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Globalization, Greed and Glocal Ecology: A Psychological Perspective

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Abstract

Evidently, a globalized society causes global environmental crises. Undoubtedly, survival of human life on the planet Earth is threatened. Is there any connection between globalization, environmental crises and psychological manifestations? What are the psychological perspectives linking the ecological damages from local to the global scale? This article explores such intricate relationships and discusses the implications. The underlying principal cause is human's unending greed to acquire maximum materials and power to control the planet and entire humanity. The greed is believed to be a bottomless pit which exhausts the person in an endless effort to satisfy the need without ever reaching satisfaction. The greedy people are supposed to have biological, psychological and sociological drives. Evidently, global destruction of the ecosystems and natural environment are directly or indirectly linked to unprecedented chronic human greed and self-indulgence. Undoubtedly, unencumbered chronic greed of a few elite institutions led by top capitalists has put the entire planet in havoc and infiltrated widespread sufferings at the global scale. Conclusively, psychological basis of environmental problems has a sociological and socio-historical scope within the frame of globalization. Psychological account of the environmental crisis is explained subsequently in this article followed by a case study of deforestation of Carpathian Mountains staged by a greedy Austrian man.

Keywords

Greed; Globalization; Ecological impact; Psychological perspective; Environmental destruction

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Introduction: The Globalization

In the modern world, the telecommunications and global economic freedom have changed the landscape of people's movements across the borders and world regions (Arnett, 2002). In the book "The Battle in Seattle, 1999", The Economist magazine writes that exports manifested in world gross domestic product (WGDP) grew from 8% in 1950 to 26% by 1998, and global travels increased by 700% since 1960 (Held, 1998). Began in 19902, globalization is known to be a complex process having varying pace and direction ascertained by different factors such as economic, social, and environmental determinants. The environmental definition of the globalization reveals that the globalization should be considered as a process of resulting environmental crises caused by global environmental externalities (e.g., pollution) (Ilić and Hafner, 2015). Hence, a globalized society causes global environmental crises. As a result, survival of human life on the planet Earth is threatened (Ilić and Hafner, 2015). Is there any connection between globalization, environmental crises and psychological manifestations? What are the psychological perspectives linking the ecological damages from local to the global scale? This article will explore such intricate relationships and discuss the implications. Arnett (2002) articulates that psychology explores indirectly the globalization in terms of psychological theory, research on acculturation, identity, and other implications.

Greed

Amid the complexity of the human behaviour, the psychology explores greed as causative agent for environmental destruction by economic externalities. Robertson (2013) defines the greed as one psychological phenomenon characterized with the selfish quest to possess objects, people, wealth, substances, status, appreciation, power, or attention beyond the extent required for basic human comfort. To simply put, Webster (2013) defined the greed as an excessive desire for more. It manifests a state of insatiability exhibiting quest for obtaining preferred goods. Scientists have further described the greed beyond mere accumulation and opined that greed may be characterized by causing potentially negative consequences that emanate from one's own actions. Apparently, an excessive desire for something is usually at the expense of others (Mussel and Hewig, 2013). Certain scientists attributed trait greed shares with other dark traits like psychopathy and machiavellianism (Furnham *et al.*, 2013; Moshagen *et al.*, 2018). Another scholar, D'Souza (1995), classified the greed as the direct outcome of dissatisfaction, emptiness, and discontentment. He argued further that an act of filling emptiness and discontentment, the greedy individual acts to acquire more resources, admiration and power, often at the cost of the comfort, livelihood and happiness of other individuals (D'Souza, 1995). As a result, greed comprises an ability to cause profound human suffering. Fromm (1939) quoted famously, "Greed is a bottomless pit which exhausts the person in an endless effort to satisfy the need without ever reaching satisfaction". According to D'Souza (1995), greed has a potential to cause sufferings at (local) community level as well as global (wider) level. At the global level, possible outcomes of greed and self-indulgence are manifested in the form of wars, extreme poverty, social instability, invasions, massacres, over-population, economic crises and climate change (D'Souza, 1995).

It is interesting to understand the epistemology of greed and acquisitiveness. The greedy people are supposed to have biological, psychological and sociological drives (D'Souza, 1995). The American Psychiatric Association (APA) articulated that greed is closely associated with biological and psychological disorders such as Narcissistic Personality Disorder (NPD), substance addiction, behavioral addiction, Obsessive-Compulsive Personality Disorder (OCPD) and Anti-Social Personality Disorder (ASPD) (Angres and Bettinardi-Angres, 2008; American Psychiatric Association, 2000). Can we relate these disorders with the state of addiction? The research on addiction suggests that disturbed balance of neurotransmitters and hormones (e.g., dopamine) can be attributed to substance addictions (Salamone, 1992; Crews, Zou and Qin, 2011; Kauer and Malenka, 2007). Psychiatrists established that behavioral or soft addictions have neurobiological correlation to dopamine (Di Chiara and Bassareo, 2007; Girault and Greengard, 2004; Brewer and Potenza, 2008). Camarena *et al.* (2001) and Denys, Zohar and Westenberg (2004) have created

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an evidence linking Obsessive-Compulsive Personality Disorder (OCPD), dopamine and serotonin hormonal regulation. Anti-Social Personality Disorder (ASPD) is found being caused by high testosterone and low serotonin levels in human body (Black, 2007; Sjöberg *et al.*, 2007). Famous psychologists, Freud and Maslow, recognized greed as a mental disorder and they strongly correlated the greed with narcissism and meta-pathology (Schultz and Schultz, 2004; Freud, 1914). Narcissistic Personality Disorder (NPD) is also believed to be primarily a psychological problem originated in an individual generally through negative childhood attachment styles (Groopman and Cooper, 1995), though inheritance and sociological factors also contribute to its development (Schulze *et al.*, 2013). Usually, majority of individuals suffering from NPD does not seek any solution as they do not treat this problem a, illness (Golomb, 1995). To understand the concept of greed and acquisitive behavior, psychoanalyses reckons that there is a strong correlation between early negative attachment styles and acquisitive behavior (Nikelly, 2006).

Beyond medico-psychiatric analysis, phenomenon of globalization can be linked with the greed through the capitalism, which is master driver for self-interests and the quest for profits. The force of capitalism demands the use of advertising bombardment for goods and services, and massive advertising leads to high competition, envy and acquisitiveness (Lasch, 1991; Holbrook, 1987). Paradoxically, in a capitalistic society, narcissism and self-interests are admired rather than rejected. Nikelly (2006) argues that vast economic and social inequalities in a society lead to severe problems of mental and physical health that develop gradually into mental disorders and addictions.

Environment

A “common heritage of mankind” is the tag used for the environment. The environmental issues are increasingly the cross-boundary and global issues, since it is impossible for one national alone to tackle these problems (Basler, 2011). The globalization is a process considered manifesting local and global environmental crises at massive scale; therefore, the problems emanating from the global economic crisis are now beyond the scope of national and regional frameworks. They are evidently global. Expanded especially after 1991, globalization brought in growth of international trade and financial surges, coupled with extended cooperation among countries and innovations in the sphere of science and technology. However, it has brought in enormous environmental destruction wherever it has occurred (D’Souza, 1995). Ilić and Hafner (2015) identified main causes of environmental problems to be the industrial production, development of traffic, growth of energy production, development of technics and technology, unprecedented exploitation of natural resources, and chemical contamination of soil and foods. Today, civilizational development has inevitably caused the gradual emergence of global warming and climate change on the planet (Ilić and Hafner, 2015).

In November 2013, the World Economic Forum commissioned a Global Risks Perception Survey (GRPS) involving 1,000 experts of economics, society, geopolitics, environment, and technology (Schwab, 2014). This GRPS identified 3 out of 10 top risks pertaining to environment: water crises, failure of climate change mitigation and adaptation, and extreme weather events. So, explicitly, the environment occupies one-third space among all the consequences that come up from globalization process. An overwhelming scientific literature clearly spelts out that the climate change occurs primarily due to surge of greenhouse gases produced as a result of anthropogenic activities (Change, 1996). It is known from many decades that greenhouse gases are emitted from industries, transport vehicles, combustion engines, and deforestation. But the world has failed mitigating climate change (Olivier, Peters and Janssens-Maenhout, 2012). More of this mitigation failure is attributed to free market capitalism carried over by excessive consumerism and corporate profits (Newell and Paterson, 2010; Klein, 2011). Precise example of greenhouse gases and resulting climate change is of developed road traffic. In other words, globalization, as a planetary process (Siriner *et al.*, 2011), has catalyzed the development of traffic. The transport infrastructure has, in turn, created a series of environmental problems, e.g., increased air pollution, high noise levels, taking up space, and unabated release of harmful and hazardous substances. In particular, traffic vehicles are mostly dependent on oil, which builds 14% of emissions into the atmosphere containing harmful gases that affect

human health (Radić Jovanović *et al.*, 2012). Thus, application of modern technology greatly contributes to global warming and increased emission of harmful gases. The global warming is a problem of ecological nature and disturbs vital functions of the planet Earth. Cited examples are the chief drivers of the resource use and exploitation, which directly spoil environmental quality and create significant environmental problems. The resource depletion beyond a threshold diminishes its ability to regenerate, brings thereby threatening with disappearance of resources (Ilić and Hafner, 2015).

For our daily life, globalization is perceived having far-reaching consequences. Is it boon or bane having faster access to technologies, effective communication networks, and bountiful innovations? There is a simple equation: development of technics and technology leads to industry evolution, development and proliferation, which adversely affects the environment. A stark example of technological advancement affecting the environment is the green revolution in agriculture. In a bid to accomplish higher agricultural production and protect the plants against pests and diseases, toxic chemicals are dosed into cropfields causing the contamination of whole agroecosystem. Notably, the use of chemicals to destroy weeds and other unwanted plants disturbs the balance in the agroecosystem. The food products obtained after the application of toxic chemicals in agriculture are proved to be very harmful to human health (Ilić and Hafner, 2015). As discussed above, the climate change is caused by anonymous human activities. To understand better the climate change, discussing weather variations seems important. Of late, weather's extreme events are observed more frequently. Heat waves, cold waves, and significant unseasonal and unusual tropical cyclones cause immense damages. The direct effects of extreme weather events can include famines, landslides, floods, draughts, and large-scale destruction of property and the ecosystem. According to the Intergovernmental Panel on Climate Change (IPCC), economic cost of extreme weather events has risen since 1980 (Meehl *et al*., 2000). IPCC and countless scientists have attributed extreme weather to human-induced temperature rise and greenhouse effects (Hansen *et al*., 2000).

Nothing has caused faster apparent impact than the water scarcity, which is supposed primarily caused by over-utilization of water, climate change, increased pollution (Postel, 1997). This is a global problem now and can be attributed to either physical water scarcity or economic water scarcity. Economic water scarcity is connected to human greed and tendency to grab the resources. It is triggered by poor water management, corrupt governments, lack of property rights, bureaucratic inertia, overconsumption, and shortage of infrastructure investment (United Nations, 2006; Zetland, 2011). The water scarcity ultimately leads to the food insecurity. As the economists articulate, food insecurity is a product of the land degradation, global water crises, land grabbing, agricultural diseases, climate change, political corruption, and infringement of food sovereignty. Explicitly, almost all of the causes are directly attributed to corporate control and political powers that take over lands for the sake of profits. Amon all these causes, land grabbing typically can be traced within countries and transboundary. Internationally, wealthy countries and powers purchase and acquire land in poorer countries in the name of corporate agriculture or industrialization. Blas and England (2008) informed that several middle eastern and western powers were involved in grabbing land in backward African countries. Similarly, political corruption in Sub-Saharan Africa has caused massive famines (Cunny and Hill, 1999). When we look behind, it is observed that the negative impacts of globalization on the environment overtake the positive ones. As explained in preceding para, the environmental destruction is not confined to national boundaries, rather it is transboundary and export oriented. Economic demand in one rich country induces the export of natural resources from poor or developing countries. For example, massive deforestation is going on in Ukrainian and Romanian Carpathians to export the wood to EU countries. Likewise, in Australia, about 90% of native forest trees is exported, thus destroying the natural heritage of Australia.[1] Moreover, according to WWF, the process of civilization and globalization has engulfed one-half of the forests once covered the Earth (Ilić and Hafner, 2015).

A discussion on how global environmental governance addresses the transboundary environmental damages is necessary. There must be an international body to address global problems and risks related to the

[1] https://www.bushheritage.org.au/who-we-are/our-challenge/land-clearing

environment, national conflicts, the global economy, geopolitics, and global political issues. Despite a number of global institutions i.e., World Bank, United Nations, International Monetary Fund, International Criminal Court, World Wildlife Fund, World Trade Organization, G-8, and North Atlantic Treaty Organization, exist, the greed-caused global environmental problems are not addressed adequately. Barnett and Duvall (2005) described this as the main reason behind failure of global governance to be attributed to power struggles between the developed countries being controlled by the global financial sector. Evidently, global destruction of the ecosystems and natural environment are directly or indirectly linked to unprecedented chronic human greed and self-indulgence. Undoubtedly, unencumbered chronic greed of a few elite institutions led by top capitalists has put the entire planet in havoc and infiltrated widespread sufferings at the global scale. In the same fashion, the greed is manifested at the community level too, as it causes same destruction at the local level (D'Souza 1995).

Conclusively, psychological basis of environmental problems has a sociological and socio-historical scope within the frame of globalization. With this backdrop, it is noted that globalization occurs in all areas of life, primarily in the economic, political, cultural, and psychological spheres (Smrečnik, 2002). Nevertheless, the environmental crisis refers to the global "invasion" on ecosystems, that is, the man's immoral behavior towards nature (Malešević, 2004). Psychological account of the environmental crisis is explained subsequently.

Psychology of Environmental Destruction

An interplay of varied human behaviours cumulatively acting as drivers is responsible for the degradation of ecological components in the nature. It is the complex attitude of man to nature that has caused the destruction of forest resources, exploitation of ores and minerals, and extinction of countless species of flora and fauna. The energy consumption for industrial purposes has multiplied in less than a decade. Scholars predict that non-renewable energy sources, such as oil, will completely disappear by the end of the 21st century (Malešević, 2004). Truly articulated that man is the only creature on Earth who is destroying own survival through consumptive and destructive attitude towards nature. In Davies' opinion, economics is the discipline that describes the way in which humans interact with the nature while ensuring the production and reproduction, which means that there is no environmental issue independent of economic relations (Davies, 2006). Since the advent of industrial society, it emphasized on maximum exploitation of nature and the environment, in order to extract maximum profits, while morality is usually ignored. With such exploitative attitudes of greedy humans, the significant destruction of nature occurs. Considering this background, Lomborg (2009) advocates for a radical change in the values and systems. Some call that Earth can be saved by promoting and imposing a spiritual dimension of environmental culture, which includes knowledge and habits, acceptance of norms about natural and social environment, adopted values, attitudes and beliefs, health care norms, and norms for quality of life (Koković, 2010).

According to Steg and Vlek (2009), "environmental behavior is driven by any or combination of three key factors: motivational factors (i.e., perceived costs and benefits, moral, and normative concerns and affect), contextual factors, and habitual behavior". More elaborate views are given by Stern (2000) who identified "four causal variables for a given environmental behavior: attitudinal factors; contextual forces; personal capabilities; and habit or routine behaviors". Steve Taylor, in his book *Back to Sanity*[2], suggests that human beings may be collectively suffering from a psychological disorder ('humania'), and their reckless abuse of the environment is one of the foremost evidences (Taylor, 2014). He quoted the example of the Indigenous people how they have been consistently appalled by American white people's lack of respect for the natural world, and a systematic abuse of nature by them. Taylor (2014) further quotes Chief Seattle comparing the white man, over 150 years ago, to "a stranger who comes in the night and takes from the land whatever he needs". Having a great foresight, Chief Seattle warned then US President Franklin Pearce that his people

[2] http://www.amazon.com/Back-To-Sanity-Healing-Madness/dp/1848505477/ref=pd_sim_b_1?ie=UTF8&refRID=0JK02F53603SMK1JT7GK

"will devour the Earth and leave behind only a desert" (Taylor, 2014). Taylor (2014) has described psychological causes of human's abusive and exploitative attitude to nature. He explained two main psychological factors. The first, "over-developed sense of ego" is the intensified sense of individuality. He explained it by differentiating between western so-called "civilised" peoples and the nature-loving tribal Indigenous peoples. The Indigenous cultures have polytheistic diversity liked world visions. Usually, the Indigenous peoples do not exist as self-centric person, selfish being and egoist individuals. They reflect a collective and community identity embedded with their land. Taylor (2014) quotes the anthropologist Silberbauer who explained features of G/wi people of the Kalahari Desert of Africa. G/wi people bears an identity grossly 'group-referenced' rather than individual; resultantly, these Indigenous individuals identify themselves representing their kin or community group instead of their solitary identity (Silberbauer, 1994). Similarly, Boydell (2001) elaborated the Indigenous peoples of Fiji having a concept of "self-embedded-in-community [which] contrasts with the western value of individualism with its idea of the self as separate and separating from others". Such collective values underlie Indigenous peoples' strong belongingness to their land. They attribute their life to the land. The Fijian anthropologist Ravuva (1983) exclaimed that Fijian's attachment to their *vanua* or land is "an extension of the concept of self. To most Fijians the idea of parting with one's *vanua* or land is tantamount to parting with one's life". On the contrary, modern societies are full of heightened sense of individuality that sows duality and separation inherently. It cages our souls within our own egos. In the words of Taylor (2014), "we perceive nature as something other that we see natural phenomena as objects which we are entitled to use for our own devices".

