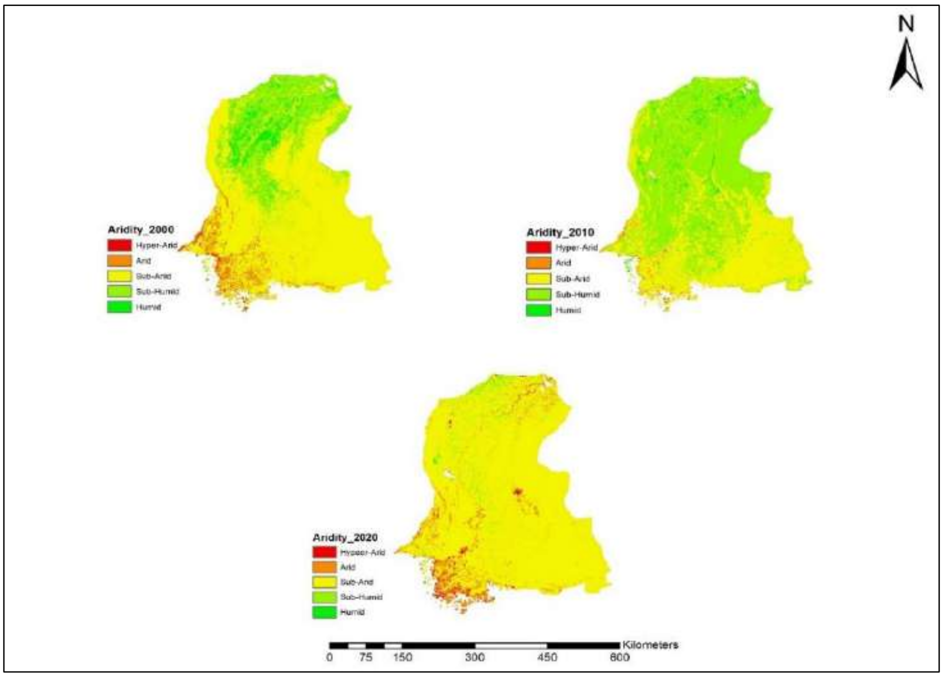

Figure11: Aridity index map of Sindh for 2000, 2010, 2020

Weighted overlay analysis of NDVI, EVI, PET, and LST over the Sindh province of 2000, 2010, and 2020 depict a clear picture of aridity distribution (figure 11). A marked variation in regional aridity distribution can be observed through this analysis. In Weighted overlay analysis, equal weights are provided to NDVI, EVI, PET, and LST as variables affecting the aridity level in a region, and then processed as in Figure 11.

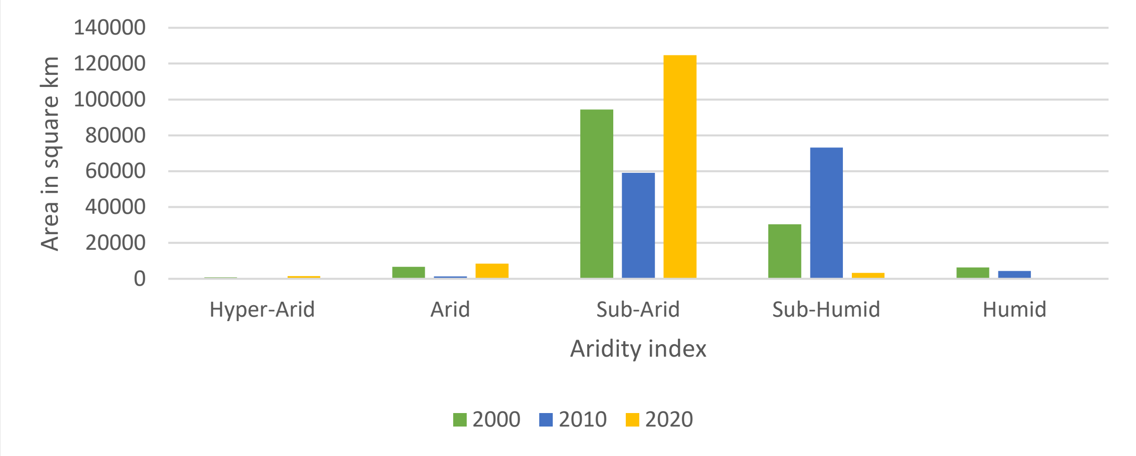

Figure 12: Area of aridity index map of Sindh in 2000, 2010, 2020

Area of Aridity trends from 2000 to 2020 is shown in Figure 12.

The change in the hyper-arid area and arid area are showed 96% and 27%, respectively. While, the changes in the sub-arid, sub-humid and humid areas are represented 32%, -89%, and -97%, respectively.

4. Conclusion

This study was carried out for the first time in Sindh, Pakistan, to estimate the extent of aridity. After Punjab, Sindh is the second province with high contribution share to Pakistan's GDP. Sindh is the alluvial plain of the Indus River and has the potential and nutrients to support agriculture. However, due to the slope of the area, it usually remains exposed to sunshine leading to high rate of evaporation which decreases the moisture content of the soil. The result of the study for NDVI and EVI maps clearly shows that vegetation rate is higher near the Indus River, such as Jacoabad, Shikarpur, Larkana, Naushero Feroz, Nawabshah, Badin. Moreover, aridity maps clearly show the high aridity characteristics in Karachi, Thatta, Dadu, Jamshore, Tharparkar, Sukkar, Umerkot, and Khairpur.

Thus, to evaluate the spectrum and pattern of aridity in Sindh, climate indices were applied for the period 1991 to 2020. The lack of government intention towards this severe issue may weaken the economy of the region at an alarming rate. Therefore, the provincial government should formulate and implement the rainwater harvesting policy to use monsoon water to tackle the severity and calamity of aridity in Sindh, which is affecting the agricultural sector slowly and steadily. In the meantime, a crop calendar and proper technologies should be implemented to deal with the global warming menace side by side. The results revealed that the aridity trend is increasing in each decade of the study area. Results of NDVI, EVI, LST, and PET highly support each other and depict an accurate picture of spatial and temporal patterns of increasing aridity trends in Sindh. The hyper-arid and arid area changes from 2000 to 2020 are shown at 96% and 27%, respectively. While the changes in the sub-arid, sub-humid and humid areas from 2000 to 2020 are represented by 32%, -89%, and -97%, respectively. Near Indus River, NDVI and EVI show high vegetation cover, and while far away from Indus River, aridity increases, such as in areas Karachi, Sukkar, Dadu, Thatta, Umerkot, Tharparkar.

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Public Opinion on the Factors Contributing to the Land Degradation in Udunuwara Divisional Secretariat of Sri Lanka

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Key Words: Agriculture, Causes, Degradation, Land, Settlement

1. Introduction

In their terrestrial ecosystems, renewable natural resources such as soil, water, plant, and wildlife are referred to as "land." Land degradation is a concept that describes how one or more combinations of human-induced processes acting on land affect the value of the biophysical environment (Eni, 2012). Land degradation is becoming a more important phenomena as a result of complex interplay between biophysical, socioeconomic, and political forces. The environment and land-use history of a certain location are also crucial in identifying the preparatory conditions for each land use and ecosystem change.

Degradation has harmed around 24 percent of the global land area, and over 1.5 billion people live on degraded lands (UNO, 2019). The impact of increased human pressure and overexploitation of ecosystem services is widely acknowledged by the expansion and increase of agricultural and animal grazing, which may significantly contribute to land degradation (Zari, 2014). Furthermore, global climate change, droughts, and landslides are putting further strain on dryland soil and water resources.

Land degradation garnered a lot of attention in the twenty-first century, and it's still on the international agenda in the twenty-second. Land degradation is now a major global concern. According to estimates of the global extent of land degradation, Asia has been the most affected, followed by Africa, and Europe has been the least affected. According to the United Nations Development Program (UNDP), $42 billion in income and 6 million hectares of productive land are lost each year, and approximately 2.6 billion people are affected by land degradation and desertification in more than 100 countries, affecting more than 33% of the earth's land surface (Barman et al., 2013).

Sri Lanka is an agricultural country, and agriculture is one of the factors influencing the country's development. Furthermore, land and water are two critical resources for Sri Lanka's development. However, in terms of population density, land is the most important resource in the country. As the population has grown, so has the demand for land and other natural resources, which is putting them at risk of deterioration.

Dryland land degradation is the result of complex interactions between biophysical variables (meteorological and biological fluctuations) and socioeconomic factors (human-related causes) (Reynolds et al, 2007). Soil erosion and soil fertility reduction are major contributors to land degradation in Sri Lanka. Groundwater overexploitation, salinization, waterlogging, and water pollution are all contributing contributors to land degradation. Aside from that, the causes of land degradation can be both natural and man-made. Droughts, landslides, floods, wetland degradation, fire, overgrazing, insufficient irrigation, fertilizer use, and over drafting, urban sprawl, commercial growth, and land pollution, especially industrial development (Bhattacharyya, 2015). As a result, it can cause wind and water erosion, soil acidification, climate change, decreased productivity, migration, harm to fundamental resources and ecosystems, food poverty, and biodiversity loss.

Land degradation in drylands is caused by complex interactions between biophysical factors (meteorological and ecological variations) and socio-economic factors. For many decades, land degradation has been identified as a significant problem in many places in the study area due to human and natural factors. Each year, the Sri Lankan government spends a significant amount of money on land protection and maintenance. Other non-governmental organizations have also received funding to help build a resilient civilization for humans. As a result, this research will be valuable in future management practices and development initiatives.

The study area situated in hill slop region where land security is at risk. According to the DS study, there has been a substantial increase in land degradation in the Udunuwara Divisional Secretariat Division during the last two decades (DSD). As a result, there has been an increase in land pollution, biodiversity loss, ecological harm, and agricultural deterioration. As a result, substantial effort was expended in determining the root causes of land degradation in Udunuwara (DSD), as this was the primary research concern. The terrestrial characteristic of the research region is likewise a hill slope. As a result, the negative repercussions of land deterioration may be severe. The primary goal of this research is to discover the underlying causes of land degradation through a public survey and to expose geographical data on the same.

So, the primary aim of this study was,

- To investigate the fundamental factors of land degradation.

To achieve this main objective, the study had to set a sub-objective as,

- To demarcate degraded areas in Udunuwara DSD.

2. Methods and materials

To meet the aforementioned goals, data were gathered from both primary and secondary sources. This study included both qualitative and quantitative methodologies, with a focus on primary quantitative data.