Next is the 'de-sacralised' vision of nature is the modern man's inability to sense the natural processes. Our vision in the childhood has intense vividness and a liveliness, but our adulthood changes the perceptions of the world to become de-sensitised and automatic. It means the world transforms to a shadowy, one-dimensional place full of material and source of materialism. In the eyes of Aboriginal people, we the modern society lose the ability to dream natural being around us. It ultimately pushes us to treat natural phenomena as objects. Implications of this vision transformation from childhood to adulthood leads humans not to have any qualms about abusing and exploiting the natural world, tearing up its surface in search of resources and polluting it with our waste (Taylor, 2014). Thus, this psychological interpretation tends to change our dilemma even more dismal. To suggest a solution to this psychological problem, Taylor (2014) adds that "only sure way of ensuring our survival as a species would be for us to undergo a psychological shift – specifically, to transcend our sense of separateness and regain a sense of connection to nature and a "sacralised" vision of the natural world".

Case Study of Forest Destruction in Romanian and Ukrainian Carpathians

Not only in Carpathian Mountains, but in entire eastern Europe, the primary forests were existing in large areas. Some of the areas still have these primary forests. However, deforestation in Carpathian areas is rampant under the nose of the EU and domestic law enforcement agencies.

Lehermayr, Reinhart and Kaiser (2020) exposes, *"Quantum of destruction of is horrific: 40 tree trunks every minute, 2400 every hour, 28,800 every shift. Virgin forests in Central-Eastern Europe are the last remaining ones on the continent, yet they are being mercilessly torn down. Part of this multi-billion Euro industry is a mafia-like system; Austrian timber companies are right at the heart of it".* According to Lehermayr, Reinhart and Kaiser (2020), insatiable hunger for wood of an Austrian man, Gerald Schweighofer, has caused massive destruction in Carpathian Mountains of Ukraine and Romania. An environmental journalism group, Addendum[3], investigated and exposed the forest destruction performed by Austrian company, Schweighofer, in Carpathian areas. Many governments including Romania and Poland have strictly monitored the activities of this Austrian company because of serious suspicion of involvement in the illegal logging of the last remaining primary forests in Eastern Europe. After the Addendum ran a campaign against

[3] https://www.addendum.org/

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Schweighofer, it has been removed from prestigious Forest Stewardship Council[4] (FSC) certification of sustainably produced timber. An FSC investigation report claimed a "clear and convincing evidence" that Schweighofer was "involved systematically […] directly and indirectly, in the trade of timber which has been harvested and/or handled in violation of existing laws and regulations" (Lehermayr, Reinhart and Kaiser, 2020). Today, Gerald Schweighofer has a palace like home in central Vienna, and after 2002 he sold his sawmills in Austria to build vastly bigger structures in Romania. The Romanian politicians welcomed him, and he now has more than 3000 staff, a turnover of 762 million Euros and 5 factories in the country, producing pellets and sawn, glued and profiled timber supplied throughout the world (Lehermayr, Reinhart and Kaiser, 2020). With annual turnover of more than 2 billion Euros, Kronospan is another company, which is world's biggest manufacturer of wood-based panels supplying to Ikea. Operating jointly with Swiss Krono, the Kaindls[5] is one of the main players in the Carpathians. Perhaps the Egger is largest global concern having 18 sites in 8 different countries.

The Global Forest Watch[6] has estimated that 317,000 hectares of Romanian forest were lost to logging between 2001 and 2017. Since 2003, nearly 260 million Romanian trees have cleared. About 38.6 million cubic metres of timber was taken from Carpathian forests between 2014 and 2018 (Lehermayr, Reinhart and Kaiser, 2020). It is articulated that half of these trees were in national parks or conservation areas. The forest utilisation plans of Romania permitted just 18 million cubic metres of wood, which means total amount felled was twice the legal limit. Remaining 20 million cubic metres of timber was actually extracted by mafia timber (Lehermayr, Reinhart and Kaiser, 2020).

Describing the process of stealing the timber right at the site of operation, Mihail Hanzu, a qualified forestry engineer who used to be Forestry Inspector for a municipality near Sibiu, told to Addendum, "It was a whole system, from the mayor to my colleagues in the forestry department. I found more than 50 ways they were going about their fraud. The most common one was by deliberately understating the volumes. They mark a tree for felling. Write in the documents that it measures 18 metres, even if it actually measures 40, and that it has a diameter of 25 centimetres, even if it is actually 50. There is a great deal of money in that difference, and that money flows into their system. The municipality issues a licence for the logging, the companies sell the timber to middlemen, who store it in their timber yards and later deliver it to the sawmills along with all the necessary legal declarations" (Lehermayr, Reinhart and Kaiser, 2020). In the words of David Gehl from the Environmental Investigation Agency (EIA), a US NGO investigating the predatory exploitation of nature throughout the world, "While the deforestation of the Amazon rainforest has been horrifying people for years, hardly anyone realises that Europe contains remnants of virgin forests that are just as important. The fact that the majority of these are on our doorstep, in the Carpathians, and are under threat remains an untold story." The EIA reports spot Schweighofer for having been the "biggest receiver of illegal timber" and having "lied about the source of its products for more than 10 years". Schweighofer receives timber from various sources, including Slovakia, the Czech Republic, Ukraine. Johannes Zahnen, a forestry expert with the WWF, pointed out that 2013 EU Timber Regulation[7] has failed addressing cross-boundary deforestation, though it was supposed to stop the illegal timber trade in the EU region (Lehermayr, Reinhart and Kaiser, 2020).

Ukraine is an important timber supplier country. The Ukrainian railway reaches directly to the doors of the Schweighofer and Egger factories in Rădăuți, north of Romania. An environmental organisation Earthsight[8] discovered in 2018 that Schweighofer alone was receiving 80 railway wagons every day from Ukraine. In Hungary, Kaindl family has opened a new chipboard factory right on border with Ukraine. In the Ukrainian Carpathians, one can witness bald forestlands. "In order to keep the timber well below the market price, foreign companies were willing to make payments to letter-box companies

[4] https://fsc.org/en/about-us
[5] https://www.addendum.org/holzmafia/kaindl-kronospan/
[6] https://www.globalforestwatch.org/
[7] https://ec.europa.eu/environment/eutr2013/index_en.htm
[8] https://www.earthsight.org.uk/

registered in Belize and Panama in the name of his wife," says Tara Ganesh from Earthsight (Earthsight, 2018a). "The head of the forestry authority is accused of having pocketed bribes from four timber companies to the tune of 13.6 million Euros between 2011 and 2014" (Earthsight, 2018a). The Earthsight (2018a) reported that "ghost trains" having false papers and full loads of logs find their way across the border with Romania at night. A forestry director was caught red-handed offering police officers $10,000 "tribute money" to turn a blind eye to illegal logging activities. Since only Ukrainian firewood and sawn wood can be exported, exports of such woods are on rise. There is a trick in this too. Higher quality timber is deliberately declared a lower grade wood, purely falsely. The greedy criminal system behind such nexus is so strong that it engages into corruption various actors at all levels – from lawyers to bankers, and from forestry directors to customs and state railway officials. The WWF inspected 149 sites over 18 months and estimated that as much as 1.4 million cubic metres of timber is being illegally felled in the Ukrainian Carpathians alone each year, compared with 4 million cubic metres of official harvesting (Earthsight, 2018b, 2018c). Anonymous sources in the government reiterated, "The forest control system in Ukraine is not functioning properly. There are fundamental problems with how felling licences are being issued in Ukraine, in particular as regards approvals for sanitary felling. It should be unthinkable that an enterprise is in charge of issuing a felling licence for its own operations, which is currently the case for all sanitary felling" (Earthsight, 2018a). The EU is by far the largest destination for Ukrainian wood exports, representing 70 per cent of the total. EU purchases have been rising rapidly, breaking 1 billion Euro in 2017. Earthsight estimates that at least 40 per cent of this wood was harvested or traded illegally (Earthsight, 2018a).

Conclusion

What is overall learning from the analytical account of this interrelationship of the greed, globalization and environmental catastrophe? The greed of acquiring resources, money, materials and power is very common and not restricted to one or two persons. Sometimes, the whole society is psychologically sick. Everyone wants to gain one benefit or the other in a chain of nexus. Yet, the champions of greedy society are undoubtedly the top capitalists operating the global institutions and controlling the chains of globalization down the line. Hence, the implications of greed are not only economic, but also social, psychological and, ultimately, environmental. So-called civilized world has damaged the planet most; this is witnessed when comparison is done with already existing examples of infringed and threatened Indigenous societies. There can be series of theoretical recommendations to address the greed syndrome by a human at psychological level. However, it might be futile exercise, as the human learns from his/her mistakes and its grave implications.

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Farmers' Trait Preferences for Varietal Replacement: A study to boost rice productivity in Odisha, India

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Abstract

The average age of the popular rice varieties being grown in the state of Odisha is higher than the stipulated 10-year timeframe. This is an obstacle to productivity enhancement through varietal replacement. Farmers in Odisha growing these varieties have expressed their desired traits for replacement of these long-grown varieties. The desired characters of an ideal variety have been mapped for major older varieties. Since varietal fitment and farmer's choice vary widely between rice eco logies, the research outcomes were compartmentalized between medium and lowland. Thus, these research outcomes will be crucially helpful for breeding program to develop varieties that match evinced expectation of the farmers. The ranking of trait preferences will also augment the varietal research program to the exact needs of the rice growers in the state. Rice productivity in Odisha is one of the least in the country. Replacement of existing older varieties with a high yielder as per farmers' choice is a strategic way to boost the productivity. The findings with regard to current varietal landscape, farmers' trait preferences are crucially important for augmenting rice productivity and strengthening food security in the state.

Keywords

Varietal replacement; Food security; Varietal landscape

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Introduction

The productivity enhancement of rice, being the staple food, overarches the food security program in a state like Odisha. The rice productivity in Odisha is stagnating at 2.04 tons per ha[1] throwing enormous challenge to feed 45 million people in the state. Substantial increment of rice productivity assumes greater significance among policy makers that results in new agriculture initiatives in the state, directed towards boosting rice yield.

Plant breeders across several research institutes are relentlessly engaged in developing new rice varieties, which primarily focus on yield improvement. But research gap exists with respect to the link between rice growers and breeders. Numbers of high yielding varieties (HYVs) are being intensively grown in the states of India, but many of them are quite old (more than 10 years) that require a replacement. A farmer considers a range of parameters other than yield while replacing the old variety by a new variety. Thus, the farmer's preferences are of paramount importance and to be included sufficiently in new variety development strategy (Dar *et al.*, 2014). In the current breeding program specific to the state of Odisha, many a times, breeders develop and release varieties without taking a broad cognizance of farmers' preferences. Though with a 'push' extension mechanism those varieties are adopted by farmers, to some extent, in a short run, but not accepted in the long run. Because of this very reason, those newly developed varieties soon become redundant in the seed system of the state and farmers hardly get the varieties of their choice. This scenario not only inefficiently utilizes resources at breeding program but also jeopardizes state's ambition to attain food security through varietal replacement. The concept of participatory plant breeding (PPB) with larger say of farmers is increasingly being adopted worldwide (Ceccarelli and Grando, 2009). This is more relevant in context of Odisha where participation of farmers in plant breeding program is largely negligible.

Keeping in mind this issue and extent of problems, present study was conducted in Odisha to produce evidence-based critical inputs that can strategically strengthen existing breeding program with farmers' choice and preferences. The specific objectives of the study were as follows:

I. To generate ecology wise current varietal landscape of Odisha to comprehend varietal spread across regions in Odisha;
II. To analyse farmers' desired traits in the varieties to replace currently grown older varieties; and
III. To prioritize farmers' preference of traits in selecting a new variety.

Methodology

This study was conducted during Kharif[2] season of 2018-19 in 12 districts of Odisha in two main rice ecologies, viz. lowland and upland. Among the 30 districts of the state, 12 districts were selected in such a way that represent both upland and lowland districts. Total 8 districts fall under upland belt and 4 under lowland areas. From each district, 4 blocks were selected randomly following SRSWOR[3] method and 15 farmers from each block were chosen in random manner. Thus, total sample size was 720 comprising of 480 farmers from upland districts and 240 from lowland districts. Mobile smartphone-based data collection tool, 'Kobo'[4] was used to gather data through a pre-tested questionnaire by well-trained 20 field investigators. Collected data were monitored and verified on daily basis to ensure highest possible level of accuracy.

To attain first and second objective as explained in 'Introduction' part above, descriptive statistics were used. For prioritization of trait preference in new varieties, Garrett's ranking tool was employed. As against the simple frequency distribution, Garrett's ranking tool arranges the constraints based on their severity as perceived by the respondents (Zalkuwi *et al.*, 2015). The percent position of each rank was converted into

[1] Directorate of Economics and Statistics, DAC&FW, 2020
[2] Kharif season, also known as wet season, starts in June and ends in October.
[3] Simple random sampling without replacement.
[4] A widely used mobile based data collection tool (https://www.kobotoolbox.org/).

scores using Garrett's table. For each constraint, scores of individual respondents were added together and were divided by total number of respondents for whom scores were added. Thus, mean score for each constraint was ranked by arranging them in descending order.

$$\text{Percent position} = \frac{100\,(Rij-0.05)}{Nij}$$

Where,
Rij is the rank given for ith item by jth individual,
Nij is the number of items ranked by the jth individual.

Results And Discussion

Farmers' profile

Respondents were profiled based on key parameters separately for two ecologies. Their characteristics are described as below:

Below poverty line: In lowland districts, 62.92% respondents were below poverty line (BPL) category, whereas 74.58% were in BPL category in upland belt.

Caste: The prevalence of other backward caste (OBC) was more (77.08%) in lowland districts compared to that of upland areas (36.88%). There were no scheduled tribe (ST) found in lowland areas, but in upland districts the STs were 50.42%. The scheduled caste (SC) representation in lowland was only 9.58%, while in lower upland areas it was 6.04% (Table 1).

Gender: The respondents were gender-segregated, and it was found that, in upland areas, 57.71% were males with 70% males in low land districts.

Age and Education: The mean age of farmers was 47 and 42 years, respectively, in lowland and upland districts. Table 1 further reveals that education level of respondents from lowland belt is little higher than upland region.

Categories of Farmers: As usual proportion of marginal farmers having land size of less than 1 ha was high in both the ecologies. Marginal farmers constitute 61.67% and 56.67%, respectively, in lowland and upland regions.

Table 1. Distribution of respondents over important socio-economic parameters

Ecology	*No*	*%*
Lowland	*240*	*100*
Non-BPL (Below Poverty Line)	89	37.08
BPL	151	62.92
General	30	12.50
OBC (Other backward Caste)	185	77.08
SC (Scheduled Caste)	23	9.58
Other	2	0.83
Male	168	70.00
Female	72	30.00
Marginal (less than 1ha)	148	61.67
Medium (4-10 ha)	6	2.50

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Ecology	*No*	*%*
Semi Medium (2-4 ha)	19	7.92
Small (1-2 ha)	67	27.92
Mean Age (years)	47	
Mean education years	8	
Upland-Medium	*480*	*100.00*
Non-BPL	122	25.42
BPL	358	74.58
General	32	6.67
OBC	177	36.88
SC	29	6.04
ST (Scheduled Tribe)	242	50.42
Male	277	57.71
Female	203	42.29
Large (more than 10 ha)	2	0.42
Marginal (less than 1ha)	272	56.67
Medium (4-10 ha)	5	1.04
Semi Medium (2-4 ha)	44	9.17
Small (1-2 ha)	157	32.71
Mean Age (years)	42	
Mean education years	6	

Current varietal landscape

Lowland districts

This study is aimed at creating a varietal landscape for both lowland and upland districts. The analysis revealed that Pooja[5], Swarna[6], Swarna sub-1[7], CR 1018[8], CR 1009[9] and Kalachampa[10] Sarala were the main varieties preferred and grown by farmers in lowland districts during the wet season. In terms of spread, 25.83% farmers have grown Pooja, closely followed by Swarna (24.58%) and Swarna sub-1 (21.67%). In fact, these three varieties together were grown by 72.08% of all farmers. The other reported varieties like CR 1009 (4.58%), CR 1018 (5.83%) and Bina dhan 11[11] (5.00%) were also grown by some of the farmers. Swarna sub-1, a recent breeding innovation as a submergence tolerant variety, has gained popularity among farmers. This is corroborated by the seed sale trend of Swarna sub-1 as evident from secondary seed sale

[5] A late maturing rice variety for lowlands
[6] A widely grown variety in eastern India, matures in 135 days
[7] A submergence tolerant variant of Swarna, popular in flood prone areas of eastern India.
[8] Also known as Gayatri, a long duration bold grained variety
[9] A long duration variety, suitable for waterlogged conditions
[10] A long duration, semi-dwarf variety, grown in rainfed and irrigated shallow lowland
[11] A medium duration variety, suitable for both wet and dry season. More details about these varieties are available at https://www.rkbodisha.in/rice-varieties-of-odisha

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data obtained from Department of Agriculture and Farmers Empowerment. The seed sale of Swarna sub-1 rose from 12,232.8 quintal to 33,142.5 quintal indicating the adoption of this variety in the state[12].

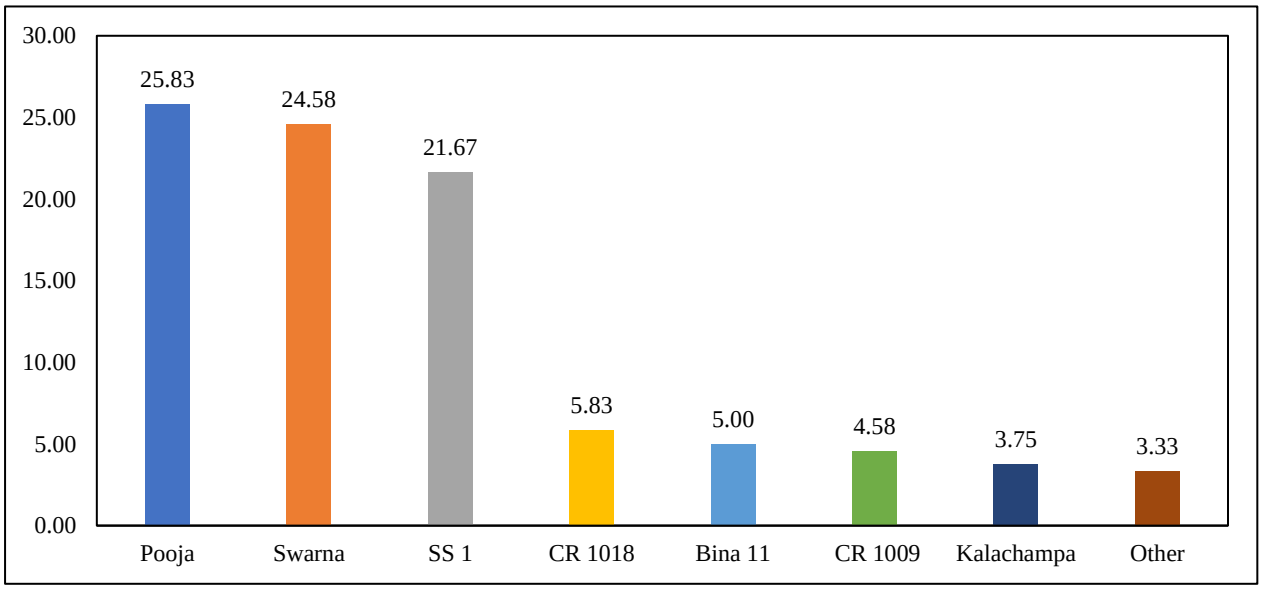

Figure 1: Percentage of farmers growing different varieties in lowland districts

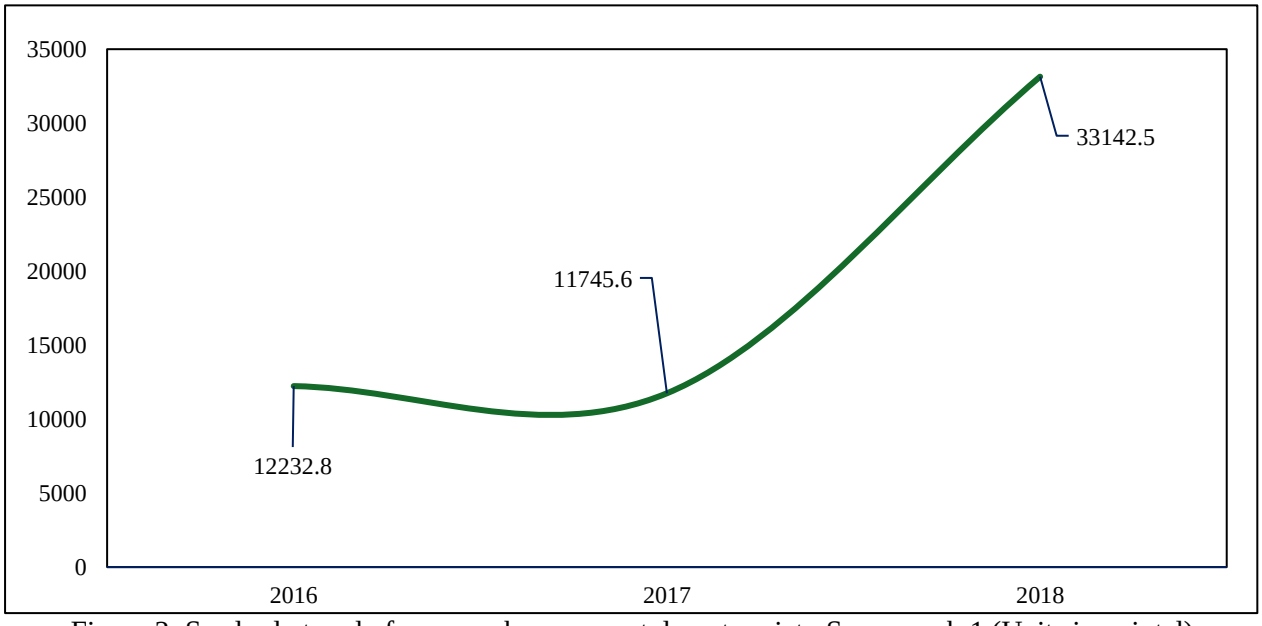

Figure 2: Seed sale trend of a new submergence tolerant variety Swarna sub 1 (Units in quintal)
(*Source*: Odisha State Agriculture Department)

[12] Unpublished data accessed from Department of Agriculture, 2018

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Upland-Medium districts

In upland and medium districts, major varieties grown by farmers were Swarna (26.25%), MTU 1010[13] (20.63%), MTU 1001[14] (16.46%), Lalat[15] (8.75%). Other important varieties preferred by the farmers in this rice ecology were Pratikshya[16] (7.92%), Sahabhagi[17] (5.21%) and DRR dhan 44[18] (2.5%). Among these, Sahabhagi was drought tolerant variety recently introduced in the seed chain of the state and quickly received acceptance by farmers as evident from the sales records of state seed corporations. Surprisingly, a large number (10.2%) of farmers reported growing Swarna despite its longer duration of maturity and water scarcity in upland ecology. Swarna, a lowland specific variety, is misplaced by farmers in upland belt (pers. comm. Dr. D.D. Sinha). This calls for a strategic approach in mobilizing farmers for best fit varietal selection. Sahabhagi is a recent short duration drought tolerant variety that has made inroads in upland areas for its ability to withstand water scarcity. The increasing sale trend of new variety Sahabhagi (Figure 4) proves its fast adoption in this ecology.

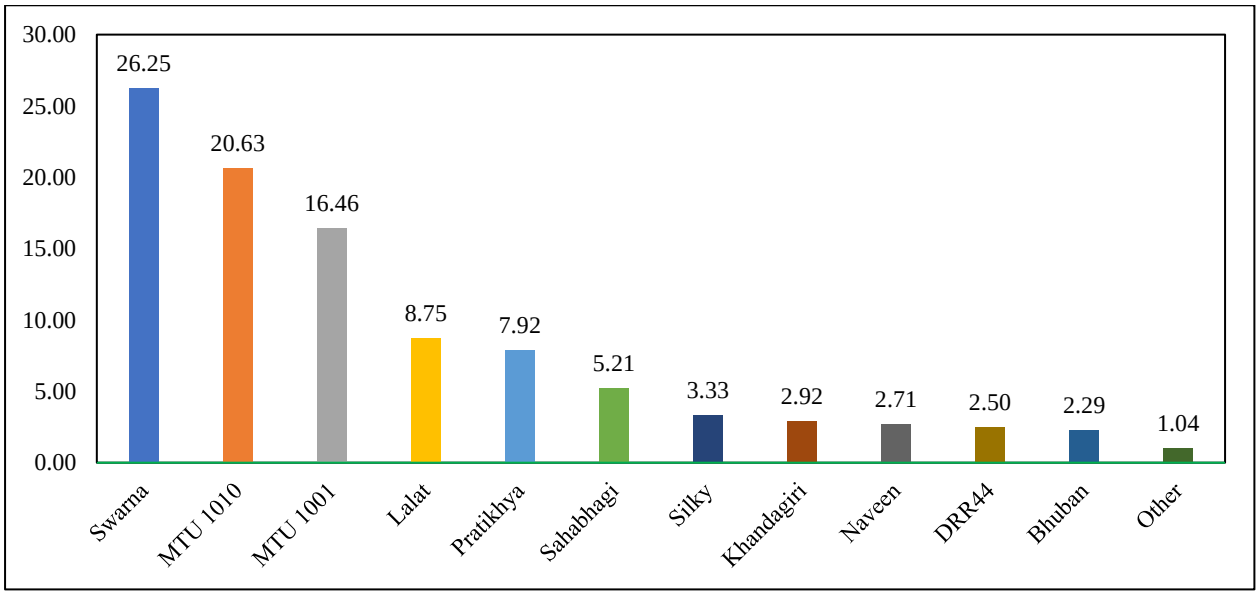

Figure 3: Percentage of farmers growing different varieties in upland-midland districts

Farmers' trait preferences in two ecologies

Lowland ecology

CR 1009

This is a popular high yielding variety in the districts like Bhadrak, Puri, Kendrapara and Jajpur. But farmers want a replacement with a variety a week shorter in duration and potential to give a yield of 6.5 tonnes per ha. The grain size preference is small bold, which is the character of CR 1009. Therefore, if a breeder designs strategy to replace CR 1009 with a better one, s/he must take duration and yield preference into consideration. About 36.8% farmers have expressed their choice for CR 1009 sub-1, an improved version of CR 1009.

[13] A semi dwarf mega variety cultivated in irrigated and medium lands
[14] Popularly known as Vijetha, suitable in both wet and dry season
[15] A semi dwarfed long slender grained variety, adapted in rainfed and irrigated medium lands
[16] A long duration semi dwarf variety, widely cultivated by framers in Odisha, India
[17] A short duration variety suitable for water deficit condition in upland areas
[18] A medium duration variety, recommended in water deficit areas. More details about these varieties is available at https://www.rkbodisha.in/rice-varieties-of-odisha

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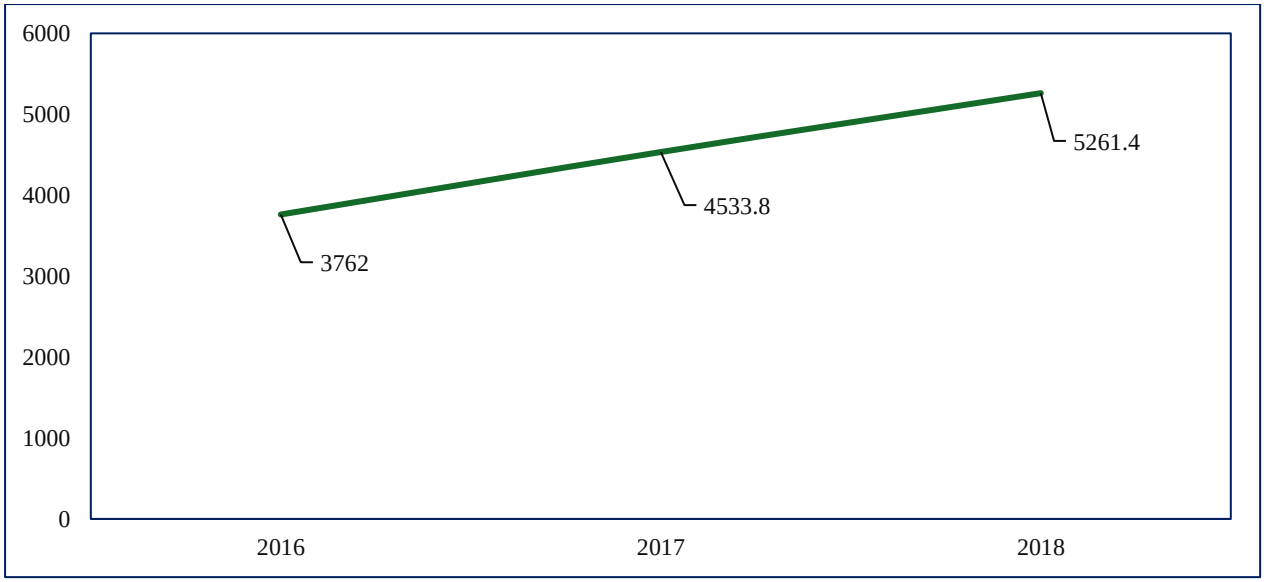

Figure 4: Seed sale trend of a new drought tolerant variety Sahbhagi (unit in quintal)
Source: State agriculture department

Pooja
Pooja is a 150-day popular variety suitable for low lying areas. Current yield potential of this variety is 5 tonnes per ha. As a substitute of this variety, farmers prefer a variety of same duration having yield potential of 5.83 ton with medium slender grain size. Therefore, any breeding program aims to bring a substitute of Pooja must focus, *inter alia*, on yield and grain size.

Kalachampa
Farmers in coastal belt of Odisha are growing Kalachampa (160 days) for quite a long time. Though the variety promises a yield of 6.5 ton per ha, but farmers reported an average yield of 5 ton from this variety. So, farmers expect this variety to be having minimum yield bearing ability of 6.15 ton per ha and it should come with medium slender grain size.

Lalat
Lalat is a short duration variety (120 days) grown in both the ecologies, but not preferred in areas where prolonged inundation is a problem. Farmers who cultivate this variety in lowland areas want to replace with a variety having a maturity in about 130 days. Lalat yields around 4.5 ton/ha. However, in a replacement variety, farmers want minimum yield of 5 tons per ha with a medium slender grain size. Like other varieties, height is not a factor for farmers if yield, duration and grain size choices are met.

Sarala
This is a long duration variety (160 days) widely grown in coastal areas of Odisha having an average yield of 4 tons per ha. Farmers in the region prefer to replace this variety if any variety with 150-days duration can give a yield of 6.22 ton per ha.

Upland and medium land ecology

Swarna
This is one of most popular and widely grown varieties in Odisha. This variety matures in 135 days and yields 5 tons per ha. In low lying coastal region, farmers will prefer a replacement with a variety maturing in 145 days and yielding 5.87 ton with medium slender grain quality. Crop height is not a matter of important

consideration for the farmers. Swarna sub-1 is relatively new in the seed chain and gaining increasing acceptance among farming community of coastal area, as 63% of sampled Swarna growers facing frequent flash floods think Swarna sub 1 is a perfect replacement.

MTU 1001
This mega variety is strongly preferred by farmers in medium high land districts. MTU 1001 has the duration of 130 days with average yield of 5 tons per ha. Farmers growing this variety now prefer a variety having slightly less duration (124 days) and giving a yield of 5.34 ton per ha.

MTU 1010
Farmers growing this variety in medium high land areas prefer a replacement of 116-days variety that can produce average yield of 5.7 ton per ha. Preferred grain size is medium slender and crop height is a redundant factor.

Khandagiri
This is a short duration (90 days) variety suitable for upland ecology. Duration wise, this is accepted by farmers; but its average yield is quite low (3 tons per ha). Farmers need a substitute variety with same duration but with higher yield (3.92 ton per ha) and medium slender grain quality.

Bhuban
Bhuban is another variety grown in medium upland districts of Odisha. It attains maturity in 135 days with yield capacity of 4 ton per ha. But farmers are ready to replace this if a variety with less duration (115 days) with yield potential of 5.2 ton per ha is available.

Naveen
This 120-days variety is widely cultivated by farmers in upland and medium high land districts of Odisha. For its replacement, farmers will prefer a comparatively shorter duration variety (115 days) with yield capacity of 5.2 ton per ha and preferred medium slender grain size.

Pratikhya
This short duration (135 days) variety is currently yielding 4 ton per ha in upland districts. A modification in duration (125 days), medium slender grain size and a yield of 5.4 ton per ha will be strong replacement traits accepted by farmers.

Varietal replacement

The major rice varieties being grown by farmers in Odisha in the cropping seasons are older than 10 years indicating a sluggish varietal replacement rate in the state. Maturity duration, expected yield, grain quality, plant height, resistance to major diseases and pests are key considerations for a farmer in adopting a variety. However, a variation in respect of trait preferences is observed between two rice growing ecologies. While a longer duration variety is sought in lowlands, a relatively shorter maturity variety is preferred by farmers in medium lands. The farmers-preferred traits are critically important as it helps breeding strategy to be more contextual and in line with choices and preferences of rice growers. Below is the description of the result of different varieties in two different ecologies.

Grain size as a varietal trait

Farmers consider grain size as an important criterion for varietal replacement. It has been observed that medium slender grain is mostly favoured by farmers in both the ecologies. In lowland districts, 81% farmers want medium slender grain in new variety. Similarly, 75% farmers demand medium slender grain in new variety in upland and medium land region.