Out of the twenty DSDs in the Kandy district, the research area is one of them. The government administrative offices, government schools, textile shops, industrial buildings, and hospitals are all located in the Udunuwara district. The area covers 65.3 square kilometers and has a population of approximately 122,296 people. It consists of 124 Grama Niladhari Divisions (GND). The research region is in Sri Lanka's central highlands. As a result, it has a hill, a mountain, and valleys. Udunuwara receives a lot of rain throughout the year. The yearly reliable rainfall is between 2,500 and 3,000 mm. The annual temperature in Udunuwara ranges between 20 and 220 degrees Celsius, and most of the study region has a pleasant climate throughout the year (Department of Meteorology, 2016).

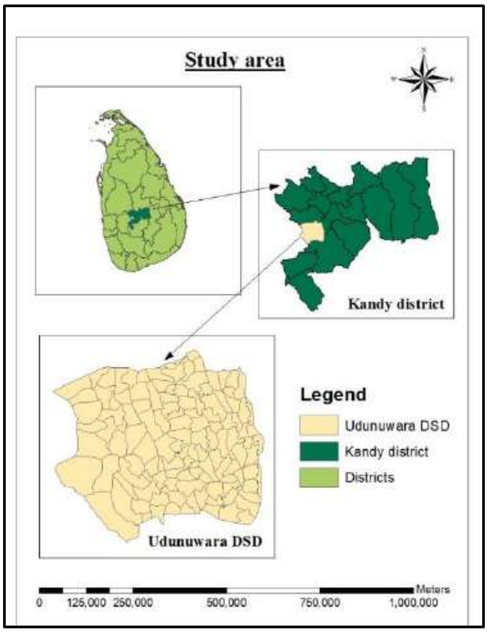

Figure 1. Udunuwara DSD; Source: Compiled by authors

There is enough water in the study area to maintain everything hydrated. These water amenities benefit the population by allowing them to cultivate a large number of hectares of land. Similarly, there are more natural resources in the area, such as streams, fertilized soil, biodiversity, and tiny forest areas. The soil type is extremely beneficial for tea and other plant production in the study region. The research area's main economic activities are paddy and tea plantation crops. The majority of the inhabitants of Udunuwara are farmers because of the abundant paddy lands. Because of the vegetable and spice production in the study area, self-employees are also plentiful.

By using the purposive sampling method, 124 questionnaires were provided to each of the Grama Niladhri officers in Udunuwara DSD to obtain fundamental physical and landscape information. Each Grama Niladhari division was included in the questionnaire survey. Other primary data have been

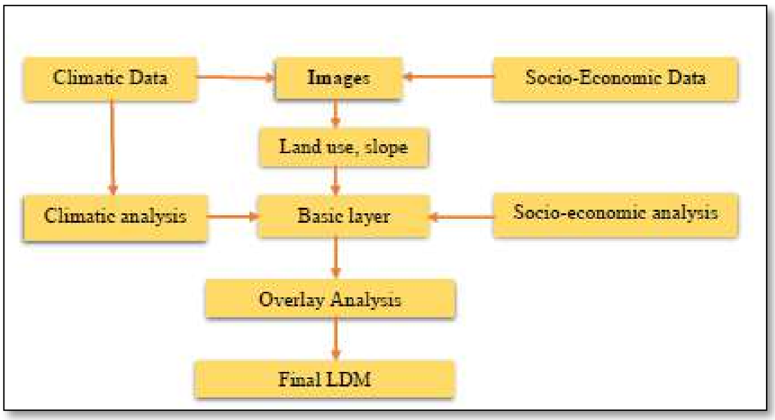

Figure 2. Data analysis method

gathered through semi-structured interviews from selective participants; the Divisional secretariat, Environment officer, and District disaster management officer, observation and informal interviews and discussions were done among the village people.

Secondary data were collected from relevant authorities such as Udunuwara DSD, Department of Agriculture, Department of Agrarian Services, Land Use Policy Planning Department, National Building Research Organization (NBRO), District Disaster Management Centre Unit (DDMCU), and published sources such as articles, journals, books, research papers, previously conducted research and reports and other relevant documents. Articles were downloaded from the internet. Images and maps were generated via Arc GIS and QGIS software. Satellite images were retrieved from Google Earth Pro. Analyzed data were presented through tables, charts, images, graphs and, maps.

3. Results and discussion

According to the questionnaire study, all locations in the Udunuwara DSD are not severely damaged. In informal interviews with the native community, it was discovered that only 39% of the respondents insisted on the incidence of land damage. The majority of the respondents (61%) insisted on a very modest degree of the same. Furthermore, it is clear that high land deterioration afflicted one-third of the region (48 GNDs out of 124 GNDs) in the research area. The native community may be unaware of the presence of land.degradation but. the existence of land degradation was accepted by the divisional secretariate officer from the interview.

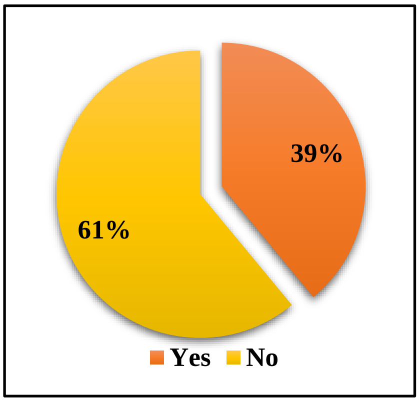

Figure 4. Existence of LD told by the native community
Source: Compiled the author from the informal interview

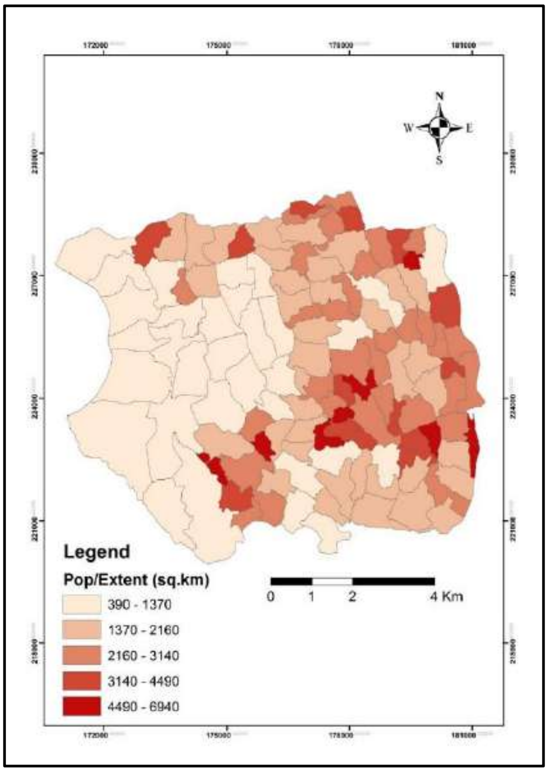

Figure 3: Density of population Udunuwara DSD
Source: Compiled by authors from Arc GIS

People who accepted the reality of land degradation and fragmentation highlighted numerous contributing causes that they witnessed. Indeed, land degradation is a result of the combination of natural and human influences. However, the factors and pressures on land degradation differ depending on the land-use system. Because natural causes are uncontrollable, human-caused degradation is critical for long-term sustainability.

Changes in rainfall patterns and temperature as a result of human interference in the environment are another cause of degradation in Udunuwara. One of the biggest causes of land degradation in this area is settlement and building construction. Many other operations, such as soil mining, solid waste disposal, agricultural activities, road building works, liquid waste, deforestation, and land degradation, including pollutants from industrial activities and livestock overgrazing.

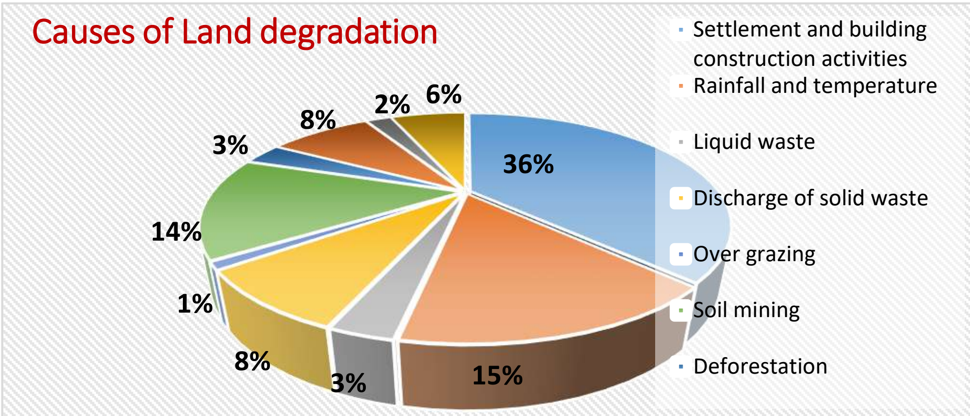

Figure 5: Causes of land degradation in Udunuwara DS;
Source: Compiled by authors through questionnaire survey

The specifics are shown in Figure 5. The land's susceptibility makes it more vulnerable to degradation. These can cause a slew of problems. It has an immediate influence on agricultural productivity and environmental sustainability.

The main cause of land deterioration in the study region is settlement and building construction activities. As the population in the study area grows, so does the demand for infrastructure such as housing and building construction. It depletes agricultural productive regions, resulting in the replacement of green flora with concrete and garbage. It reduces biomass output while destroying productive land, resulting in land degradation. And the construction of road infrastructure necessitates the degradation of fertile land.

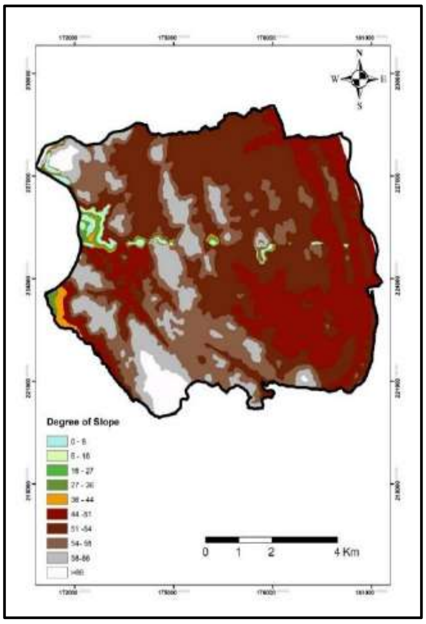

Figure 6. Slope map of the study area
Source: Compiled by the authors from Arc GIS

Changes in temperature and rainfall have a profound impact on the land. Increased industrial activity in the investigated area has had an impact on greenhouse gas emissions and land-use changes. The effects of temperature and precipitation on terrestrial vegetation are well documented. Soil erosion is exacerbated by increased rainfall. In other regions, high temperatures have also had an effect on the terrain.