Prioritization of preferred traits

There are several traits that farmers contemplate before selecting or replacing a variety. It was evident that there was not substantial variation in ranking order between two ecologies. The first ranked trait is the yield followed by the duration, resistance of diseases and pests, grain quality and crop height. Interestingly, disease pest resistance trait was placed just after the yield and duration. The corresponding mean Garett's scores in lowland ecology for duration, yield, grain quality, crop height, and resistance to diseases and pests are 61.46, 64.00, 34.13, 31.13 and 59. 29, respectively (Table 2). In upland belt, the same scores are 60.49, 65.15, 34.74, 30.28, 59.36, respectively (Table 3).

This holds importance from plant breeding perspective. A well-designed breeding program should integrate this trait ranking order. This will satisfy tastes and preferences of rice growers of different varieties. Therefore, these traits in order will feed breeding strategy for developing and replacing varieties in different ecologies of Odisha.

Table 2: Garrett's ranking technique for trait preferences by the sample farmers for varietal replacement in lowland districts of Odisha

Factor	*Mean score*	*Rank*
Duration (days)	61.46	2
Yield (t/ha)	64.00	1
Grain Quality	34.13	4
Height	31.13	5
Resistance to diseases and pest	59.29	3

Table 3: Garrett's ranking technique for trait preferences by the sample farmers for varietal replacement in Upland districts of Odisha

Factor	*Mean Score*	*Rank*
Duration (days)	60.49	2
Yield (t/ha)	65.15	1
Grain Quality	34.74	4
Height	30.28	5
Resistance to diseases and pest	59.36	3

Conclusion and Recommendations

Varietal replacement dynamics from farmers' perspective is an integral part of the breeding program for development of improved varieties. The study aims at sketching a current varietal map in two main ecologies — lowland and upland in Odisha. This study also delves into comprehending farmers' preferences about varietal traits in order to replace currently grown major varieties and identify deciding factors that come into play while farmers contemplate varietal replacement. The major varieties grown in lowland region are Pooja, Swarna, Swarna sub-1, Kalachampa and Sarala. In upland and midland ecology, farmers mainly grow Swarna, MTU 1001, MTU 1010, Pratikshya, Lalat, DRR 44 and Sahabhagi dhan. In lowland ecology, for varietal replacement farmers would prefer a variety of 140-150 days with yield potential of 5-6.5 tonnes per hectare. In midland and upland, preference is given to the variety of 90 to 125 days' duration along with yield potential of 4-5.5 tons per hectare. Medium slender grain size is preferred in lowland and midland and upland by 81% and 75% farmers, respectively. Crop height has been proved a non-significant factor for variety selection in both the ecologies. In both the ecologies, the ranking order of factors were yield,

duration, resistance to disease and pest, grain size and crop height. These finding complements the efforts of ongoing plant breeding research and food security programs.

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Author's Declarations and Essential Ethical Compliances

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Adoption of Renewable Energy Technologies and Energy Source Choice of Households

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Abstract

Renewable energy technologies are the best option for rural peoples until hydroelectric power is well disseminated in the country of Ethiopia where critical energy access and supply problems exist with a poorly ventilated cooking places. The current study examined the factors determining households' decision to adopt renewable energy technologies and energy source choices in Boset District. A two-stage stratified random sampling was employed to draw a sample of 210 respondents. Binary logit model has revealed that age, family size, education, income, number of livestock owned, landholding size, and training were significant to adopt technologies. On the other hand, multinomial model has indicated that age, family size, landholding size, income, livestock ownership, education, and training have significant role in the modern and mixed energy choices vis-à-vis traditional energy. The study has suggested that continued training and education are required to enhance households' awareness concerning renewable energy sources.

Keywords

Determinant; Adoption; Choice; Renewable energy; Technologies

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Introduction

Energy poverty at the household level is explained by lack of access to electricity and the reliance on the traditional use of biomass for cooking (IEA, UNDP, and UNIDO, 2010). It is estimated that 1.4 billion people all over the world have no access to electricity, with 85% of them are living in rural areas and 2.7 billion people (i.e., 40% of the global population) rely on traditional biomass energy for cooking (IEA, 2014). Over 620 and 730 million people in sub-Saharan African countries do not have access to electricity and clean cooking facilities, respectively (IEA, 2014). It is projected that 1.2 billion people around the globe will have no access to electricity, and traditional biomass is expected to be used by 2.8 billion people in the year 2030 (IEA, 2014).

The women and children living in unventilated cooking places are vulnerable to critical health problems such as pneumonia, chronic lung diseases, and lung cancer (WHO and UNDP, 2009; Hanawi *et al.*, 2020; Faller *et al*., 2020). Like many other developing countries, Ethiopia has been facing problems of critical energy access and supply. It is estimated that only 23% of the country's population has access to electricity, of which 86% population is of urbanites and only 5% is of rural residents (GIZ, 2015). According to Dereje (2013), traditional biomass energy sources such as firewood, dung cake, and agricultural residues are the major energy source that accounts for more than 90% of the country's energy supply. Resultantly, extensive utilization of forest has led to the depletion of tree stock of the country by 15% (ENA, 2015).

Energy poverty exacerbates in the rural part of the country. Out of total rural residents in the country, more than 95% meet their daily energy needs from unclean and traditional energy sources (GIZ, 2015). In the study area, biomass energy source, especially firewood, constitutes the greater portion of domestic energy supply for both rural and urban areas followed by dung and charcoal consumption (BDFEDO, 2019). Ethiopia has endowed with abundant clean energy sources; however, their development and utilization remained very low (Dawit, 2014). Different empirical studies have been conducted so far by Dawit (2008), Alemu and Köhlin (2008), Yonas *et al*. (2013), Yonas *et al.* (2015) and Gebreegziabher *et al*. (2012) on the determinants of households' energy technology adoption and energy source choice in Ethiopia. The above-mentioned studies have either focused on identifying factors that influence the adoption of energy technologies or addressed the issue of household fuel choice focusing in urban areas.

Having large area and the population, access to the modern energy source is the major impediment in rural parts of Ethiopia. Currently, renewable energy technologies are the best option for rural peoples until hydroelectric power is well distributed in the country. Besides examining the determinant factors of renewable energy source adoption, it is to investigate rural households' energy source choice focusing modern energy sources. Thus, this study was intended to fill the aforementioned gap by identifying factors affecting renewable energy technology adoption and rural households' energy source choice focusing on the utilization of modern energy sources.

Material and Method

The study was conducted in East Shewa Zone of Boset district. The district covers an area of151,406.6 km^2 and divided into 32 rural and 4 town kebeles. The total population accounts for 185,401 (111,572 male and 73,829 female) (BDFEDO, 2019). Boset has a one-season ('Meher') crop production cycle. Mixed agriculture is a common economic activity in the district. The district is known for its renewable energy source potential, especially solar energy. But, the energy source for the district is mainly from traditional biomass; and, firewood constitutes a greater coverage of domestic energy supply both in rural and urban areas (BDFEDO, 2019). This study was conducted in 2019-20.

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Study Design

Cross-sectional survey design was employed incorporating both quantitative and qualitative survey methods. The data collected for this study included both primary and secondary data sources. The primary data of the study was collected directly from technology adopters and non-adopters. The data was obtained using the key informant interviews and focus group discussions. The secondary sources were Woreda's Finance and Economic Development and Energy Offices that provided access to renewable energy technology reports and other documents. Quantitative data was collected directly from respondents using a semi-structured questionnaire. Qualitative information of the study was obtained using interviews and focus group discussions.

Sample Size Determination

The study used formula provided by Anderson *et al*. (2007 to determine required sample size.

$$N = \frac{(z)^2\ (p)(q)}{e^2} ----(1)$$

Where, p = Estimated characteristics of the target population proportion (expected prevalence), $Z_{a/2}$ = 95% confidence level that corresponds to the value of 1.96, e = Proportion of sampling error tolerated at 0.05, q=1-p. Based on the information provided by the District Finance and Economic Development Office, the expected prevalence of technologies' dissemination in the district is 15% (BDFEDO, 2019). Thus, using p = 0.15, the value of q becomes 0.85; taking these numbers in the above formula, the sample size of the study comes:

$$N = \frac{(1.96)^2(0.15)(0.85)}{(0.05)^2} = 196$$

By considering 7% non-response rate, the total sample size was 196+14 = 210.

Sampling Technique

Two-stage sampling technique was employed to draw sample households. First, using information obtained from Boset District Energy Office, major, medium, and lower technologies' adopter kebeles were listed and stratified accordingly. Then, from each stratum, two study kebeles were selected using a simple random sampling method which resulted into a total of 6 kebeles. Finally, using the calculated sample size, all randomly selected kebeles were included in the study with their total number of households. Study participants from each kebele were included in the study using probability proportional to their size (PPS). Each technology user and non-user was selected using a simple random sampling method.

Method of Data Analysis

The study employed both descriptive statistics and econometric model to analyze the collected data. To run statistical analysis, data were coded and entered a computer program, i.e., SPSS package. Both binary logit and multinomial model were employed to investigate the issue under question. Moreover, data collected through key informant interviews and focus group discussions were analyzed using textual analysis.

Results and Discussion

The survey result shows that from a total sampled respondents about 193 (91.4%) respondents were male-headed households and the remaining 18 (8.6%) respondents were female-headed households. The mean age and family size of sample households were 41.98 and 5.52, respectively (Table 1).

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Table 1: Descriptive Statistics of Sample Respondents

Explanatory variables	*Minimum*	*Maximum*	*Mean*	*Standard Deviation*
Age of HH head (Year)	18	67	41.98	10.39
Family size of HH(Number)	2	10	5.52	1.68
	Category	*Total Number*		*Percentage*
Sex	Female Male	18 193		8.60 91.40

Out of the total of 210 sampled households, 123 respondents (58.6%) were found to be non-adopters, while 87 (41.4%) were the adopters of renewable energy technology (Table 2). This implies the majority of the households were found to be non-adopters of renewable energy resources.

Table 1: Renewable Energy Technology Adoption of Sampled Households

Adoption	*Number of households*	*Percent (%)*
Non-adopter	123	58.6
Adopter	87	41.4
Total	210	100.0

Out of the total of 210 households, 37 (17.6%) of them utilize modern energy sources, while 50 (23.8%) were users of both traditional and renewable energy technology as their main energy source. The remaining 123 (58.6%) were traditional energy source users (Table 3).

Table 2: Energy Source Choice of Households

Energy choice	*Frequency*	*Percent (%)*
Modern energy	37	17.6
Mixed energy	50	23.8
Traditional energy	123	58.6
Total	210	100.0

Econometric Model Results

Binary logistic model results:
Out of the total of ten (10) explanatory variables included into the model, seven (7) were found to determine the renewable energy adoption decision of sample households (Table 4).

Table 3: Logistic Regression Result: Determinants of adoption of renewable energy technology

_adoption-	*Coef.*	*Std. Err.*	*Z*	*P>Z*	*Marginal Effect*
_Isex_1	1.016705	.8179536	0.02	0.984	.0038569
Age	-0.93594	.0229955	-2.69	0.007***	-.0154378
Family_ size	-0.73747	.1000446	-2.24	0.025**	-.071020
Education	1.39668	.1500088	3.11	0.002***	.0779177
Total_ land_ size	2.103738	.7582701	2.06	0.039**	.1734479
Livestock _TLU	1.354025	.1454835	2.82	0.005***	.0706841
Ln_ income	2.651386	1.130436	2.29	0.022**	.2274067
Amount_ credit	.9999627	.0000821	-0.45	0.649	-8.70e-06

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_adoption-	*Coef.*	*Std. Err.*	*Z*	*P>Z*	*Marginal Effect*
Distance_ market	.981148	.0245233	-0.76	0.446	-.0044386
_Itraining_1	5.015261	2.434803	3.32	0.001***	.3474101
_cons	.0002495	.0009812	-2.11	0.035	.476853

Source: Computed from own survey data (2019-20)
** And *** = significant at 5% and 1% level of significance, respectively.

Discussion on significant variables to the determinants of adoption of renewable energy technologies is follows.

Age of Household Head:
The relationship between the age of the household head and the adoption of renewable energy technologies has become negative and significant. The marginal effect with the value of 0.0154 implies that, keeping other factors constant, as the age of the household head increases by one year the probability of adopting renewable energy technology decreased by 0.0154 (1.54%). This might be because older people are more reluctant to accept new technologies and prefer to keep on using something they are familiar with. This result is similar to the studies conducted by Tigabu (2014).

Family Size:
The model result shows that family size affects adoption of renewable energy technology in a negative and significant way. The marginal effect indicates that, assuming everything constant, as family size increases by one unit the probability of adopting renewable energy technology decrease by 0.071 (7.1%). This may be because households with large family size hinder adoption of new technologies. In other words, household with larger family size means more labour available to collect free traditional fuels like firewood and dung, which might make households reluctant to adopt energy technologies. The finding of this study is in harmony with the finding of Yonas *et al*. (2015).

Education Level:
Education level of household was a significant determinant of adoption decision for renewable energy technology of households. The marginal effect of 0.077 for education shows that, keeping other factors constant, the probability of adopting renewable energy technologies increases by 7.7% for one grade increment in the educational level of the household head. The finding of this study is in accord with the previous works of Kabir (2013) and Iqbal (2013).

Total Land Size:
Total landholding of households was a positive and significant determinant affecting renewable technologies' adoption. The marginal effect value of total land size was 0.173 on the adoption of renewable energy technologies. That means, keeping other things constant, the probability of adopting renewable energy technologies increased by 17.3 percent as the landholding size of households increased by one hectare. The study result is in harmony with the findings of Alemu and Köhlin (2009) and Iqbal (2013).

Livestock Holding (TLU):
Livestock holding has a positive and significant relationship with the adoption decision of households. The marginal effect with a value of 0.07 indicates that, keeping other factors constant, as the livestock increases by one unit the likelihood to adopt renewable energy technology increases by 7%. Livestock is a mean through which households kept their wealth, especially in rural Ethiopia. So, households having large livestock ownership tend to adopt new technologies. This result is similar to the findings of Iqbal (2013) and Kabir (2013).

Total Income:
Total annual income of households affects the adoption of renewable energy technology positively and significantly. Households with high annual income were found to be more adopters of the technology than those households with lower annual income. The marginal effect of income on the adoption decision of households has a value of 0.227. This implies that, holding other factors constant, as the income level of a household increases by one birr[1] the probability of adopting the technology increases by 22.7 percent. A similar finding was reported by Lay (2012) and Ouedraogo (2006).

Training:
Access of training on energy technology adoption was positively and significantly related to adoption of renewable energy technology. The marginal effect of this variable is 0.347 implying that the probability of renewable energy technology adoption for trained households increases by 34.7 percent as compared to untrained households. The result of this study is similar to the finding of Abadi (2006).

Multinomial Logistic Model Results

This model estimates the effect of each covariate/variable on the energy choice of sampled households (That is modern, mixed, and traditional). And traditional energy is used as a reference group (Table 5).

Table 4: Multinomial Logistic Result: Determinants of energy choice of sample households

Choice		*Modern Energy*				*Mixed Energy*		
Variables	Coef.	dy/dx	Z	P>z	Coef	dy/dx	Z	P>z
Sex Male	-1.220198	-.1589791	-1.19	0.234	.1624919	.0990379	0.13	0.898
Age	-.0605755	-.002315	-1.90	0.058*	-.064682	-.003376	-2.1	0.030**
Family Size	-.2945361	-.0054745	-1.60	0.110	-.403639	-.026485	-2.2	0.026**
Education	.4660993	.0179083	3.16	0.002**	.4962204	.0258144	3.49	0.000**
Total land size	.5773503	-.0049131	1.32	0.187	1.032406	.0791591	2.40	0.016**
Livestock in TLU	.4133841	.0215668	3.28	0.001**	.3524681	.0129972	2.82	0.005**
Amount Credit	-.0001896	-.0000242	-1.47	0.141	.0000593	.000019	0.58	0.560
Distance to Market	-.0449613	.0004865	-1.30	0.193	-.082000	-.006345	-2.4	0.016**
Training Yes	1.194264	.0449281	2.00	0.046**	1.37473	.0812816	2.28	0.023**
Ln income	1.107211	.0247193	2.06	0.040**	1.453524	.0923552	2.73	0.006**
_cons	-11.18369	.034212	-2.37	0.018	-14.1072	.05467	-2.8	0.004

Source: Computed from own survey data (2019- 2020)

Age of Household Head:
As depicted in the table 5, age of household head has negative and significant association with both modern and mixed energy choices. The marginal effect of the household head on energy choice of households has a value of -0.0023 and -0.0033 for modern and mixed energy choices, respectively. It indicates that, assuming other factors constant, the choice of modern and mixed energy sources decreases by 0.23% and

[1]Ethiopian currency having values equivalent to USD 0.023

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0.33% for one year increment in the age of the household head compared to traditional energy sources. The finding of this study is similar to the work of Waweru (2014).

Family Size:
For a mixed energy choice, family size has shown a negative and significant relationship. The marginal effect, that is -0.026, shows that, keeping other factors constant, the probability of choosing a mixed energy source decreases by 2.6% relatively, as one-unit increment in family size occurs. This may be due to free labour availability to collect free traditional energy source or preparing food to all family members requiring huge energy, which might not be satisfied either by modern or mixed energy sources that obliged households to pursue using traditional energy sources. This study finding is similar to the work of Waweru (2014).

Education:
The education has a positive and significant influence on both modern and mixed energy choices. The marginal effect 0.0179 and 0.0258 of education for both the energy categories indicates that, keeping other factors constant, the probability of choosing modern and mixed energy sources increases by 17.9 and 25.8%, respectively, relative to one-grade increment in education, compared to traditional energy sources. The study finding is in line with the finding of Ouedraogo (2006).

Land Size:
For mixed energy choice, landholding size has shown a significant and positive relationship. The marginal effect of landholding size on the choice of mixed energy source indicates that, assuming everything is constant, an increase in landholding size increases the probability of choosing mixed energy as their main energy source by 7.9% compared to traditional energy sources. The model result shows that landholding size has direct relationship with the choice of energy sources. This study result is in agreement with the findings of Alemu and Köhlin (2009).

Livestock Holding (TLU):
For both modern and mixed energy source choices, livestock ownership has shown a significant relationship. The marginal effect of households' livestock holding on the choice of modern and mixed energy sources with a value of 0.0215 and 0.0129, respectively, indicates that, keeping other factors constant, as a livestock holding in TLU increases by one unit the choice of modern and mixed energy as main energy sources increases by 2.15% and 1.29%, respectively, compared to traditional energy sources. Since livestock possession is one-way of keeping households' wealth in rural Ethiopia, the study finding confirms the energy ladder hypothesis of income/wealth that affects modern energy choice of households (Heltberg, 2003).

Distance to Market:
An increase in the market distance led to a decrease in the probability of choosing mixed energy over traditional energy sources. The marginal effect value of -0.006 indicates that, assuming everything constant, the choice of the mixed energy source as the main fuel decreased by 0.6% for a one-kilometer increment in the distance of the market centre.

Training:
It significantly determines both modern and mixed energy choices. The marginal effect of training for both energy categories was 0.044 and 0.081, respectively. This implies that, keeping other factors constant, the probability of choosing modern energy over traditional energy increased by 4.4% for trained households compared to untrained households, and the likelihood of choosing mixed energy over traditional energy increases by 8.1% for households who are provided with training compared to untrained one. This means that households provided with training know more about the positive benefits of utilizing renewable energy

technologies and modern energy sources, which motivate them to choose cleaner energy sources to meet their daily energy needs.

Annual Income:
It significantly determines both modern and mixed energy choices. The marginal effect of annual income on energy choice of households has a value of 0.0247 and 0.0923 for modern and mixed energy choices, respectively. It indicates that, assuming other factors constant, the choice of modern and mixed energy sources increases by 2.47% and 9.23% for one birr (Ethiopian currency) increment in income level of households compared to traditional energy sources. The study finding concord with Alemu and Kolhin (2008) and Ouedraogo (2006). Besides, the finding of this study proves the energy ladder hypothesis, which confirms that, as the income level of a household increases, their preference to clean energy sources would increase.

Conclusions

The finding of this study indicates that the major determining factors of renewable technology adoption and modern energy source choice of rural households are age, family size, annual income, total landholding size, livestock ownership (TLU), education, and training of the household head. These factors affect the adoption decision and modern energy source choice of rural households one way or the other. Besides, affordability and multi-purpose use of technologies were mentioned as major challenges for technologies' adoption during focus group discussions. Based on the finding of the study, the following recommendations are made. Stakeholders should strengthen and provide different educational opportunities like adult education and training for rural households to make them more informed about the benefits of utilizing cleaner energy sources. Concerned bodies should facilitate credit and subsidy schemes to make renewable energy technologies affordable for the rural poor. Efforts should be made by concerned bodies so that households engaged in different income generating activities, like irrigation schemes, to improve their income level and thereby enhance adoption and utilization of modern energy sources and reduce energy poverty at the household level. Due emphasis should be given by stakeholders for technological research to revise and adjust renewable energy technologies' limitations.

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Application of Introduced Representatives of *Lonicera pileata* Oliv. in Landscaping of the Right-Bank Forest-Steppe of Ukraine

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Abstract

This article deals with the possibilities to introduce the ornamental shrub *Lonicera pileata* Oliv. belonging to *Caprifoliaceae* Vent. family in the landscaping of the Right-Bank Forest-Steppe of Ukraine. The representatives of *Lonicera pileata* Oliv. (Cultivars *Pileata*, form *Variegata* and form *Lemon Beauty*) endure winter well and adapt to new climatic conditions of the planting site. The plants were found tolerant to shade, cold, pruning, and urban ecological conditions with polluted air. It has been revealed that, depending on the purpose of the landscaping object, these shrubs can perform various functions: create architectural and artistic image of the object; promote biological land reclamation along with other plants; protect against dust and noise; regulate moisture and temperature. Simultaneously, to grow plants of *Lonicera pileata* Oliv. successfully, it is critical to use farming techniques developed by the author scientists. When the representatives of evergreen shrubs of *Lonicera pileata* Oliv. are introduced in the landscaping of residential areas, they can be used to decorate landscape-gardening objects with different functional use creating landscape compositions in gardens and parks, on the plots with different exposition and slopes, as anti-erosion plants, in alpine landscapes, as freestanding shrubs or in group plantations, at the background of lawns, in flowerbeds, in alpine screen gardens, in rockeries, in freely growing and trimmed hedges, and as ground-covering plants.

Keywords

Urban environment; Vegetation period; Farming technique; Decorative effect

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Introduction

Enrichment of plant varieties with ornamental plants, especially those that do not require too much care and adapt to extreme factors of changing climate, is an important task of solving current problems while retaining biodiversity, effective use of plant resources and optimization of the state of green space. To improve the structure and decorative effect of garden compositions in urban environment in Ukraine, promising and less common plants belonging to the family *Caprifoliaceae* Vent. are helpful. One popular genus of the family is *Lonicera*. There are over 200 species of *Lonicera* genus (also known as honeysuckle) all over the world, only 30 species became widespread in ornamental gardening, landscaping of residential areas, and landscape design, as described in "Flora of USSR" (Shyshkin, 1958; Karpun, 2004).

All species under *Lonicera* genus can be categorized into three types: upright plants, creepers and climber plants. The upright standing plants are generally the shrubs having fruits not edible, round-shaped, red, purple or orange berries arranged close to leaf axil. *Lonicera pileata* Oliv. is a species belonging to the family *Caprifoliaceous* Vent. In the wild, it is widespread in the mountains of central and western China. At the beginning of the 20th century, it was brought under cultivation. Due to their unusual look, the shrubs became widespread all over Europe, especially in its western part, and later it entered Ukraine, but it got acclimatized only in its southern part of the country (Levon and Kusnietsov, 2001; Hessayon, 2000).

The main usage of evergreen shrub *Lonicera pileata* Oliv. is ornamental decoration of open landscape garden having different functional uses: concealing alpine landscapes, rockeries, creation of alpine screen gardens, small group plantations, free growths and trimmed hedges, and organization of rest areas. However, the value of this shrub *Lonicera pileata* Oliv. lies not only in the decorative uses but also in other functional uses (Kucheriavyi, 2008). Plants of this species endure winter season very well and adapt to new climate conditions at its site (Laptiev, 2001).

When new plants are introduced in landscape planning, plants adapt successfully and manifest high biological durability. It means that these plants are not affected by late spring and early autumn frosts, and winter frosts or droughts; and plants produce similar seeds that can ensure the availability of planting material for next time. The utility of such plants is in growing and introducing ornamental plants in the landscaping of residential areas in Ukraine. Therefore, the research on *Lonicera pileata* Oliv. is relevant and it generates scientific and practical interest. Hence, the objective of this study is to explore the ecological and biological properties of evergreen ornamental shrubs of *Lonicera* genus having utility in landscaping; to define the regularities of all stages of introduction process; and to perform general analysis of farming practices and care of *Lonicera pileata* Oliv. plantations. This research has been conducted in the experimental plots of the Department of Landscape Gardening of Uman National University of Horticulture, Ukraine. This research has introduced representatives of *Lonicera pileata* Oliv.: *Pileata* variety and Variegata and *Lemon Beauty* forms were tested in this study. The scientific novelty of this research is that, for the first time, a less common ornamental plant *Lonicera pileata* Oliv. from the family *Caprifoliaceae* Vent. is introduced in the Right-Bank Forest-Steppe of Ukraine.

Materials and Methods

20 *Lonicera pileata* Oliv. shrubs were selected for the research, including 6 shrubs of form *Variegata*, 6 shrubs of form *Lemon Beauty* and 8 shrubs of cultivar *Pileata*. General scientific analysis, synthesis and observation, and general biological research methods were followed to conduct this research. During the experiment, observation was carried out over the period from 2017 to 2020 on the experimental plot at the Department of Landscape Gardening, Uman National University of Horticulture. This methodology of phenological observations was developed for botanical gardens to study the vegetation in the botanical gardens of the USSR (1975). The selection of trees and shrubs for introducing the plants was based on the methods developed by (Kochno and Kuznietsov, 2005). During the research on the growing of *Lonicera*

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pileata Oliv., some farming techniques were developed based on the experiences of the scientists in this field (Varlashchenko, 2016; Hessayon, 2000).

A group of 20 young plants having 3-year age was performed in autumn of 2017 in the area of 144 m^2, taking into account the fact that, in spring, the buds swell very quickly and, as a result, they do not survive longer. The holes under young plants were prepared beforehand at the distance of 2 x 2 m, with the diameter of 40 x 40 cm, followed by the holes were filled with soil rich in nutrients in a cone-like manner. The upper layer of the soil was mixed up with a bucket of manure. A young plant was put into a hole, the roots were spread and covered with a thin layer of earth. The soil was compacted and well-watered. Sawdust was used as mulch. After the planting, young plants were trained only during the second year by cutting off sick and damaged shoots.

The first fertilization was performed 2 years after planting in early spring. 25-30 g of ammonium nitrate was put under every shrub. In summer month of July, the plants were fertilized with manure: one bucket of compost per 1 m^2; whereas in autumn, 1-2 glasses of ash and 30 g of superphosphate. During sanitation pruning, the damaged and sick shoots were cut off. Regenerative pruning was performed only after 5 years.

Photo 1: The *Pileata* variety

During the research on *Lonicera pileata* Oliv., ecological and biological properties of both introduced forms *Lonicera pileata Variegata* and *Lemon Beauty* and cultivar *Pileata* for landscaping were studied, stages of introduction process in the changed climate conditions were analyzed, farming techniques and treatment of plantations were suggested.

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Results and Discussion

The analysis has shown that, among green vegetation of Uman National University of Horticulture, a considerable percentage consists of ornamental trees and leafy shrubs, while evergreen plants are not common in the landscaping of this territory. In 2017, 20 shrubs of *Lonicera pileata* Oliv. were planted on the site of the experimental plot: 8 *Pileata* cultivars, 6 of Variegate form and 6 of Lemon Beauty form of the shrub. Ecological and biological features of the shrubs were studied during the research period (2017-2020). *Lonicera pileata* Oliv. cultivar *Pileata* is one of the rare varieties of the ornamental plants having upright honeysuckle features. Originated in Japan, it is a low, evergreen or semi-evergreen wide-branched shrub that grows to the height of 0.4-1.0 m. The leaves are small, 0.5-2 cm long, ovate, lance-shaped with wedge-shaped basis, glossy, dark green on the surface and pale green on the reverse side, lightly hairy, and arranged in pairs on the stems of short petioles. Fragrant flowers are arranged in pairs on upright flower stalks having 0.5 cm length. Bilabiate corolla is tubular and cone-shaped, white with red coating, 0.8 cm long, hairy on the outside or almost bare. Stamens and pistils are hairy and longer than corolla. Floral bracts are awl-shaped, almost of the same length as ovary. Fruits are translucent, round-shaped berries, 0.5 cm across, of amethyst or purple and velvet coloring. It blossoms in May–June and bears fruits in October. The plant grows slowly, endures shade well, and reproduces vegetatively (Varlashchenko and Balabak, 2021; Kohno and Kurdyuk,1994). It looks attractive in solitary and in group plantations.

Lonicera pileata Oliv. variegated form (*Lonicera pileata* Variegate) is evergreen dwarf shrub, 20 cm high with small 1-2 cm long lance-shaped leaves, dark-green, glossy, opposite leaves, similar to boxwood leaves (that quickly grow after cutting). If watered regularly, the shrub grows high; otherwise, it remains dwarf and ground covering. It blossoms in the middle of May–June and produces beautiful fragrant white flowers. Berries are elongated, 6 mm across, translucent, red or light blue-purple, early ripening (September–October), and not edible. It reproduces by suckers, layers and grafts (Varlashchenko and Balabak, 2021; Karpun, 2004).

In landscape design, *Lonicera pileata* Variegate looks nice and attractive in different compositions and is the best alternative to boxwood (*Bucsus sempervires* L.). It grows quickly, endures easily the pruning and training, grows well in the sun and in partial shadow, and is drought and cold resistant. The plant needs covering during frosty winters without snow. It is planted in rockeries, shrub groups, and among coniferous plantings (as a groundcover plant).

Lonicera pileata Oliv., form *Lemon Beauty* (shining honeysuckle), originates from Western China, and grows in mountainous areas of provinces Sichuan and Yunnan. It has been in cultivation since 2008. It is evergreen shrub in southern areas and semi-evergreen with partially deciduous leaves in northern areas. The shrub may grow up to 1.2 m height and spread its dome-like crown up to 1.5 m in diameter. Stems are covered with smooth scaled bark; shoots are thin, light brown with olive-green tint. Leaves are small, oval, egg-shaped, glossy, light green with white edging (Varlashchenko and Balabak, 2021; Sikura and Kapustyan, 2003).

The complicated characters of introduced plant were observed. The process of introducing a plant can be roughly divided into three successive stages: the selection of plant to be introduced, testing of the plant, and introduction of plant in the cultivation process (Laptiev, 2001). It is an important observation that there is a difference in the phenological stages among different representatives of *Lonicera pileata* Oliv. genus during the process of phylogenies. The absence of blossoms in the first year of growing the cultivar *Pileata*, form *Variegate*, and form *Lemon Beauty* reduces the acclimatization feature of the introduced plants, though it is not a crucial feature for determining the potential of the plants. This fact is caused by insufficient sun-exposure of the habitat, physiological and ecological hardiness of the plants under conditions of the research (Lapin, 2019).

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Duration indices of vegetation period of the representatives of *Lonicera pileata* Oliv. in the town of Uman are presented in table 1.

Table 1: Duration indices of vegetation period of the representatives of *Lonicera pileata* Oliv. in the Right-Bank Forest-Steppe of Ukraine

№	*Cultivar, forms*	*Duration of Vegetation Period (days)*
1.	Pileata	196±15
2.	Variegata	190±10
3.	Lemon Beauty	194±12

The duration indices of the vegetation period show that all the investigated representatives of *Lonicera* genus are suitable for growing and arranging compositions in the town of Uman. It is worth mentioning that given shrubs undergo all phenological stages of development when introduced in the Right-Bank Forest-Steppe of Ukraine and are characterized by the starting and final dates of flowering, stems growth, blossoming, fruiting and ripening of fruits, etc. (Table 2).

Table 2: Phenological stages of growth and development of *Lonicera pileata* Oliv. in the Right-Bank Forest-Steppe of Ukraine (from 2017 to 2020)

№	*Cultivar, forms*	*Dates of phonological stages of development*			*Duration of blossoming (Days)*
		Buds swelling	*Buds breaking*	*Leaves unfolding*	
1.	*Pileata*	16.03–25.03	31.03–21.04	18.04–20.05	18.05–18.06
2.	*Variegata*	12.03–21.03	25.03–17.04	14.04–17.05	15.05–19.06
3.	*Lemon Beauty*	14.0 –24.03	28.03 – 20.04	15.04–18.05	16.05–17.06

On an average, the vegetation period of *Lonicera pileata* Oliv. representative during the research was 205.6 days. Form *Lonicera pileata* Variegata was recorded to have the shortest duration of vegetation period, while cultivar *Pileata* had the longest period. Bud swelling and bud breaking are regarded to be the beginning of the vegetation - trees or shrubs. Phenological observations over honeysuckle cultivar have shown that breaking of reproductive buds takes place at an average daily temperature +7…10°C with sum of effective temperatures 12…20°C (Table 2). Over the period of research, this stage took place in the second half of March. The breaking of reproductive buds was not simultaneous: the buds on the lower shoots opened earlier than those on the upper shoots.

In years having long winter thaws, lower reproductive buds that received more warmth from the soil surface swelled and began to break. Under further fall of temperature, their development ceased, and they successfully endured the fall of temperature. The breaking of flower buds depended on weather conditions and lasted from 12 to 25 days. Flower-bud formation began when the sum of effective temperatures was 70–90^{0}C in the first half of April (Table 2). The duration of this phase depended on the temperature that lasted 12–18 days.

The findings of the research have shown that in the Right-Bank Forest-Steppe of Ukraine the blossoming of the representatives of *Lonicera pileata* Oliv., on an average, began on 15th–18th of May under the average daily temperature 12-14°C and on sum of effective temperatures 170°C. The duration of blossoming lasted 30–33 days and depended, to the great extent, on the atmospheric temperature and humidity. Linear growth of shoots began during massive blossoming and finished in dry years (2019, 2020) in the second half of July, and under sufficient moistening (2018), at the beginning of August. It has been established that the deviation of some dates of certain stages over the years of research depends on the climate and weather indices of a particular year. The difference in the starting dates of certain phenological stages of all shrubs

depended on the time of blossoming, from 15th – 18th of May to 16th – 18th of June and complete ripening of berries from 16th of September to 15th of October.