People have mined for soil for construction projects in Udunuwara. The excavation process alters the structure of the land, causes soil loss owing to discharging mine wastes, and causes overburden to lie on the land after mining. Quarrying for stone and sand has resulted in the loss of fertile topsoil and the degradation of land. This soil mining also leads to land fragmentation, which is often caused by the loss of surrounding vegetation. The highest rate of mining was identified in Udunuwara DSD areas such as Welamboda, Watadeniya, Liyangahawatta, Kiriwewula west, and Pamunuwa west GNDs.

Another cause of land degradation in Udunuwara is deforestation. Certain trees have been cut down and burned for human use as timber, wood fire, industrialization, and building and settlement construction. People in this area force deforestation by seeking land for agriculture and homes. Figure 8 depicts the various forms of land use activities. It has lowered the amount of water in the soil, dried the atmosphere, and caused less rain in some locations, all of which have an impact on natural biodiversity. Furthermore, deforestation causes soil erosion and degrades land. Similarly, overgrazing has lowered plant density. It will not provide a time frame for vegetation regrowth. In the research region, it has resulted in soil infiltration, rapid runoff, and soil erosion. When asked about the cause of deforestation and land degradation, participants stated that "deforestation activities has increased the temperature." Because the water temperature is very high, organisms in the water are seriously harmed by this phenomena, according to one of the respondents.

Figure 7. Low degraded land in Udunuwara DSD
Source: By author through observation

The fish population has declined in channels and small streams, particularly near paddy fields. "Previously, people naturally created habitats in their trees and vegetation-covered places for birds, rabbits, and other animals coming to their paddy fields and home gardens, but it is no longer apparent anywhere," said one of the respondents.

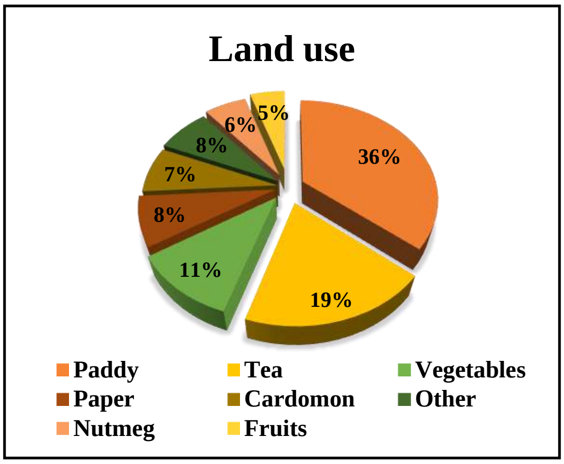

Figure 8: Extent of land use in the study area
Source: Udunuwara DSD

Garbage is being dumped on the streets by houses, shops, and hotels, according to interviewees. Wastes such as polythene, plastic, and cardboard are also dumped into the research area's main channels and tiny streams. Wastes clog the water flow of channels and streams, allowing sewage to pour onto the ground and degrade the land. Despite the fact that the Pradheshiya Sabha gathers waste from the neighborhood (households, stores, and hotels), polythene bags from shops and hotels are routinely tossed into the channels at night without anyone's knowledge. However, they were punished by the police and Pradheshiya Sabha personnel. Even though local authorities are responding to these types of illegal operations, they are unable to cover the entire area and cover only 30% of the study area, which consists primarily of town areas. So, in many regions of the study area, these types of illegal activities have been done by local people.

Solid waste disposal is also a significant cause of land degradation and has several environmental implications in the studied area. Pradheshiya Sabha collected separate solid garbage in Udunuwara, which included wastes such as paper, cardboard, glass, coconut shell, tins, plastic, and polythene. They also provide the cost of solid trash per kilogram. However, most people are unaware of this and dump these items into their surroundings. Apart from land exploitation, it has been identified by the

Pradheshiya Sabha that, according to their findings, CFL bulbs and batteries have been thrown into the soil, and their harmful gases have combined with water, polluting freshwater supplies. Furthermore, research suggested that it had badly harmed a human's neuron system and brain. These wastes have had an impact on biodiversity in the area surrounding the Kiriwewula open dumping site in Udunuwara DSD.

Land degradation is caused by both human and natural processes. Land degradation is mostly caused by settlement and building construction operations, as well as changes in climatic measures. Many more sources include soil mining, solid waste discharge, agricultural activities, road construction, liquid waste, deforestation, and land contamination. Deforestation has also become a significant cause of land degradation in some areas with a high human density. As a result, it is very obvious that the individuals destroying the forest are doing so for settlement and building construction, road development, and agricultural purposes. Some areas of Udunuwara have a steep incline. As a result, construction operations and the removal of vegetation cover in certain areas contribute to landslides and soil erosion. In Udunuwara, 65 of 124 GNDs are under risk of landslides. Thus, human-caused environmental variables constitute the primary source of land degradation in the studied area. These construction activities such as settlements, buildings, and roads made more impact on environmental unsustainability.

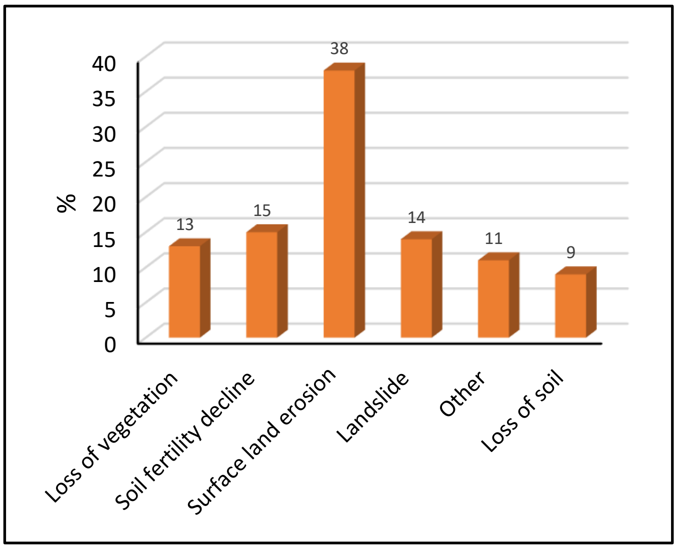

Figure 9: Types of land degradation in the study area
Source: DS Report

4. Conclusion

The process of land degradation is a worldwide issue, but the forms, extent, degree, and severity trends vary from country to country (IPCC, 2020). However, land degradation has been a significant issue in Udunuwara in recent decades. It appears to be many years ago. By examining the process of land degradation, we can determine the primary sources of the negative outcomes in the studied area. It was determined from secondary and primary sources that land degradation is occurring in the research area.

This research was carried out in order to compile the most important aspects relating to land degradation. It was discovered that most people, including Grama Niladhari personnel, are unaware of the detrimental repercussions of land deterioration. Some people purposefully pollute their environment. As a result, important contributors to land destruction were identified, and highly degraded land regions were exposed using spatial maps. Human-induced causes, rather than natural terrestrial processes, are the primary source of land degradation in the study region.

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The Analysis of the Land Use Change Detection Integrated with Geospatial Technology: Study on Dompe DSD in Gampaha District

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Keywords: Dompe, Geospatial technology, Land use/Land cover, Satellite images

1. Introduction

The land is one of the most valuable resources on the Earth. It is a complex and dynamic combination of factors: geology, topography, hydrology, soils, microclimates, and communities of plants and animals that are continually interacting under the influences of climate and human activities (Rinos and Nishanthi, 2016). Changes in land use and land cover mean certain changes in the land caused by human and natural factors. Especially, human activities play a major role in land-use changes. Eg; agricultural expansions, forest loggings, commercial plantations, minings, industries, and urbanization. A well-established land cover and land use management can be driven through understanding patterns, changes, and interactions between human activities and natural phenomena (Pathmanandakumar, 2020).

Land use can be generally classified into an urban or built-up area, agricultural land, rang land, forest land, water land, wetland, barren land, tundra, and perennial snow or ice. Urban land and agricultural land are changing through development (Gangodawila, 1988). Therefore, it is also important to observe how land use and landcover patterns have been changed over time

Although land-use changes are prominent, they are difficult to grasp when they occur incrementally and difficult to be determined due to the paucity of information and limitations in the information availability. One of the most appropriate sources for monitoring these processes is remotely sensed data. Remote sensing is an appropriate technology in identifying the changes most importantly it helps to save time (Fahad, *et al*., 2020). The primary purpose of using remote sensing-based change detection is to monitor land cover change very effectively and efficiently.

Objectives

The main objective of this study is to assess the land use and land cover (LULC) changes of the Dompe Divisional Secretariat Division in Gampaha district for the period of 2000 and 2021.

2. Material and Methods

Study Area Description

Dompe Divisional Secretariat is one of the 13 Divisional Secretariat Divisions (DSD) in the Gampaha District. This DSD is located to the southeast of the southern border of the Gampaha District. Dompe DSD consists of 133 Grama Niladhari Divisions and covers an area of 176.82 km^2. The study area covers 13% of the total area of 1387 km^2 in the Gampaha district, and the total population of the area is 171794. The area is bordered to the north by the Attanagalla DSD, to the south by the Kelani River, to the west by the Biyagama and Mahara DSD, and to the east, by the Kegalle District of the Sabaragamuwa Province**.** Geographically, it is located at 80° 00' 80° 11' N latitudes and 6° 54' 7° 05' E longitudes (Figure 01).