Winter hardiness of shrubs was determined visually, after analyzing the state of plants during and after the winter. Frequent thaws caused damage to shrubs, resulting in freezing of shoots in 2019 and 2020. The observations were generalized over three years, taking into account the character of freezing. It turned out that one and the same representative in different years had different winter resistance. It is worth mentioning that some shrubs froze under -23°C frost when there was no snow, but under considerable snow covering frosts did not cause considerable damage to shrubs. In general, all introduced representatives of *Lonicera pileata* Oliv. have a good level of acclimatization and they can be recommended for the introduction in the landscaping of the Right-Bank Forest-Steppe of Ukraine.

Conclusions

The representatives of *Lonicera pileata* Oliv. have hard and inflexible stems sprawling on earth and easily take roots when touching the soil. The pest and diseases rarely afflict the plants, but during cold and wet summer, fungal infection may appear, such as powdery mildew, rust. Very often, juicy shoots can be attacked by aphis (*Aphidoidea*), leaf moth (*Cameraria ohridella*) and red spiders (*Purrhoris apterus*). To fight diseases, it is necessary to use systemic fungicides: Vectra, Topaz, and Hamiar. Inta-Vira, Akhtar and Aktelika were used to fight pest. All plants grow well both in the sun and shade, on the sites protected against wind, and on drained loamy soils with neutral pH. Performance of all farming techniques applied to grow *Lonicera pileata* Oliv. ensures excellent decorative effect and durability of plantings. So, according to ecological and biological features, the representatives of *Lonicera pileata* Oliv. can be grown as decorative plants that are able to emphasize the uniqueness of a garden or a household plot. Dwarf shrubs can be used in both landscape and panoramic compositions. Thick and dense crown of shrubs give any relief a beautiful and noble look. However, to select introduced representatives of *Lonicera pileata* Oliv., *Pileata* cultivar, *Variegated* form and shining honeysuckle form *Lemon Beauty*, it is necessary to take into account their ornamental properties.

Introduced cultivars of *Lonicera pileata* Oliv., cultivars *Pileata*, *Variegata* and *Lemon Beauty*, were researched. It has been established that their ecological and biological variable indices of decorative effect (of shoots, leaves, crown shapes, flowers, and fruits) and resistance to environmental factors make their use in the landscaping in the Right-Bank Forest-Steppe of Ukraine justifiable and suitable for introduction. Performance of all farming techniques used to grow and care the evergreen shrubs of *Lonicera pileata* Oliv. will provide with high decorative effect and improve their durability in the plantings having various combinations: in flowerbeds, hedges, rockeries, alpine screen gardens, etc.

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Agroforestry Practices for Climate Change Adaptation and its Contribution to Farmers' Income

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Abstract

Agroforestry practices offer a unique opportunity to address climate change impacts while securing the livelihoods of the rural communities. This study was carried out in Tillotama municipality of Rupandehi district, Nepal. Agroforestry system practices at the study site were identified through reconnaissance survey and discussions with ward officials. With 10% sampling intensity, purposive sampling was adopted for the study using the structured questionnaire, key informant interview, and field observation. For mean comparison, one-way ANOVA and Least Significant Difference (LSD) as post-hoc tests were carried out. Local communities were adopting eight different types of agroforestry practices under four agroforestry systems, namely agri-silvicultural, silvo-pastoral, agro-silvopastoral and silvi-fishery. The agroforestry system shared up to 50.54% of total households' income, in which income from agriculture was the highest. Agroforestry income was dependent on the economic status of the households. Change in cropping calendar was found as a major adaptation strategy. Scaling up of agroforestry system and commercialization of agroforestry products were recommended.

Keywords

Adaptation; Agroforestry; Climate change; Impacts; Income

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Introduction

Agroforestry is a climate-smart production system and is considered more resilient than mono-cropping (Charles *et al*., 2014; Haile *et al*., 2019). It is one of the most experimented land-use systems across landscapes and agro-ecological zones in Nepal (Nair, 2007; McCord *et al*., 2015). With food shortages and increased threats of climate change, interest in agroforestry is gathering for its potential to address various on-farm adaptation needs, and fulfill many roles in AFOLU (agriculture, forestry, and other land-use) related mitigation pathways (Mbow *et al*., 2014). It can play a crucial role in improving resilience to uncertain climates through micro-climate buffering and regulation of water flow (Stigter, 2015). When it provides assets and income from carbon, wood energy, improved soil fertility, and enhancement of local climate conditions, it provides ecosystem services and reduces human impacts on natural forests (Moreno *et al*., 2018). Most of these are direct benefits for local adaptation while contributing to global efforts to control atmospheric greenhouse gas concentrations (Rosenzweig and Tubiello, 2007). Furthermore, agroforestry provides a particular example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the system's ability to adapt to adverse impacts of changing climatic conditions (Verchot *et al*., 2007; Mbow *et al*., 2014).

Climate change is projected to affect agricultural and natural ecosystems around the world, and there is no reason to expect that agroforestry systems will be spared (Luedeling *et al*., 2014). As the impacts of climate change have become apparent around the world, adaptation has attracted increasing attention (Mimura *et al*., 2015). With the world's population increase, the need for more productive and sustainable use of the land becomes more urgent. To meet the demand for food by 2050, world food production will have to increase by over 60% (Mckenzie and Williams, 2015). But the shortfall in domestic cereals production in the developing world was expected to widen from around 100 million tons in 1997 to around 190 million tons in the year 2020 (Rosegrant *et al*., 2001; Verchot *et al*., 2007). In many regions of the world, there will be limited ability for new varieties and increased fertilizer use to further increase the yields (Huang, Pray and Rozelle, 2002; Balemi and Negisho, 2012).

Agroforestry systems include both traditional and modern land-use system dynamics, and ecologically based natural resource management systems that diversify and sustain production in order to increase social, economic, and environmental benefits for land users at all scales (Pandey, 2007). Agroforestry as a tree-based system combines trees and/or shrubs, animals, and agronomic crops. It provides a particular example of a set of innovations designed to enhance REDD+ through carbon substitution, carbon conservation, and carbon sequestration in the agricultural landscape (Charles, Nzunda and Munishi, 2014). The rapid increase in Earth's surface temperature and changing precipitation pattern has resulted in direct implications to multiple sectors and livelihood of communities (Rao and Leal Filho, 2015). The poorest and vulnerable people are being affected the most (Mustafa, 2011). The data trend from 1975 to 2005 shows that the mean annual temperature has increased by 0.06°C, while the mean rainfall has decreased by 3.7 mm (-3.2%) per month per decade (MoE, 2012). Similarly, mean annual temperature is predicted to be increased between 1.3°C to 3.8°C by the 2060s and 1.8°C to 5.8°C by the 2090s while annual precipitation could reduce by the range of 10 to 20 percent across the country Nepal (Joshi and Singh, 2020; MoE, 2010). Studies also indicate that the observed warming trend is not uniform across the country. Agroforestry land-use management is necessary for increasing soil carbon stocks and socio-economic development of farmers; and the research on the carbon sequestration rate of agroforestry is necessary for making future policies and strategies on the issue of climate change. However, there were limited research (Neupane and Thapa, 2001; Regmi, 2003) carried out in the field of agroforestry, mostly focusing on soil fertility and local livelihood.

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Methodology

Study Area

The study was carried out in Gangolia village of Tilottama municipality in Rupandehi district, which lies in the Southern part of Lumbini Province of Nepal with the coordinates of 27°37′48″ N latitude and 83°27′36″ E longitude. The district Rupandehi lies in the southern and western parts of Nepal. On the East, it shares a border with Nawalparasi district, on the West with Kapilvastu district, on the North with Palpa district, and on South with India. The elevation of the district lies between 100 m to 1229 m from sea level. The total area of the district is 1,360 km^2 with 16.1% in Churia Range and the rest in the Terai[1] region. Recently, the Government of Nepal is planning to extend the agroforestry system in the Rupandehi district by considering an agroforestry pocket area. Only a few farmers have been practicing different types of agroforestry systems for few decades, although such type of study is lacking in this area.

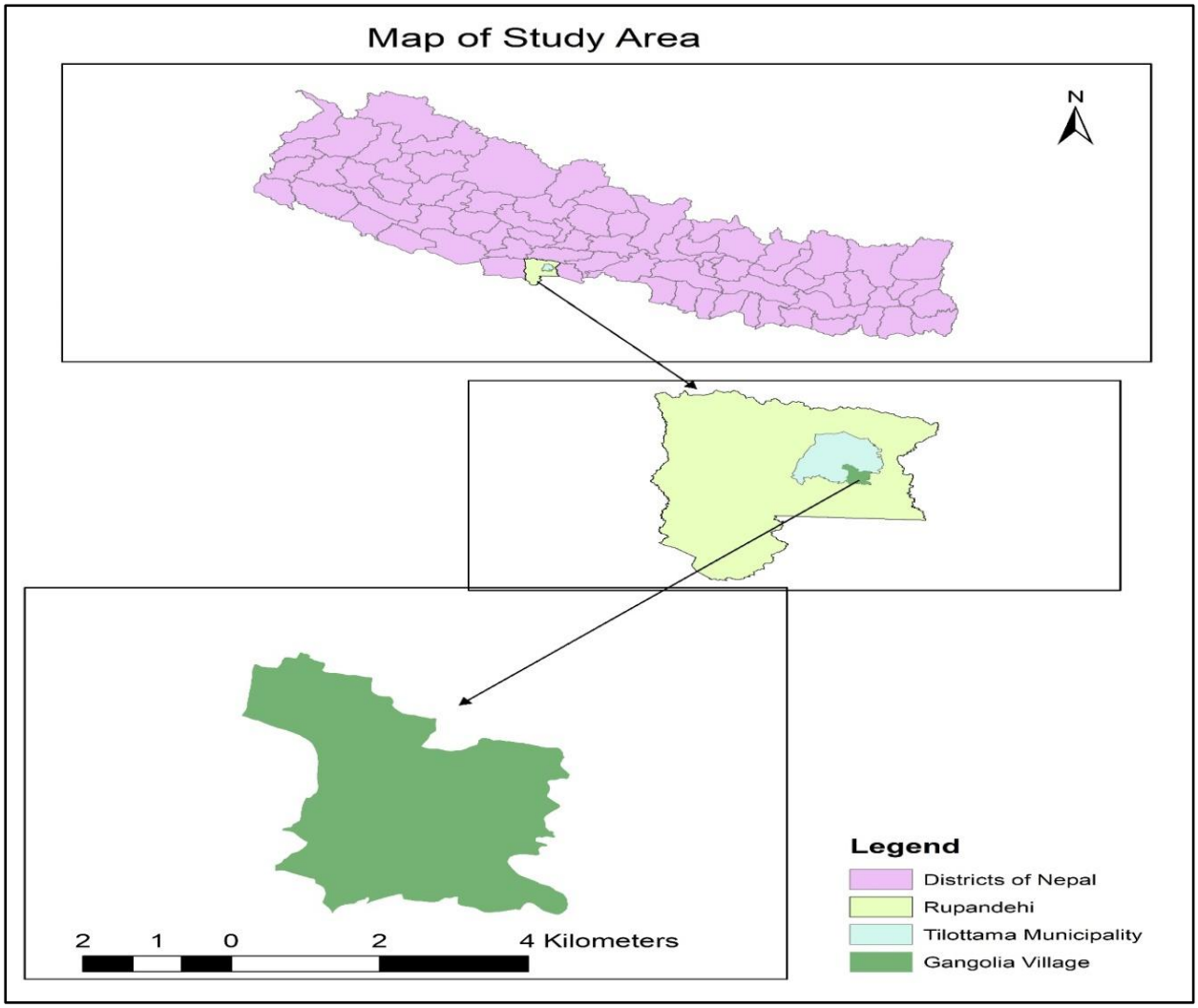

Figure 1: Map of the study area

[1] Terai is a lowland belt of southern Nepal, mainly characterized by tall grasslands, scrub savannah, Sal forests and clay rich swamps (Dahal *et al*., 2021).

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Data Collection

The primary data were collected from the study site by employing a combination of social survey methods involving participatory techniques such as on-site field observation, household survey questionnaire, and key informant interview. The sampling used for this study was purposive sampling with a sampling intensity of 10% (Kombo and Tromp, 2006). Out of the total 304 households in Gangolia village of Rupandehi district, 33 households (10% sampling intensity) were sampled.

The various relevant and related secondary data were derived from published research papers, articles, newspapers, brochures, leaflets, annual reports, progress report and other publications of various related authorities. Secondary databases of precipitation and temperature were collected from the Department of Hydrology and Meteorology.

Data Processing and Analysis

Quantitative data were analyzed using descriptive and inferential statistics such as percentage, mean, frequency distribution, and use of graphics and parametric test i.e., F-test (ANOVA). F-test was used to compare the income of farmers from the agroforestry system with its determining factors like caste, well-being ranking, education level, and family size. Similarly, rainfall and temperature data of 30 years (1989-2018) were analyzed using the Least square curve fitting technique i.e., $Y=a+bt$ where, y=temperature or rainfall, t=time (year), a and b are constant estimated.

Results and Discussion

Socio-Demographic Status of Respondents

The age group of the respondents mostly lies between 35 to 60 years. The major castes/ethnic groups in the study area were Brahmin/Chhetri, Janjati, Dalit, and others represented by 30%, 50%, 10%, and 10%, respectively, among the sampled households. Literacy level among the sample respondents was primary level (33.3%), secondary level (30%), and higher secondary and above (36.7%). Most of the households (HHs) had 4 to 12 members. Among the sampled households, about 3.3% HHs were having less than 6 family members, 40% having 6 to 7, 40% sampled households 7 to 9 family members and 16.6% HHs more than 10 family members.

Annual Income of Farmer

The majority of the household income was from agroforestry (50.19%) followed by remittances/pensions (21.01%), services, business, and wages to be 15.79%, 9.27%, and 3.73%, respectively. An increase in size of these parameters brought about an increase in the household's annual income and, thus, contributing to poverty alleviation. Contribution of agroforestry components on total farm income of the farmers showed that mean annual income from agriculture was found to be 42%, followed by livestock, fisheries, poultry, tree and fuelwood with 27%, 16%, 11%, 3%, and 1%, respectively (Figure 2).

Mean Test of Agroforestry Income of the Farmer with respect to different Socio-economic Variables

Distribution of the socio-economic factors influencing agroforestry income showed overall significance to only wellbeing status (rich/medium/poor) of the household. In regard to caste, Brahmin/Chhetri with Janjati was significant; but Brahmin/Chhetri with Dalit and Other are insignificant at a 5% level of significance. Similarly, education level and family size are also insignificant to the total annual income of agroforestry income. So, we can conclude that level of education and family size did not affect the income from agroforestry.

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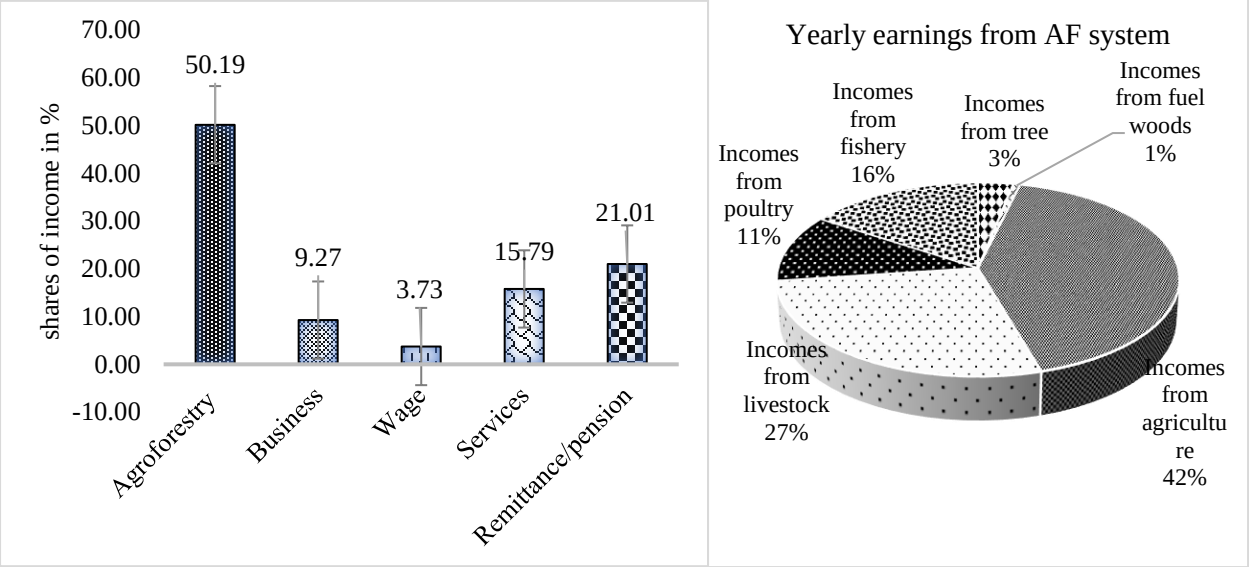

Figure 2: Gross Annual income of Farmer with Yearly Earnings from AF System

Table 1: Mean Test of Agroforestry Income of the Farmer with respect to different Socio-economic Variables

Caste					
Variables	*Co-variates*	*Sig.*	*Overall df*	*Overall F*	*Overall Sig.*
Brahimin/Chhetri	Janajati	0.890	(3, 26)	2.70	0.65
	Dalit	0.027*			
	Other	0.042*			
Wellbeing					
Rich	Middle class	0.0005	(2, 27)	9.43	0.01
	Poor	0.001			
Education level					
Primary level	Secondary level	0.852	(2, 27)	0.17	0.87
	Higher secondary & above	0.609			
Family size					
Family size	-	-	29	3.13	0.29

*The mean difference is significance at the 0.05 level.