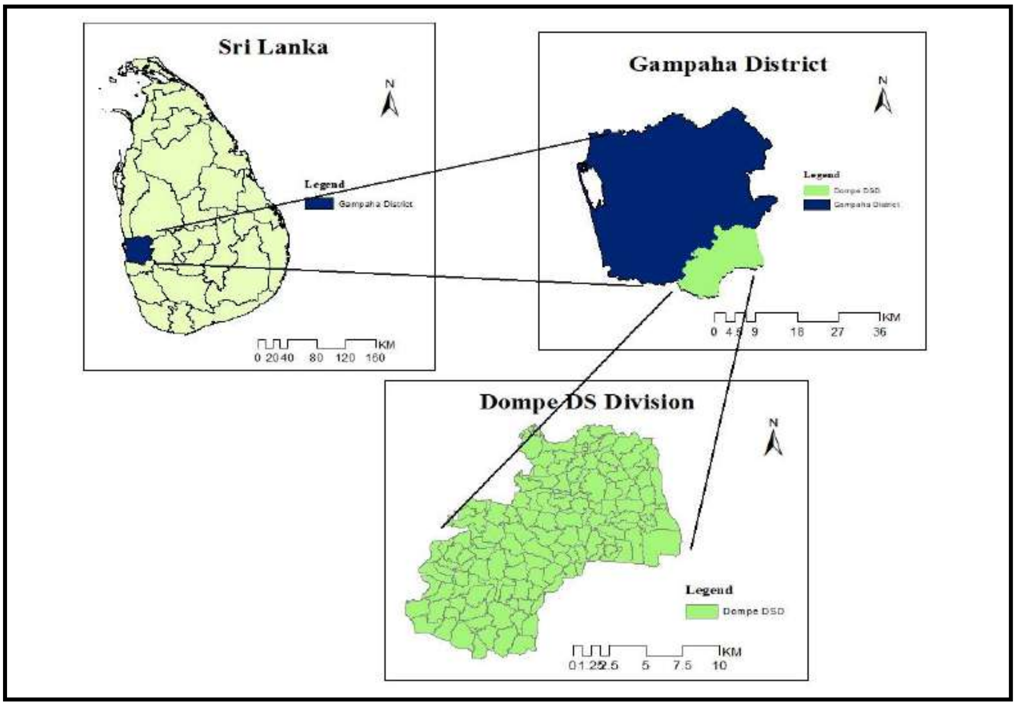

Figure 01: Location of the study area

Source: Survey department digital data layers, 2020

Materials

The study was mainly based on remotely sensed data. LANDSAT TM and LANDSAT OLI for 2000 and 2021 were obtained through the USGS website for analysis. Geo-reference was done for all four land-use layers in 2000 and 2021. And all the layers were clipped to the boundary of the Dompe DSD area.

In addition, reports such as the resource profile of the Dompe Divisional Secretariat and relevant data and land use maps of the Survey Department in Sri Lanka were also utilized for the study. A summary of the secondary data sources is depicted in Table 1.

Image Post Processing

Using Arc GIS 10.8, land use classes were classified according to the Maximum Likelihood Classification Algorithm based on the supervised image classification. here are five color bands in Landsat 4/5, 7 bands in Landsat 7, 8 bands in Landsat 8, and they were tested, and the land-use changes were decided according to those color bands**.**

2.2.2 Image Classification

Changes in land use in Dompe Divisional Secretariat are categorized based on five main classes. The areas under each land use category have been determined using the calculating geometry function. The methodological diagram of the study is displayed in figure 02.

Table 01: Summary of the secondary data sources

Data sources	Types of Data Sources	Acquisition Date	Objective
USGS/earth explorer	Landsat 7ETM	23/01/2000	Identification of the LU changes
USGS/ earth explorer	Landsat 8 OLI/TIRS	09/02/2021	Identification of the LU changes
Google earth pro	Google earth pro images	2000 and 2021	Observe of the nature of the area
Dompe DSD Sampath pathikada	Land use map of DSD	2020	Identification of land use patterns
Survey department GramaNiladhari boundary map	GramaNildhari boundary map	2020	Identify of study area

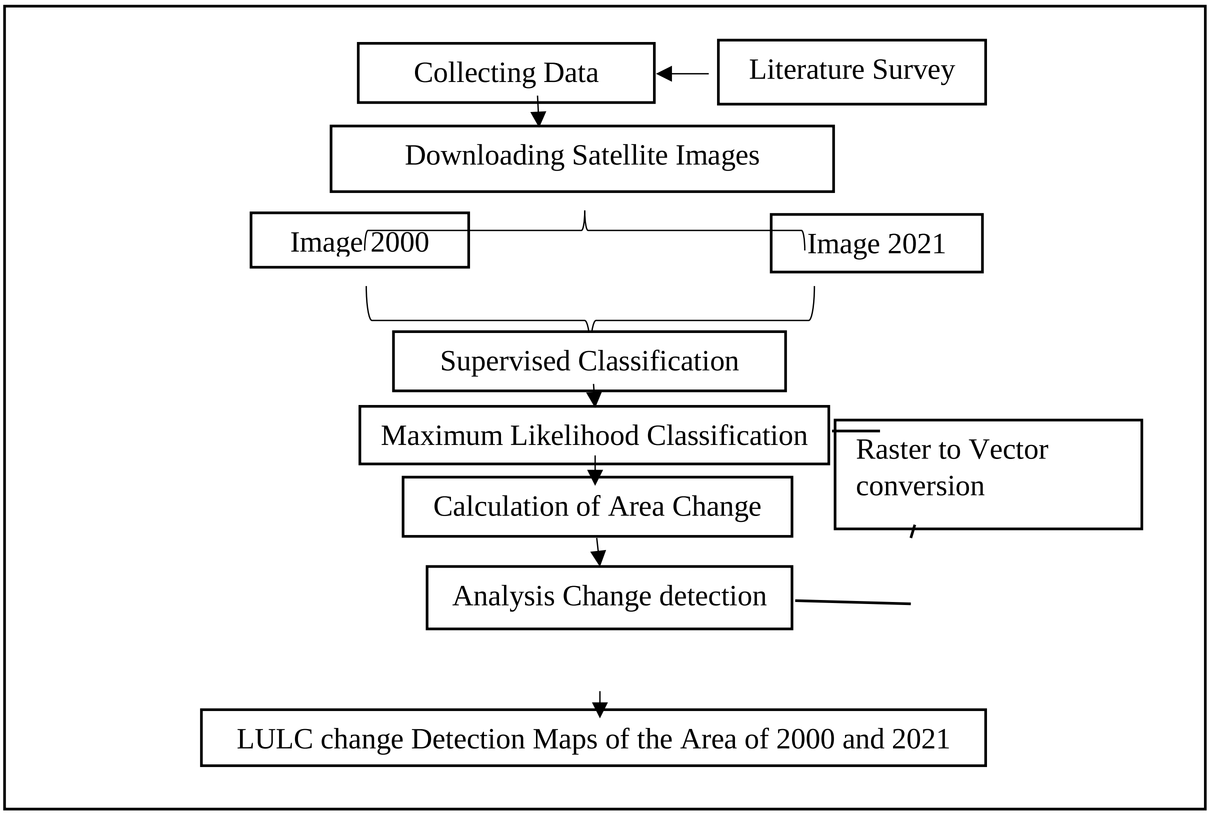

Figure 02: Methodology of the study

3. Results and Discussion

The total land area of the Dompe Divisional Secretariat is 176.82 $km^{2.}$ Changes in land use and land cover in Dompe Divisional Secretariat have been analyzed for 2000 and 2021 and relevant maps are shown in figure 03. **F**ive land use and land cover categories were identified namely patterns, paddy lands, vegetation cover, water, built-up area, and homestead gardens (Table 2)**.** Table number 3 provides the land extents under each land use category, Changes in land use and land covers during the past twenty-one years revealed a clear link between land use and development initiatives (Figure 3).

Table 2: Description of the LULC category in the area

Land use classes description	
Built-up areas	Industry, urban area, cemetery, quarry, ground
Vegetation Cover	Forest, Rubber, Scrub
Water	River, Marshlands
Paddy Lands	Paddy lands
Homestead	Field crops, mix crops, coconut, pineapple, banana, rambutan etc

A detailed assessment of individual LULC categories during the period under consideration is explained separately in the following sections. The characteristics of individual LULC categories can be described under four groups as follows.

i. LULCs displaying growing trends
ii. LULCs displaying decreasing trends

Three LULC categories, namely Built-up areas, Home gardens, and paddy areas showed significant growing trends. Among them, Built-up areas indicated a continuously growing trend. Water and Vegetation areas displayed decreasing trend (Table 3 and Figures 3).

Results revealed that paddy cultivation in the area was 9.81 km^2 of the total land area in 2000, it was 11.25 km^2 in 2021. However, the Paddy land use category was dramatically increased. The paddy areas are highly concentrated in the eastern half of the Dompe DS division. In 2000 the Builtup areas had claimed 2.81 km^2 of the total LULC under consideration and 7.50 km^2 in 2021. The development of urban areas and the establishment of small-scale industries have contributed to this growth. The towns of Kiridiwela and Pugoda are also located as urban areas in the area. It had increased up to 7.50 km^2. There were 143.66 km^2 represented by Home gardens and in 2021 home gardens increased up to 148.69 km^2 in 2021. Homestead is the mainland use activity in the area and it contains coconut, pineapple, rambutan, and banana plantations. Vegetation claimed the second-highest land use category in 2000 claiming 20.66 km^2 of the total land area. It gradually decreased to 10.86 km^2 in 2021. The water exhibited a considerable coverage of the total land area, showing a decreasing trend over time throughout the selected period. The Kelani River is the main catchment area of the area and in addition, a small number of marshlands are included in the water system. The researcher observed that minor water bodies in the area have been destroyed by land reclamation (Figure 3 and Figure 4).

Vegetation claimed the second-highest land use category in 2000 claiming 20.66% of the total land area. It gradually decreased in 2021 respectively.

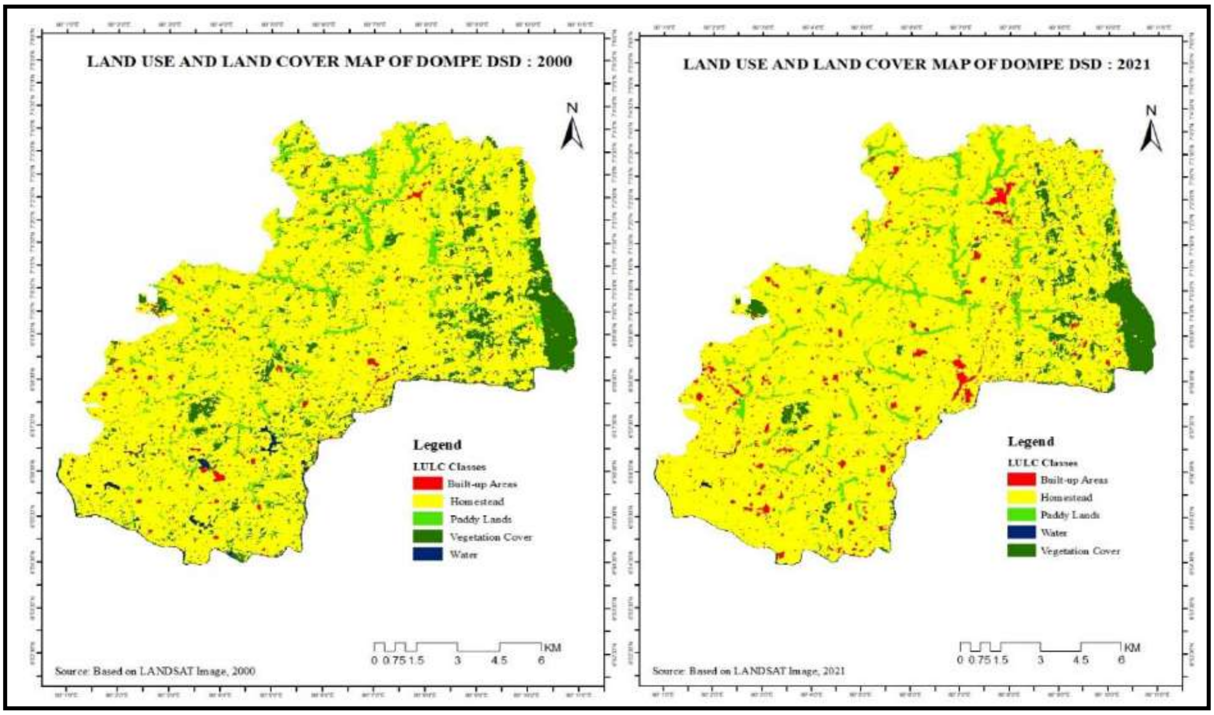

Figure 3: Land use/ land cover classification of Dompe DS Division in 2000 and 2021

Table 3: Land use change (sq.km) of Dompe DSD from 2000 to 2021

LULC Classes	2000		2021		Changes between 2000 and 2021	
	Area	%	Area	%	Area	%
Paddy Lands	9.81	5.47	11.25	6.28	+1.44	+0.81
Vegetation Cover	20.66	11.53	10.86	6.06	-9.8	-5.47
Water	2.09*	1.16	0.73	0.40	-1.36	-0.76
Built-up Areas	2.81*	1.56	7.50	4.18	+4.69	+.2.62
Homestead	143.66	80.24	148.69	83.05	+5.03	+2.81
Total	179.03	99.96	179.03	99.97		

Source: GIS-based area calculation

*****There is an error records because some paddy lands and homestead are calculated as water and built-up areas

LULC change detection rate from 2000 to 2021

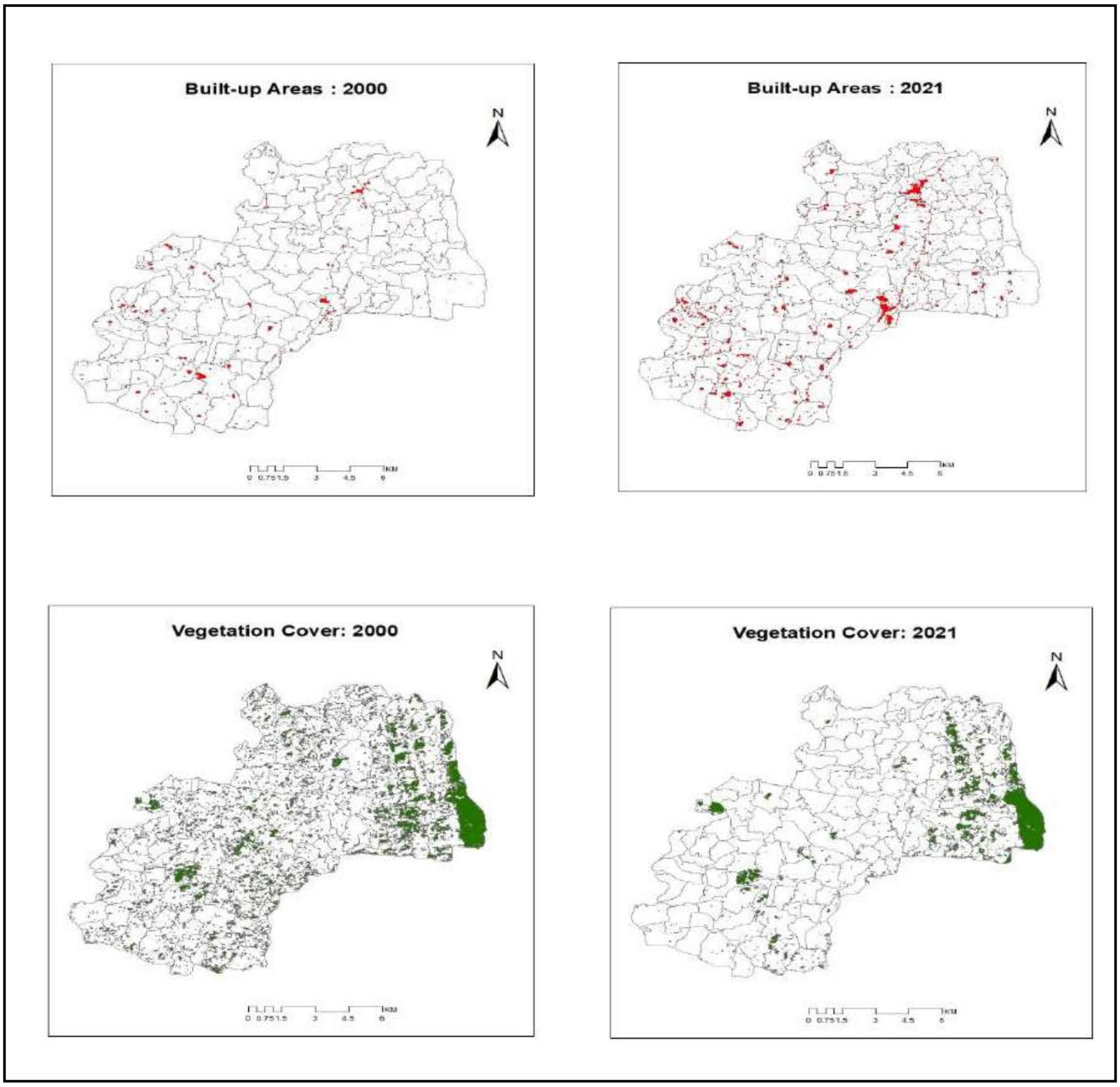

Figure 4: Changes in built-up areas and vegetation cover of the area

4. Conclusion

Thematic maps were created in the study area to illustrate the difference between land use and land coverage between 2000 and 2021. Five main classes of land use have been identified in the area. From 2000 to 2021 the building area has grown significantly, and there has been a clear decrease in vegetation cover and water bodies. Based on these facts, a general pattern can be identified with regard to these land-use changes. It is clear that Home gardens surrounding Built-up areas get converted to Built-up areas rapidly. A rapid increase in Built-up areas can be identified in the northern, eastern, western, and southern parts of the study area.

5. Acknowledgment

We express our gratitude to the Dompe DS Division for providing institutional reports and grateful to the United States Geological Survey (USGS) and Survey Department of Sri Lanka for providing the Landsatimage and digital data layers of the study area free of charge.

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Impacts of Caves on Evolution of Sri Lankan Landscape: With Reference to the Wet Zone in Sri Lanka

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Keywords: *Caves, Proterozoic Metamorphic Rocks, Metamorphosed carbonates, Weathering, Landscape Evolution*

1. Introduction

The denudation process in tropical countries such as Sri Lanka plays a vital role in the evolution of a variety of landscapes at a higher rate (Hewawasam and Kubik, 2004; Vanacker et al., 2007). Though the both physical and chemical weathering in tropical climate is high, impacts of it on metamorphosed silicate rocks are quite complicated since some silicates minerals such as quartz show a greater resistance to weathering; hence the rocks composed of the same mineral assemblages too (Hewawasam and Kubik, 2004). The influences of such processes in metamorphosed silicate terrains are quite complicated with slow rates (Dunne, 1978; Gardener and Walshb, 2009; Lyons et al., 2020) rather than the that of in sedimentary carbonate terrains of worldwide (Ryb et al., 2014).

As a result of the weathering process, caves have been resulted and commonly found on sedimentary carbonate terrains (Trudgill, 1985; Onac and Goran, 2018). Even though 80 % of the Cratonic basement of Sri Lanka is composed of the high grade metamorphic rocks, the country shows a higher density and diversity of caves and it has been found that most of the caves have been concentrated to the wet zone of the country (Jayasingha et al., 2010, 2014, 2018; Osborn et al. 2013). With the growing concerns in speleogenesis which is resulted from natural weathering process, the attention to Sri Lankan caves have been paid to study in many aspects including geological, biological, morphological, archaeological and tourism too. But it is well noted that no attempt has been made to study their impacts on landscape evolution. Hence the research focuses on studying the impacts of cave formation on landscape evolution of Sri Lanka and the study was focused to the cave terrains in wet zone of the country.

Study area

Most of the studied caves in metamorphic terrains of Sri Lanka were located in the wet zone where the environmental conditions are highly favorable for natural weathering process and the cave formation can be expected to be significant as the denudation process which may be high. Hence the impact of caves on the evolution of landscape can easily be identified and studied. The studied caves are Batadomba Cave, Batathota Cave and Sthreepura Cave at Kuruwita, Wawulpone Cave at Kahawatta, Endirilena Cave at Pallebedda, Roopa Gallena Cave at Rathganga, Malena at Siripagama, Pothgullena Cave at alawala, Attanagalla, Belilena at Kithulgala, Kosgala Cave at Kosgala, Pelpola cave at Rathnapura and Pahiyangala Cave at Pahiyangala

Physiography of the study area

Since the studied area is located in the wet zone of the country, those area receives high rainfalls as more than 2500 mm as the average annual rainfall, while the average annual temperature is 30 degrees in centigrade. All most all the caves have been formed in mountainous terrains and are mostly located on the slopes of those mountains. The valleys and mountains ridges are structurally controlled. Mainly, Kalu river, Seetha Ganga, Kelani, Gurugoda Oya and Ritigaha Oya Rivers and their tributaries signify the hydrology of the study area. The vegetation of study locations is mostly characterized by secondary wet zone forests, plantations and abandoned home gardens in some instances.

General Geology of the Study Area

The study area belongs to the Highland Complex of Sri Lanka and the area is characterized by Proterozoic high-grade metamorphic rocks (Cooray, 1994). The rocks are mostly gneiss, migmatite, charnokite, marble, calc gneiss, quartzites and pegmatite. The structural geology characterizes the area with shear zones, some faults, lineaments in NE-SW and NW-SW directions commonly and differentially aligned joint patterns. Most of the rock show NE-SW directed foliations. The insitu soil profiles are dominant with red podsolic nature showing high leaching and slightly acidic conditions due to high rainfall most of the time of the year. In addition, the thickness of the soil profiles varies place to place, but in average, it’s about two to three-meter high. Soil erosion seems high and frequently recorded landslide occurrences evidence it. Hence the sedimentation can be expected high specially in the valley areas which have been formed along the geological structural weak planes.