Climate Change Adaptation Strategies through Agroforestry System Practices

Almost 30 years' climatic data from 1989 to 2018 of Bhairahawa meteorological station showed that the average annual rainfall was in increasing trend with 0.034 cm per year which is shown in figure 3. The trend of the maximum temperature was also in increasing order of 0.026°C per year as shown in figure 4.

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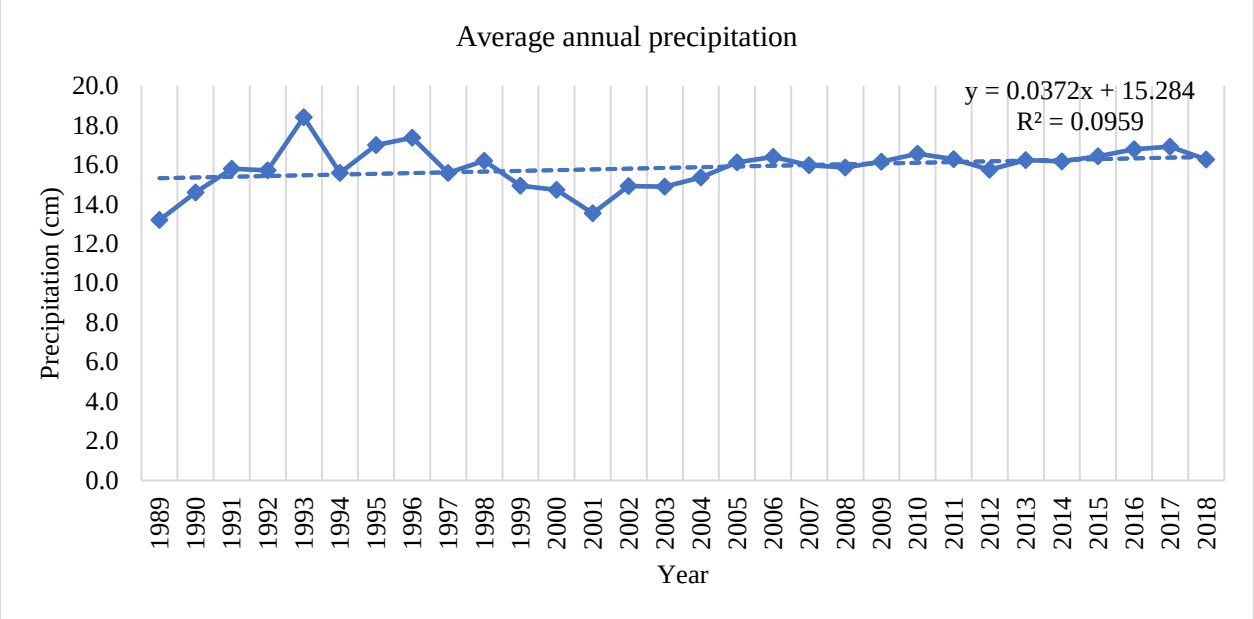

Figure 3: Average annual precipitation

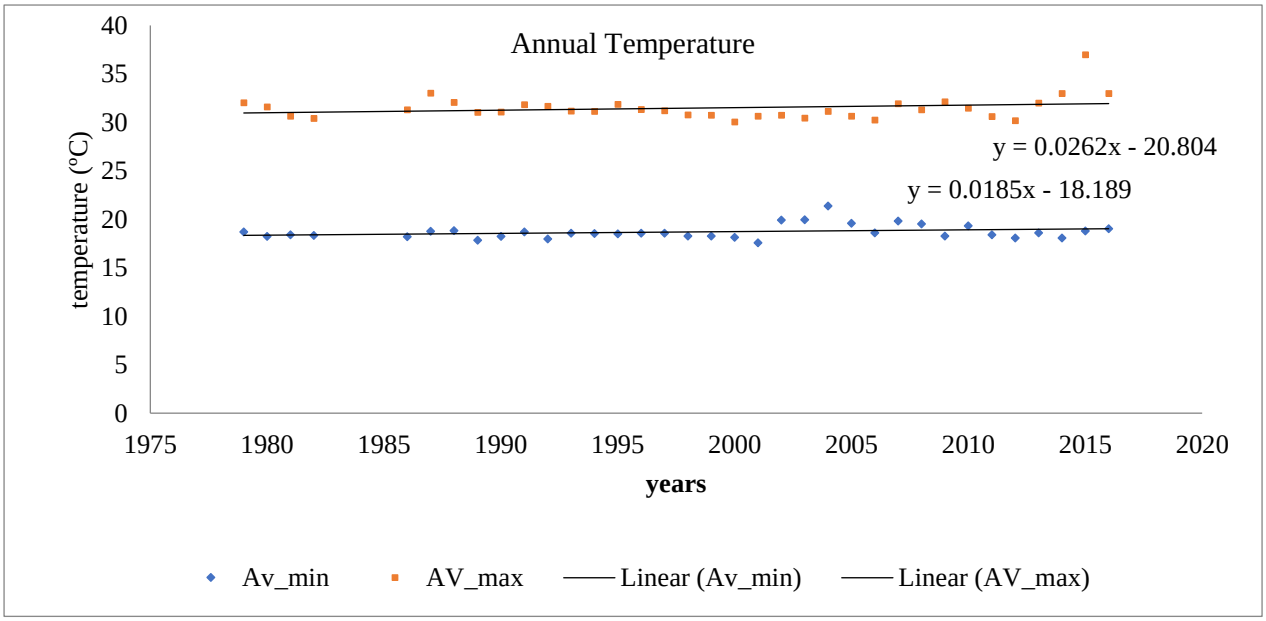

Figure 4: Average annual temperature

Specific Adaptation Strategies' Adopted at Households level

The strategies adopted by the farmers against climate change were found mainly in the form of using chemical fertilizers and pesticides (25%), diversification of income-generating activities (27%), agroforestry (18%), and changing the crop calendar (30%). Similar findings like crop-livestock diversification and multiple cropping strategies were reported by several scholars (Assoumana *et al*., 2016; Gebreeyesus, 2017; Mekuria and Mekonnen, 2018).

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The respondents who practiced agroforestry experienced various benefits such as improved soil fertility rate (32%), improved micro-climate (24%), increased catchment for pump set and boring (29%), and increased wood products (15%), although these methods are not sufficient to control climate change effects.

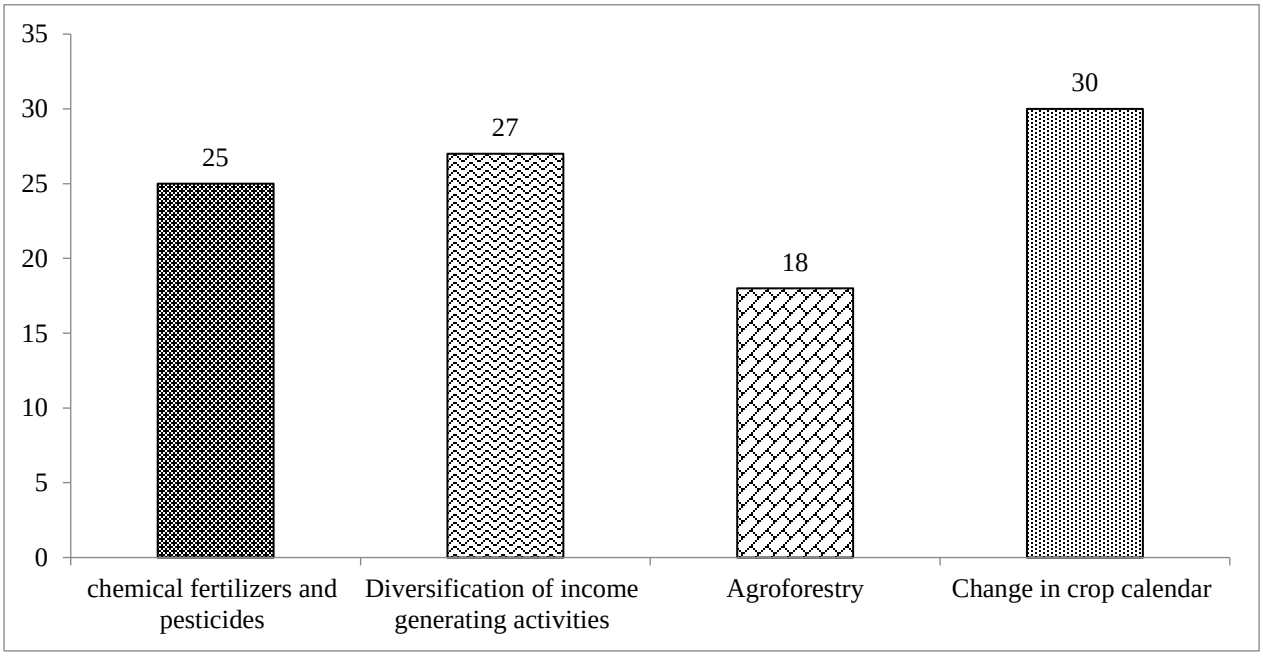

Figure 5: Specific adaptation strategies adopted at household level

Conclusion and Recommendation

Agroforestry has a significant impact on the livelihood of people engaged in agriculture primarily and on those who have low adaptive capacity. In the study area, trees on farmland were found as part of traditional practices. Agroforestry shares about 50% of total HH's income, in which the income from agriculture was highest. Income from the agroforestry system was found highly dependent on the socio-economic status of the households. The temperature has been increased by 0.026°C per year and rainfall by 0.04 cm per year. Change in the cropping calendar was found as a major climate change adaptation strategy by the farmers.

Agroforestry is one of the best options to make the community more resilient from adverse impacts of climate change through increased income and environmental services. Thus, the promotion of agroforestry practices in private land should be emphasized by the government. The practice of agroforestry should be done on a large scale to mitigate the adverse effects of climate change. Commercialization of agroforestry products should be done to enhance the farmer's income. To encourage the farmers to practice agroforestry practices, they should be provided with capacity building, training, and information to make them aware of the benefits of agroforestry.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3
Conceived and designed the research or analysis	Yes	Yes	Yes
Collected the data	Yes	No	No
Contributed to data analysis & interpretation	Yes	No	Yes
Wrote the article/paper	Yes	Yes	Yes
Critical revision of the article/paper	No	Yes	No
Editing of the article/paper	Yes	Yes	Yes
Supervision	No	Yes	No
Project Administration	Yes	Yes	Yes
Funding Acquisition	Yes	Yes	Yes
Overall Contribution Proportion (%)	40	30	30

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Research involving human bodies (Helsinki Declaration)
Has this research used human subjects for experimentation? No

Research involving animals (ARRIVE Checklist)
Has this research involved animal subjects for experimentation? No

Research involving Plants
During the research, the authors followed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Yes

Research on Indigenous Peoples and/or Traditional Knowledge
Has this research involved Indigenous Peoples as participants or respondents? No

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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M – 00243 | Research Article

Assessment of the Ecological Risks of Landslide Damages in the Carpathian Region

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Abstract

The dynamism of the landslides within the Carpathian region of Ukraine is because of the difficult engineering and geological conditions. High landslide den sity and significant population density contribute to the fact that environmental parameters worsen and require rational management. Permanent natural factors like clay flysch formation, fault tectonics, high seismic activity, and dense network of rivers mostly facilitate the active development of landslides in the Carpathian region. However, it is triggered by extreme long-term precipitation. The numerical parameters of population density, the landslide damage coefficient, and the predictive range of landslide intensification were selected to assess the ecological risk of damages in the area. The landslide dam age coefficient characterizes the tendency of the area to landslide development, considering all the factors contributing to the landslides. Risk, as a multifunctional calculated complex, includes the calculation of damage, according to which we can assess the possibility of risk for the human being while assuming the equal distribution of the population within the study area. The integral components of the risk are calculated based on the data gathered to assess the growth of risks in the future, considering the area distribution and predictive time series of the landslide intensification. This analysis has identified engineering and geological areas having the greatest risk to human life.

Keywords

Ecological risk; Integrated risk; Landslides; Assessment; Long-term prediction

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Introduction

The development of landslides within the Carpathian region has a significant impact on the state of natural and man-made safety and determines the search for new ways of forecasting to assess the risks of their negative effects. The spread and expansion of the landslides affect the environment with a cardinal change in the relief. Here, the extensive forest areas are being destroyed, the riverbeds are deforming. Besides, the consequences of the landslide intensification cause meaningful economic and social losses to the local population, roads and power lines. This occurs frequently in the fragile mountainous areas, where the greatest landslide damages can be observed.

Academic studies of the scholars pay special attention to the issues of the risks of landslide intensification and the needful early warning about the possible landslides in the mountainous areas. Bonnard, Forlati and Scavia (2004) present the method of risk management and mitigation strategy regarding the landslide consequences in the Alpine mountain valleys. Corominas *et. al*. (2014) recommended methodologies for quantitative analyses of the landslide hazard, damage and risks at different spatial scales. They suggested to adopt the managerial decisions for financial assessment of risks at the local and regional level. Abella and van Westen (2007) specified a procedure for creating quantitative landslide risk maps submitted to the national early warning system providing information about probable danger and the need of early evacuation of people from the landslide prone areas.

Overview of the Area and Study Trends

High water and floods may develop in the rivers in the Carpathian region several times a year. The map of engineering and geological areas of the study area is presented in figure 1. If the upper layer of soil contains the previous moisture, the floods will provoke the development of landslides. The State Emergency Service of Ukraine[1] classified the last high water on 17-29 June 2020, which covered the western regions. It is like a natural disaster at the state level. By the disasters, 349 populated localities and over 14,300homes were flooded; 3,500 household buildings, 654 kilometers of roads and 266 bridges were completely damaged in 2020. According to the preliminary estimates, more than UAH 1,000 million were required to repair the damaged facilities.[2] There was an intensification of the landslides.

The spread and intensity of developing exogenous geologic processes, landslides in particular, are influenced by the tectonic, seismic regime of the area, features of geological, geomorphological structure and hydrogeological conditions. Area zoning is necessary to determine the patterns of spread and development of exogenous geologic processes, landslides in particular. In Ukraine, the issue of environmental safety is dealt with at the state level. The Law 'On Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period up to 2030'[3] (28.02.2019) was adopted in 2019. One of the tasks of the law is "to reduce the environmental risks by minimizing its effects on the ecosystems, social and economic development and the people's health. There is an introduction of ecological risk management based on a modelling in real-time with the involvement of the latest information technologies."

Relevant research papers of the different scholars, e.g., Rudko (1991), Rudko *et al*. (1999), Rudko and Erysh (2006), Adamenko, Rudko and Kovalchuk (2000), Ivanyuta and Kaczynski (2012), Kasiyanchuk (2015, 2016), Bodnar (2015), and Klymchuk *et al.* (2008), are devoted to the prediction and assessment of the natural disaster risk in order to understand dangerous geological processes.