2. Materials and Methods

Some wet zone caves in Sri Lanka were studied with respect their genesis, geology and their structures, interior morphology and, more specifically, weathering process. The adopted methodology was twofold. Desk study conducted before connected with the field was characterized with studying literature such as previously published papers and also available maps of Geology and topography of the study area. Then the field works were conducted with the scope of studying geology and mineralogy, geological structures, hydrology, dominant weathering pattern and interior morphology. Surface geological mapping and mapping of cave interior morphology have been manually conducted. Hence morphological base maps of the cave interior were finally produced in terms of understanding the underground geographic distribution. The orientation of the interior shapes of the caves was correlated with the existing structural discontinuities to understand the role of weathering, its impacts and future expansion. The regional and local landscape of the study locations has also been studied with regard to understanding the dominant geomorphological features.

3. Results and Discussion

It is well noted that most of the studied caves are located on the silicate metamorphic rocks such as Gneiss and Charnokite. In addition, few of them are located on Metamorphosed Carbonates such as Marble. Rare occurrence of Tufa formation which was resulted from chemical precipitation of dissolved carbonates from freshwater sources, has also been recorded in Wawulpane Cave at Pallebedda. But the well noted feature of each and every cave site is the presence of some relics of metamorphosed carbonates indicating the initiation of cave formation by dissolution of carbonate materials during a period of high CO_2 pressure in the past (Berner et al., 1983). The results of the cave interior mapping show the morphology of the cave have been affected by the weak structural discontinuities along which the cave interiors have been extended (Figure 1). It has been evidenced by the breakdown files of various sizes of boulders observed in the cave interior (Figure 2). Hence it can be inferred that the formation and extension of cave interior and its morphology can first be connected with the dissolution of carbonates as the initiation process and followed by physical weathering process by which a break down file could be deposited.

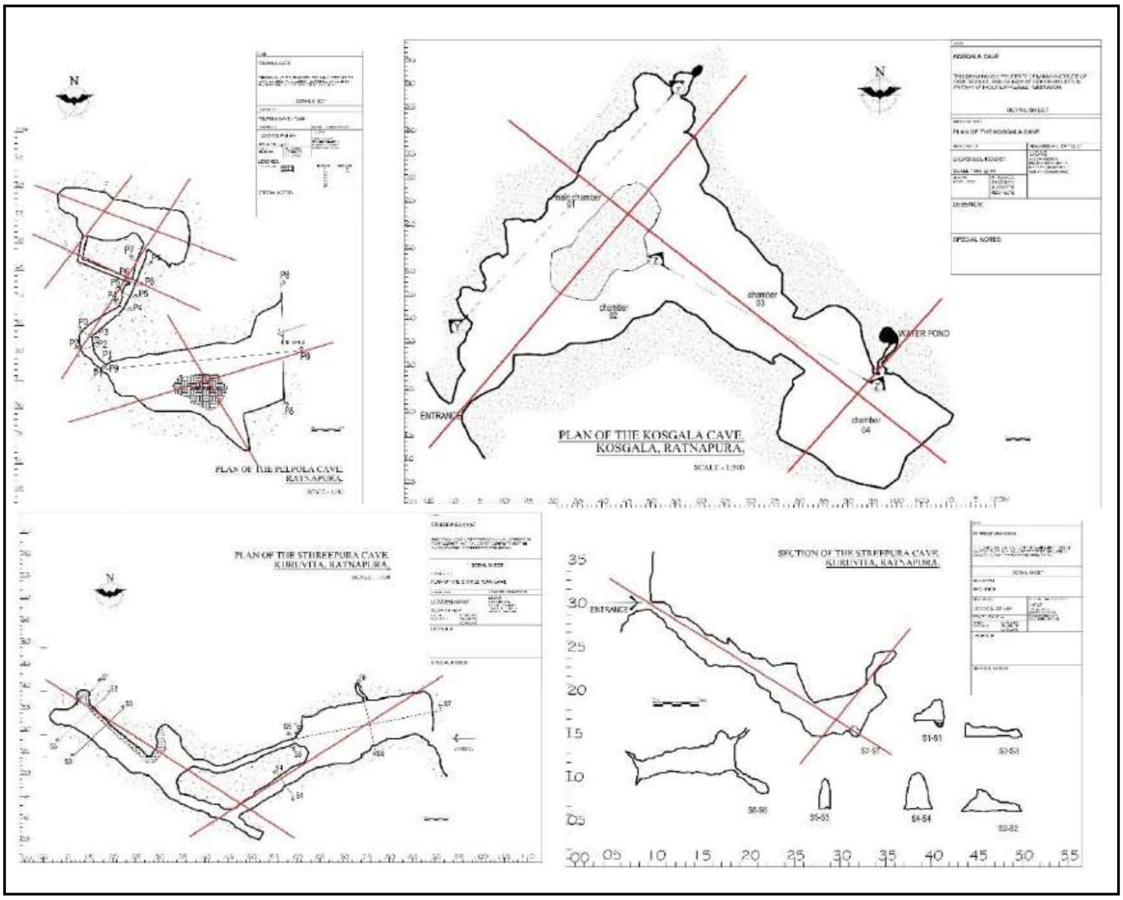

Figure 1: Maps of interior morphologies of some studied caves; read line shows the structural discontinuities of the bed rock

Figure 2: Collapsed breakdown pile (fallen weathered rock boulders)

The results of the study show that the caves are erosional features which mostly forms various shapes of interior morphologies (Figure 1) and those are hidden to the surface. But it is again well noticed that the hidden nature of the studied caves can be exposed by formation of various shapes and sizes of cave entrances which affect the surface morphology and landscape of the surrounding area. However, the well noted fact from the field observations is the impact of the cave to the local landscape emerging with the formation of cave entrance which is being potentially expanding and enlarging and making the cave interior more visible to the outside. It can be believed that, as a results of continuous weathering process until the cave entrances get enlarged to merge the interior with the surrounding landscape, no or little impact on local landscape can be observed. This fact is evidenced by the local landscape developed in Pothgullena at Alawala, Belilena at Kithulgala, Pahiynagala at Pahiynagala, Batadombalena and Batathotalena at Kuruwita where the cave entrances have already been merged with the local landscape due to enlarging and expanding (Figure 3). Further it has been recorded that the subsidence potential that can be triggered by the progressive development of cave network inside the subsurface may cause a greater impact on changing the local landscape (Jayasingha et al., 2015). Some sink hole formations can also be seen in the premises of carbonate caves such as Malena at Siripagama and Roopagallena at Rathganga. In addition, the local landscape of those locations has been affected with karstic features due to rapid dissolution process. The other observed caves such as Endirilena and Kosgala are yet to be exposed.

Figure 3: Crescent shape cave entrance of Batadombalena Cave at Kuruwita: Red line shows the possible expanding in future.

The interesting feature observed with the Caves of Belilena, Batabomaba and Pahiynlena with crescent shape entrances is the cutting of the steep cliff at the bottom of which those cave have been developed. By studying the way of enlargement of the cave entrances, it can be inferred that the cliffs of those locations can be carved to the top of them in future affecting the local landscapes.

The erosional process in the caves of some locations are triggered by a small stream flowing through it and also the seepages on the wet surface of cave walls and from ceiling. This has been evidenced by highly sharpen quartz gains of the host rocks of the caves, although the quartz is highly resistance to chemical weathering. Though the Tufa deposition at Wawulpane formed a hummocky landscape is also getting eroded due to the action of the stream flowing through the cave.

4. Conclusion

The caves are erosional features, and their impact on the evolution of the landscape is highly localized and varied. In most instances, it seems that caves are being developed mainly into the earth but also enlarging upward vertically due to the collapsing of the ceiling and also horizontally mainly resulting by the physical weathering process, hence future subsidence may cause landscape shaping greatly at the local surrounding of caves. The cave entrances have been merged with the landscape showing the potential of future impacts on shaping the surrounding area.

Future Studies

It is necessary to study the impacts of cave formation on landscape evolution in details.

5. Acknowledgement

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The Consequences of Anthropogenic Activities on Changing Coastal Landscape in Hikkaduwa Coastal Zone, Sri Lanka

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Key Words: Coastal, Erosion, Landscape Change, Tourism

1. Introduction

Sri Lanka is an island with a coastline of approximately 1750 km (National Science Foundation, 2000) in length, and it is the boundary between the land and the sea to protect the country's landmass. Coastal areas are significant for human beings, as they witness the culture and economic exchanges between different nations. Most of the big cities that are famous around the world are situated in coastal areas. One-third of the world's population lives near or on the seashore. Due to abundant natural resources, urbanization and the population have rapidly increased in coastal areas. In addition, various developmental projects are installed in the shoreline areas, placing tremendous pressure on them and leading to various coastal hazards like sea erosion, seawater intrusion, coral bleaching, shoreline change, etc. Due to those impacts, the Hikkaduwa coastal landscape area has changed since 2003. So, the purpose of the study is to identify the human activities that influence the changes in the coastal landscape.

Hikkaduwa is the most popular coastal tourism site in Sri Lanka. The total length of the beach is about four km. The Marine Sanctuary, which is endowed with beautiful coral reefs and marine life, is the focal point of the tourist attraction of Hikkaduwa (CRMP, 1994). However, as revealed by questionnaire surveys, there are a variety of other attractions to supplement the Marine Sanctuary. These are; a warm, sunny climate, a clear blue sea, sandy beaches, shopping for local handicrafts, opportunities for diving, surfing, snorkeling, interaction with friendly and helpful people, indigenous cultural performances, etc. Both foreign and domestic tourists visit Hikkaduwa. Hikkaduwa is a major tourist attraction in Sri Lanka and is famous for its beautiful beaches and corals. It is a suburb of Galle. Approximately 5 kilometers southeast of the city center and 108 kilometers south of Colombo.

Implications of tourism in Hikkaduwa

- Degradation of the coral reef

The main contributory factor is the usage of glass-bottom boats to view the corals and coral fish by tourists. The overloaded boats touch and damage the surface of the coral layer. In addition, to get a closer look at the coral, some tourists are inclined to jump out of the boats, thus causing damage to the coral reef.

- Solid waste and sewerage disposal

Due to the development that has taken place in tourism business establishments, there is no proper system of solid waste and sewerage disposal. As these tourism establishments are located very near the coastal waters, such discharges to the ground through septic tanks and pits contaminate the groundwater, causing seawater pollution. In addition, some establishments discharge the sewerage through pipes extended to the sea by which the seawater is directly polluted with effluents.

- Garbage dispersal and environmental pollution

Garbage dispersal and pollution of the environment are done by all parties concerned in varied proportions. The foreign and domestic tourists, the establishments, and the general public are all responsible for littering items such as plastic bottles, paper bags, and other waste on the roads and beaches. In addition, the garbage collection system of the local authority is not efficient enough to keep the streets and beaches free from garbage.

Objectives

The main objective of this study is to examine "the impact of human activities on the changing coastal landscape, with special reference to the Hikkaduwa Coastal Zone. In addition to the main objective, this study concerned the following aspects:

1 Identify the existing human activities in the study area.
2. Analyze the changing patterns of the coastal landscape in the years from 2003 to 2021.
3. Examine the impacts of human activities on coastal landscape change.

Considering the literature relevant to the experiment, various researchers have defined coastal terms. The Coastal Zone is the boundary between the land and the sea and could be identified as a strip. The reason is that many activities, physical, chemical, or biological, in the nearshore area or the immediate onshore affect the land/water interface, resulting in erosion or accretion. Thus, activities at any coastal location may cause instabilities in the locality or sometimes in distant coastal areas (Dayananda, 1992).

2. Methods and Materials

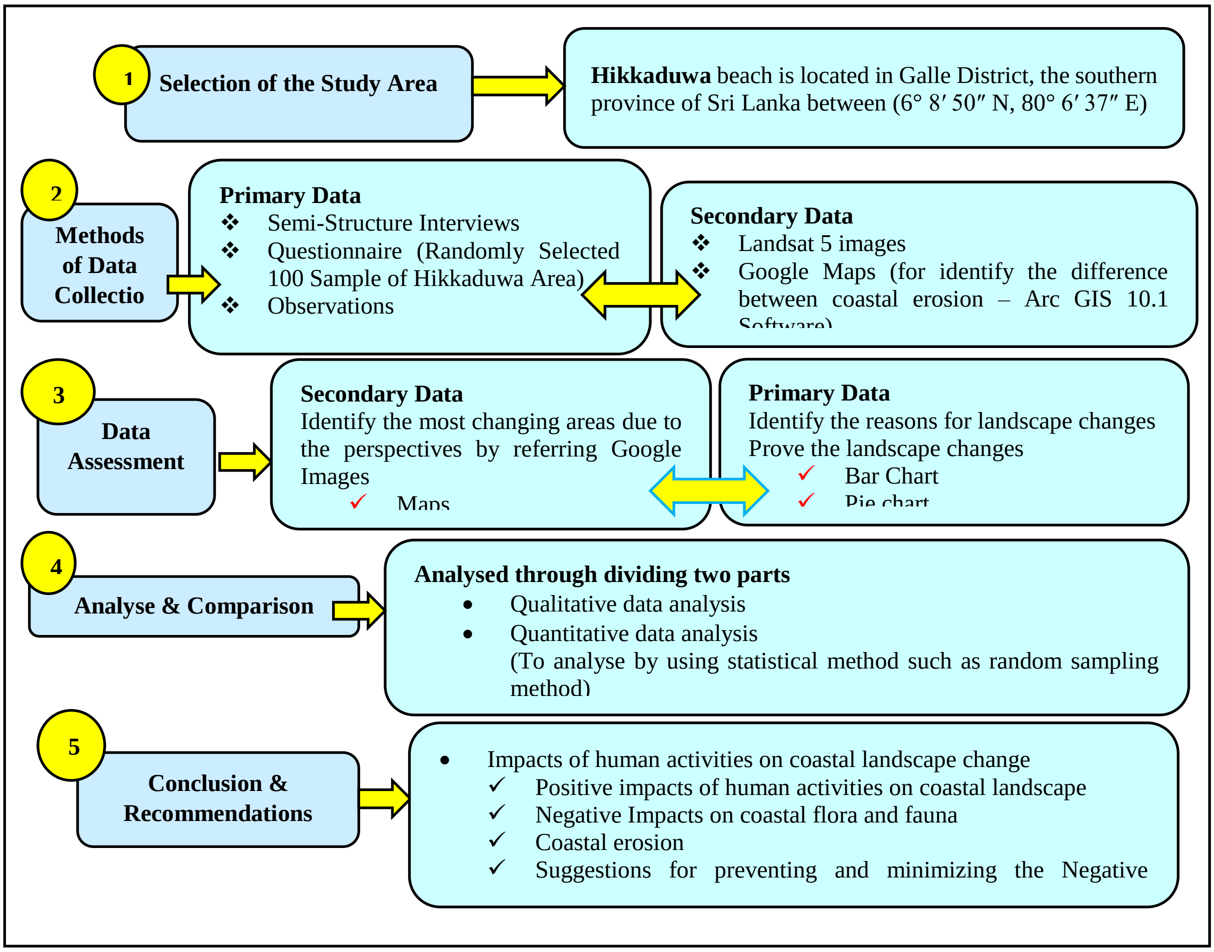


Figure 1: Conceptual research framework

Study Area

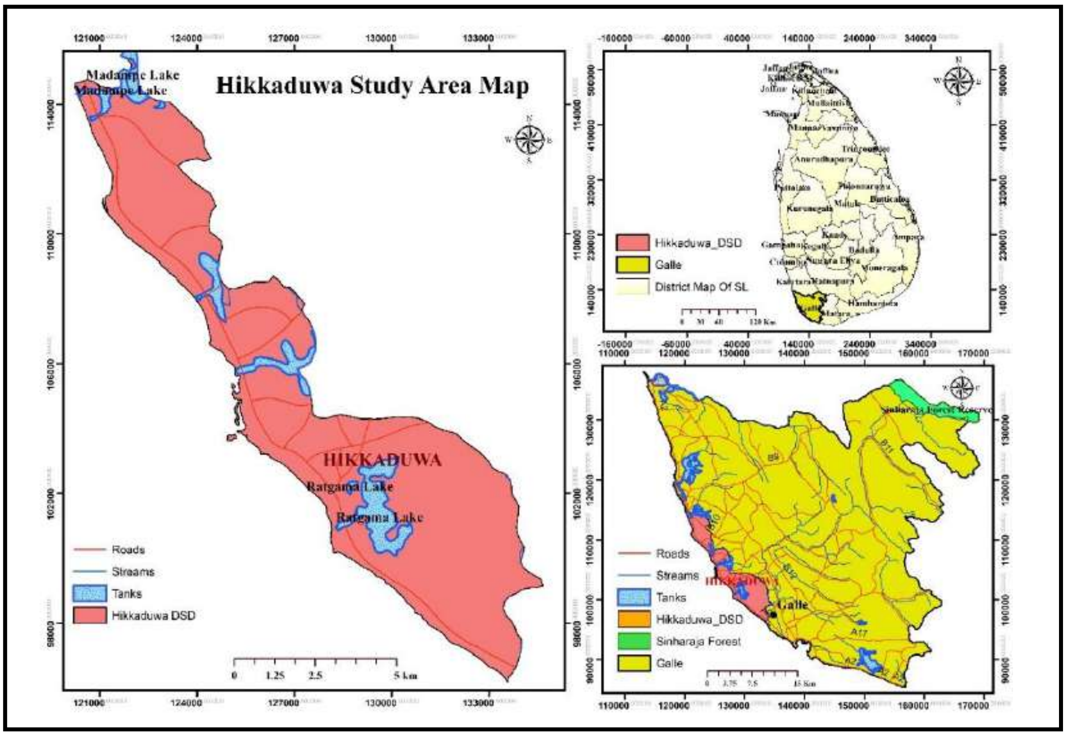
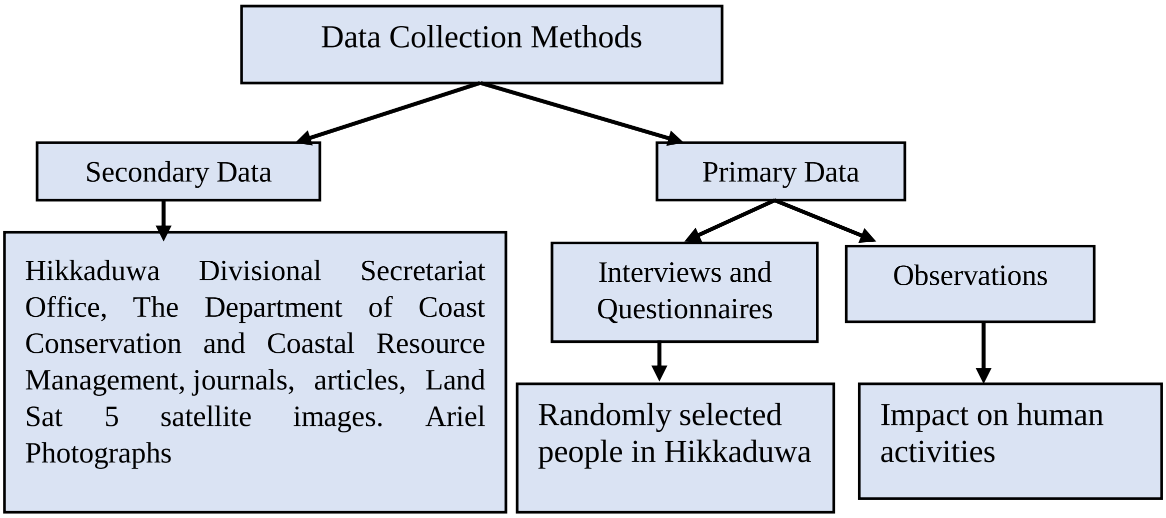


Figure 2 Hikkaduwa study area map

Data Collection

Both the primary and secondary data have been used to fulfill the objectives of the study. A randomly selected 100 residents around the beach area were subjected to collecting primary data through a questionnaire survey.



Data Analysis

As the secondary data, Landsat 5 images are downloaded and composited. Google maps also collected and identified the places where the changes can mostly be identified by referring to the images. Then compare the Landsat and the Google map by checking the selected sample point. Then quantitatively measuring (area calculation) the land-use changes can be done by referring to those values. It can be used to calculate the changing percentages of the land quantitatively. Quantitative data is assumed to be analyzed by using statistical methods such as the random sampling method. The collected data is presented in tables and charts. The data is supposed to be synthesized and analyzed with theories. The last decision was accepted to design the study by analyzing the quantitative and qualitative data.

3. Results and Discussions

Existing Human Activities in the Study Area

Considering all the observed and analyzed data, it could be identified that this area has now reached its highest development stage as a tourism area. All the features of under urbanization, such as population growth and migration patterns, are highly affected by that dynamism. Among them, residences in the coastal zone, fishing, and aquaculture, shipping, land-use practices (agriculture, industrial development, and unauthorized construction) are the main existing human activities that could be identified in the area.

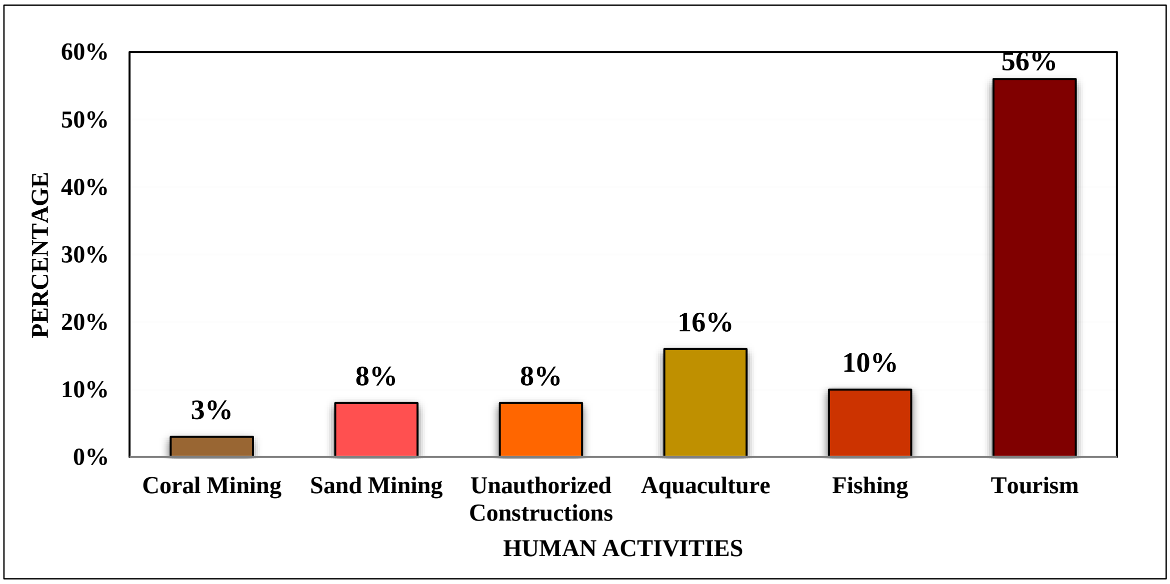


Figure 4 Existing human activities in the study area
Source - Compiled by author based on primary data, 2019

As seen in figure 4, amongst the sample of 100 households used in the research, the most abundant human activity on the Hikkaduwa coast is the tourism industry, representing 56% of the sample. A minimum of 3% could be identified as coral mining. Thus, about 16% of the moderate percentage value can be understood in the above data analysis, indicating the impact of Aquaculture on human activities.

As the information obtained from the field study, coral reef mining is very limited in the area. In the field study, the people stated that some people are doing this activity secretly, although the rules and regulations restrict the breaking up of coral reefs. Therefore, there is no more coral reef mining as in the past, as is clear from the information and observations received (Burrows. S, 2008). However, sand mining is another existing human activity that operates in the study area somewhat. Some youths secretly do sand mining, while the hotel and restaurant owners take sand near their construction to open up beach platforms. However, the Coast Conservation Department is taking steps to avoid illegal sand extraction, and field officers are responsible for reporting such activities to the Department weekly.

Changing Patterns of Coastal Landscape from the year 2003 to 2021.

The mangroves of the surrounding coastal area have been destroyed for several kilometers. The tsunami in 2004 was a significant factor in this, and the saltwater mixing caused damage to the forests and agricultural lands. Other tourist resorts and other buildings were also massively destroyed. However, the number of installations increased again in 2006. Tourism has gathered around the strip, and boat services have been increased since 2006.

The Hikkaduwa Sea has reduced coral reefs due to the sea waves being rapidly sinking. The coral is threatened due to the release of sewage and garbage into the sea and careless boating, diving, surfing, and fishing. By 2009, an incredible incident had taken place, and there was no beach there. The coastline has been severely damaged, eroded the shore's surface, and therefore, collapsed buildings. However, the sea level has increased, and the depth of the sea has also been increased. According to figure 5, the coast has become eroded to the point where a coastline has not been visible. It is also possible to study the damage to the buildings on the coast due to the rapidly colliding sea currents.

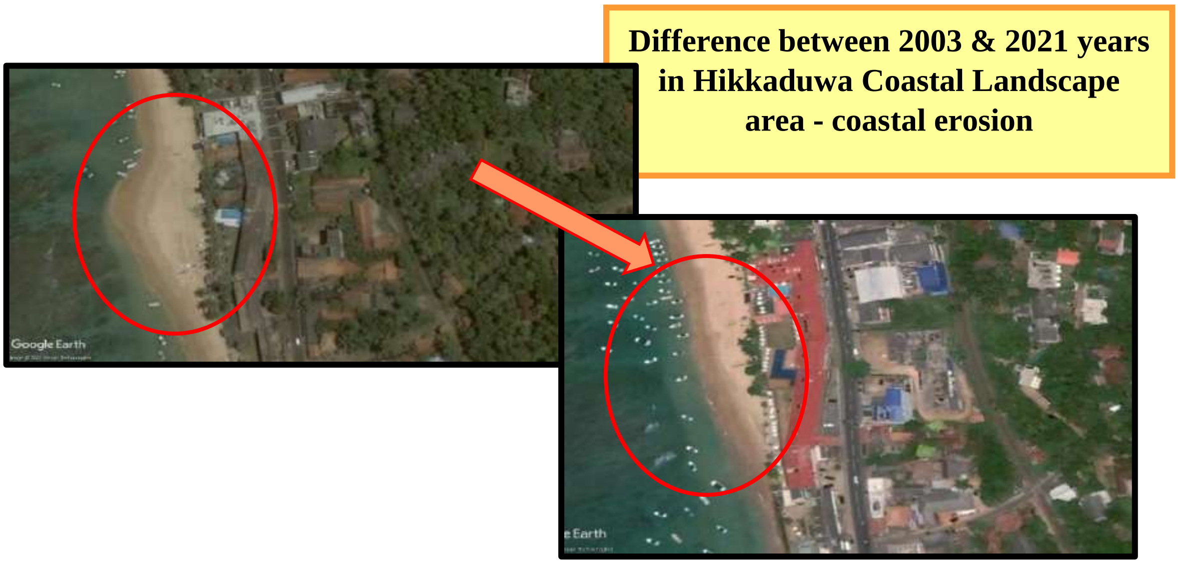


Figure 5 Changing patterns of coastal landscape, 2021 -Hikkaduwa Beach

The pattern of Coastal Landscape Change

According to the data obtained from the study area, the response given by the people to the pattern of changing the Hikkaduwa coastal area is as follows (Figure 6).

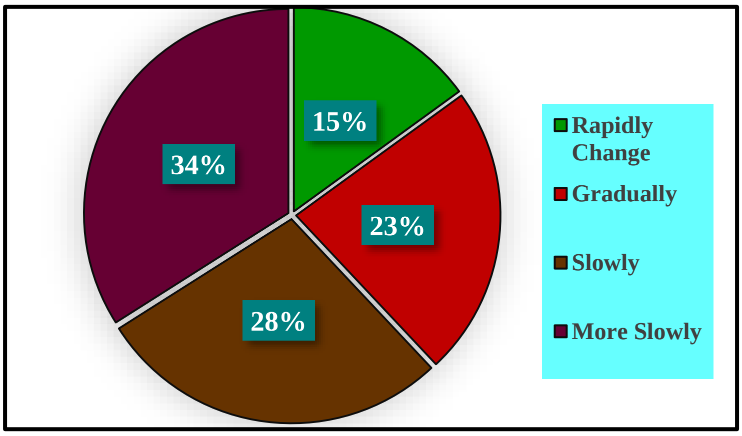


Figure 6 Existing human activities in the study area
Source - Compiled by author based on primary data, 2019

When analyzing the data obtained from the field survey, 34% of the respondents' opinion is that coastal landscape change is more slowly taking place. In contrast, 23% stated that this process is gradually slower. 15% think that rapid change is taking place. According to this information, it is assumed that a long time has elapsed to change the landscape, although this coastline has been rapidly and progressively altered by sea-level fluctuations.

Impacts of human activities on coastal landscape Change

- **Problems related to waste products and marine water pollution**

It has been identified that hotels, guest houses, restaurants, and other similar places have no formal wastewater disposal systems, and they discharge the wastewater into water sources. It pollutes both underground water and surface water. Another main tourist activity that can be seen in the Hikkaduwa coastal area is motorboat tours. Tourists use boats for watching corals and for having entertainment. Those motorboats are also a reason for marine pollution. Oil spilling from boats is harmful to the marine environment.

- **Negative impacts on coastal flora and fauna**

According to the Coastal Conservation Departmental information, tourism is the main threat to the turtles' resources. A large number of tourists, loud noises from beach hotels, beach festivals, strong light ways, and the use of turtle shells to make fancy items all pose a threat to turtle survival. Turtle conservation projects preserve turtles from these threats.

- **Coastal Erosion**

As a consequence of the increase in the human population in the coastal area in Hikkaduwa, which has often resulted in chaotic demographic expansion, some beach ridge systems have been completely destroyed in the process of providing space for buildings, residential developments, tourist resorts, and recreation areas. In addition, massive tourism demand has led to the virtualization of the coastline.

- **Positive Impacts of Human Activities on the Coastal Landscape**

Environment Preservation Projects, Water State Management Projects, Conservation of Coral Reefs, and Specific Area Management processes could be identified in Hikkaduwa area.

4. Conclusion

Coastal landscape changes have a wide range of consequences at all spatial and temporal scales. Compared to the 2003 and 2021 years in the Hikkaduwa Coastal Landscape area, the coastline has been severely damaged, and the surface of the shore has been eroded, resulting in the building's collapse. In order to detect and analyze changing coastal landscapes, these techniques were implemented. Compared with 2003–2021, development areas related to tourism also increased in the Hikkaduwa area. And also, the majority of the respondents' opinion is that the coastal landscape is changing more slowly (34%).

But, a significant number of respondents noted that the coastline is rapidly changing (15%). Development within coastal areas has increased interest in erosion problems. It has led to major efforts to manage coastal erosion problems and to restore coastal capacity to accommodate short-and long-term changes induced by human activities, extreme events, and sea-level rise.

5. Recommendations

To educate all people, including tourists, the local community, and tourism employees, about the adverse effects of tourism on the environment and the importance of preserving it. Besides that, it is vital to organize workshops and seminars for the living community of coastal areas and employees of the tourist industry to educate them on achieving sustainable environmental development and reaching sustainable economic and social preservatives through coastal conservation.

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