[1] https://www.dsns.gov.ua/
[2] http://komekolog.rada.gov.ua/uploads/documents/35969.pdf
[3] https://zakon.rada.gov.ua/laws/show/2697-19#Text

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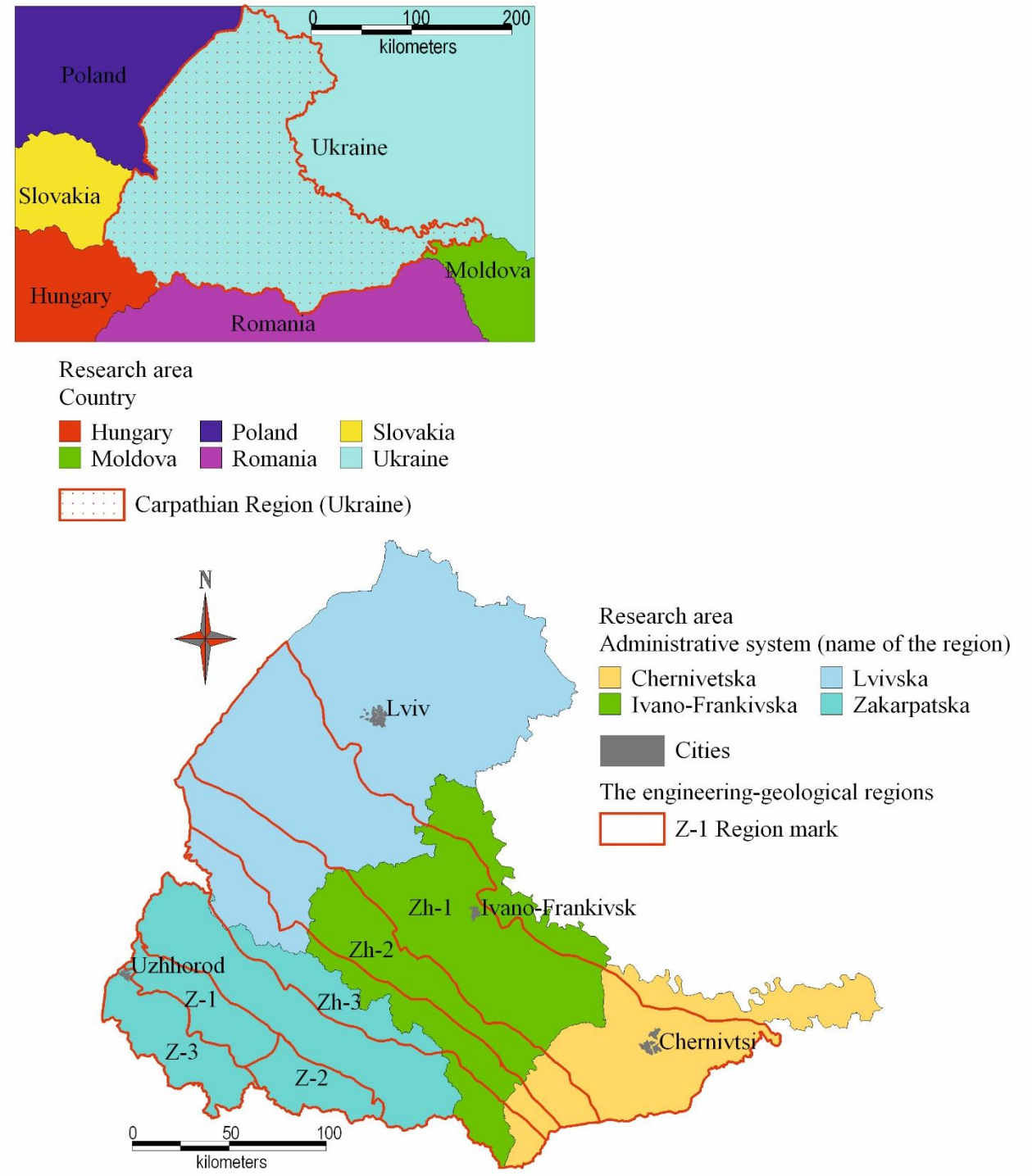

Figure 1: Engineering-geology maps of the study area

The spread and intensity of developing exogenous geologic processes, landslides, in particular, are influenced by the tectonic, seismic regime of the area, features of geological, geomorphological structure and hydrogeological conditions. Area zoning is necessary to determine the patterns of spread and development of exogenous geologic processes, landslides, in particular. According to the scheme of regional engineering geological zoning (Bodnar *et al.*, 2015), the studied area of Transcarpathian region and Chernivtsi region is located within the Transcarpathian Inner Depression and the Carpathian Fold System.

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This area, because of the differences in individual areas regarding the geological and climatic conditions of landslide development, was considered consisting of two separate regions: the Folded Carpathians and the Precarpathian Depression.

Methodology

This study was performed using the Geographic Information System MapInfo. An engineering geological zoning map with the contours of regions was drawn up. Since the studied region is characterized by zoning from northwest to southeast, main engineering and geological units are located in the same direction. The spatial database[4]included 2,339 landslides in Transcarpathian region and 1,119 landslides in Chernivtsi region (3,458 landslides in total) (figure 2). Such data set offers a possibility to conduct full analysis to assess risks based on an integrated time indicator. Nowadays, environmental risk modeling is performed through several approaches. The calculation of risk as an environmental and economic component of losses is basic tool. This article offers, for the first time, to expand and represent the principle, which would consider not only one component (population - the number of shifts) but also a full-fledged basis for developing a geo-information model based on spatial temporal analysis. This approach was implemented through the proposed method of calculating the environmental risk from the perspective of the negative effects of landslides.

Risk Assessment Technologies

The concept of 'environmental risk' defines the possibility of negative consequences that may arise because of landslides as they affect the health and safety for two reasons: first, a threat to human life during the landslide intensification; the second, huge economic losses with the destruction of the buildings, power lines, roads, which are located in the areas affected by the displaced rocks. Assessment of the environmental risk within the engineering and geological domain considers the registered landslides having special features of engineering and geological conditions of developing with the differences in the temporal factors, mode of landslide intensification(including the seismic activity), dynamic climatic factors such as annual temperature, annual precipitation, groundwater levels (Davybida *et al.*, 2018; Pona *et al.*, 2016; Tymkiv *et al.*, 2019) and solar activity (Shtohryn *et al.*, 2020), the influence of which is manifested indirectly through the air circulation, precipitation, and temperature. To determine the extent to which the engineering and geological regions, within the studied area, are covered by landslides, the 'damage coefficient' K_i, considering the influence of the natural factors and the tendency of the area developing the specified processes (Equation (1)), was used:

$$K_i = S_i / \sum S_i , (1)$$

Where S_i is the area of landslides within the engineering and geological region; $\sum S_i$ is the area of engineering and geological regions.

Transcarpathian Inner Depression covers an area of 5.58 thousand square kilometers. The landslides develop in quaternary clay alluvial-diluvial deposits on the river slopes and in the weathered layer of volcanic rocks. By the type of displacement, they are landslides of flow and landslides of sideslip (Velychko *et al.*, 2019). 820 landslides were registered in total within an area of 74.7 square kilometers with the damage coefficient of 1.4%, and a population density of 96.63 people per square kilometer within the depression. Average values of the landslide characteristics are absolute marks of 416.5 meters and the longitudinal profile steepness is 20.8°. The landslides have small dimensions: the length is 335.8 meters; the width is 339.3

[4]https://geoinf.kiev.ua/publikatsiyi/shchorichnyky/

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meters; the average deposit thickness is 3.85 meters. The main factors contributing to the development of landslides include special features of the geological structure (Shtohryn *et al.*, 2021), fault tectonics, high seismic activity, and the river network's density of 0.8-1.6 kilometers per square kilometer, which often form the floods and develop the lateral erosion, humid climate and human activity (Davybida *et al.*, 2018). The landslide intensification for the studied period took place in 1970, 1974, 1980, 1998-1999, 2001, 2008, and in 2010.

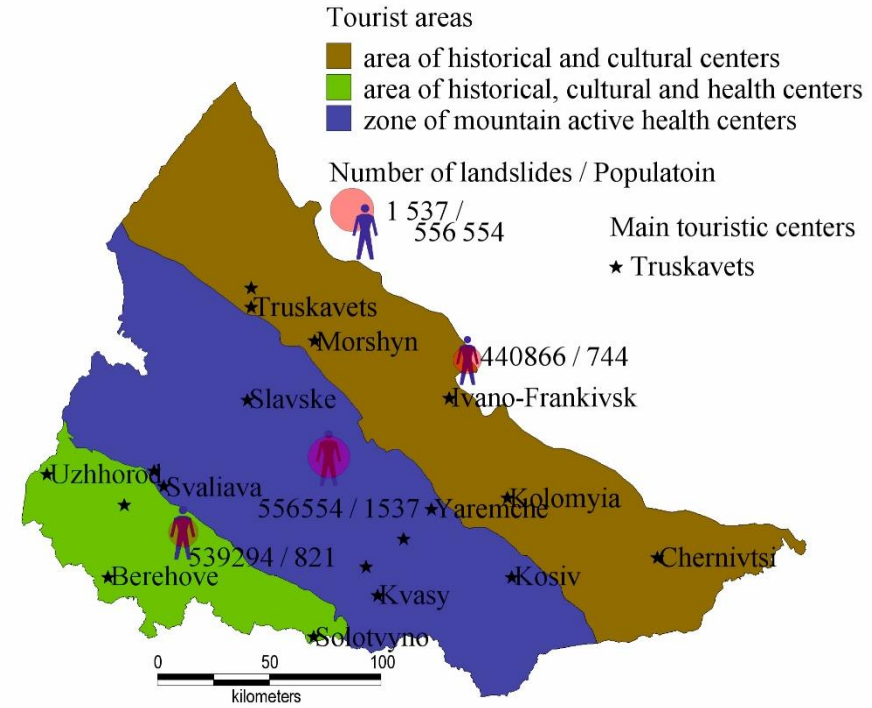

Figure 2: The map of the landslide activities, population and touristic zones

1,532 landslides were registered having an area of 256.17 square kilometers with the damage coefficient of 3% and the population density of 64.59 people per square kilometer in the studied Folded Carpathians expanded over an area of 8.62 square kilometer. Structural plastic flow landslides and complicated landslides, which develop at the junction of structural tectonic zones, were the most common. The flow landslides and landslides of sideslip predominate by the type of displacement. Important natural factors contributing to the development of the landslides include fine-grained clay flysch formation, which offers the conducive environment for landslides, seismic activity, a dense network of mountain rivers of 1.4-2.0 kilometers per square kilometer, significant relief energy, excessive atmospheric precipitation (average 1,180 mm per year), and human activity e.g., deforestation and slope cutting during construction works. The landslides are characterized by the following average parameters: absolute marks of 621.6 meters, the steepness of the longitudinal profile of 25.4°, the length of 442.2 meters, the width of 325.9 meters, and the deposit thickness of 13.1 meters. The landslide intensification for the studied period took place in 1970, 1974, 1980, 1998-1999, 2001, 2008 and in 2010.

The Precarpathian Depression within the studied region covers an area of 4.54 square kilometers, and it is the area that is the most damaged by the landslides. We have registered 744 landslides with an area of 351.6 square kilometers; the coefficient of damage is 7.8%, the population density is 97.2% people per square kilometer. Landslides of the Precarpathian Depression develop in quaternary clay alluvial-diluvial deposits, which accumulate in valleys of the Prut River and the Seret River. Absolute marks of the landslides are 270.7 meters, the steepness of the longitudinal profile is 17.2°, the length is 327.6 meters; the width is 1,046.5 meters, the deposit thickness is 4.9 meters. Besides the geological structure, the development of

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landslides is affected by the density of the river network i.e.,1.11 kilometers per square kilometer, the frequent high water in the local rivers, the low groundwater level and human activity (cutting slopes during the construction of linear-type facilities, selection of gravel and crushed stones). Time series of the landslide intensification includes 1969-1970, 1974, 1979-1980, 1998, 2001, 2005, 2008, and 2010. As we can see from the above, for the engineering geological regions, there are both common periods of widespread landslide activity and different periods that are regional stages of landslides stipulated by the local regime of climatic parameters.

Assessment of Ecological Risk of Landslides

Risk is a complicated system of calculations that must primarily study the cause-and-effect linkage between the factors of spatial spread and temporal dynamics of landslides. An important step shall be the analysis of the area in terms of the spread of the landslide areas or likely impact on human life. The first component is calculated as the damage, which has the physical meaning of the process for the spatial spread of landslides. The second component is the probability of risk for a human being under the condition of even distribution of the population. The first component of the spatial spread of the risk of landslides for individual regions was calculated according to the formula (2):

$$R_{yp_i} = \sum_{i=1}^{n} f\left(\Phi_{ij}\right) \cdot K_i \quad \ldots\ldots (2)$$

where $f(\Phi_{ij})$ is the value of the predicted probability of landslides within the region; K_i is the damage coefficient. The second component of the probability of risk formation for a human being within the individual engineering and geological regions was calculated according to the formula (3):

$$R_{pop_i} = \sum_{i=1}^{n} f\left(\Phi_{ij}\right) \cdot N / \sum S_i \quad \ldots\ldots\ldots (3)$$

Where $f(\Phi_{ij})$ is the value of the predicted probability of landslides within the region; N is the population within individual engineering and geological regions; $\sum S_i$ is the area of engineering and geological regions.

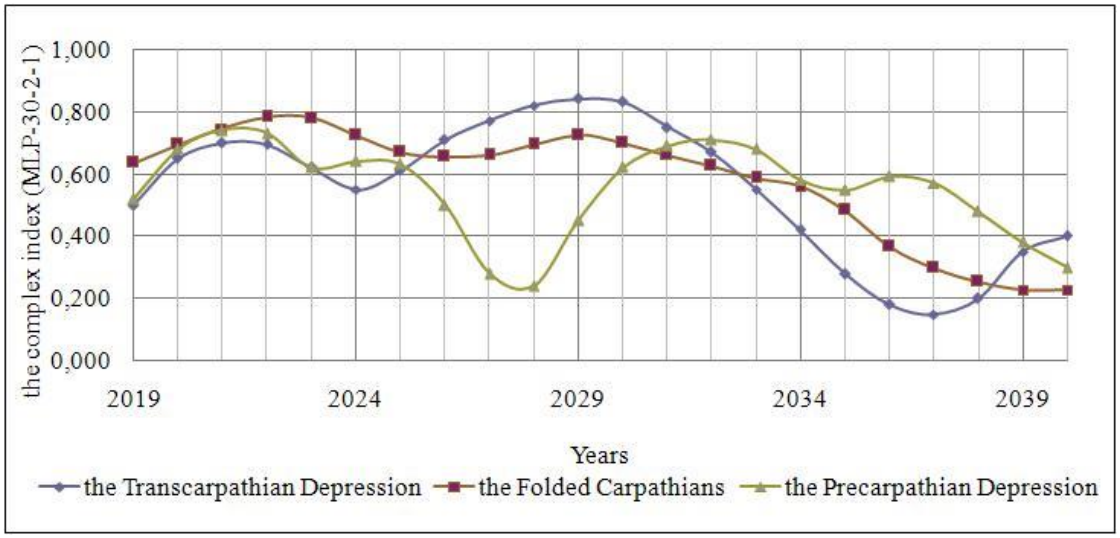

Figure 3: The temporal graphs of the probability of landslides

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Figure 3 demonstrates the temporal graphs of the probability of landslides in an average of values based on three points and the prediction using the MathCad integrated mathematical package and neural networks (Shtohryn *et al*., 2020).

An integrated risk assessment is performed by accumulating risks, which allows to assess to which extent the potential danger is growing in the future, considering the spatial distribution and predictive time series of landslide intensifications. Figure 4 demonstrates the risks of damage in the areas (a scale on the left) and risks to the life of the population (a scale on the right).

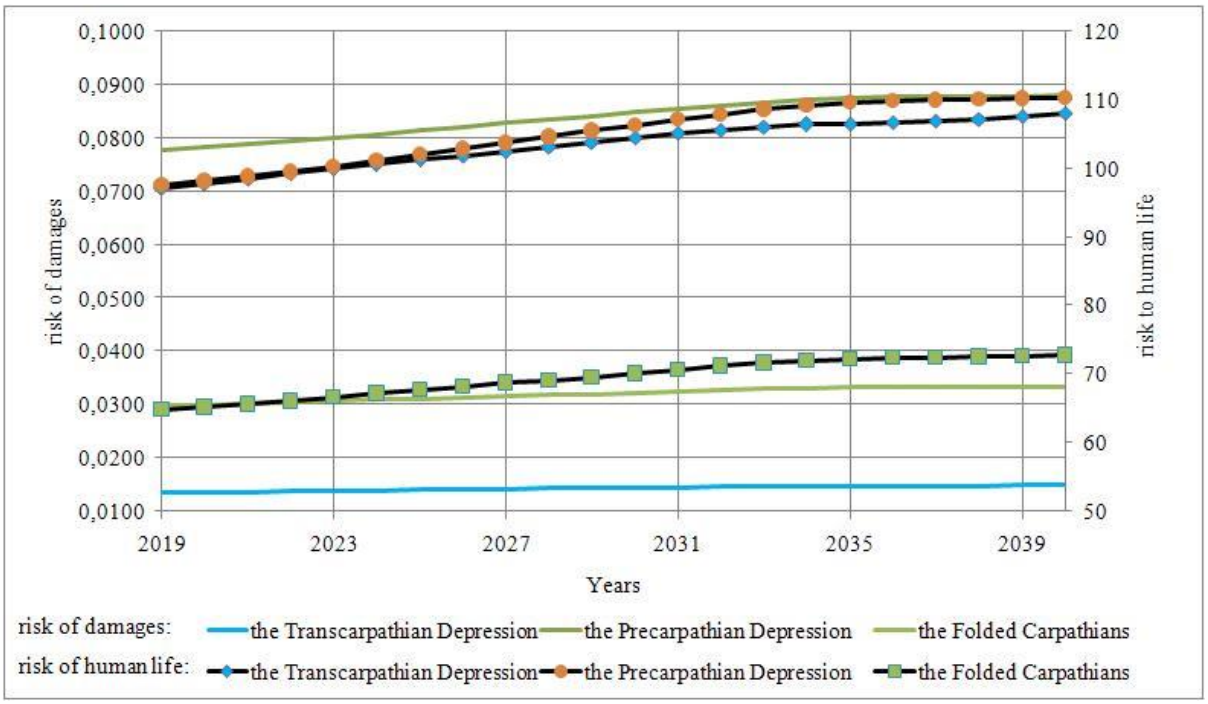

Figure 4: Natural environmental risk of long-term prediction of landslide possibility: the Transcarpathian Depression; the Folded Carpathians; the Precarpathian Depression

Analysis of the conducted calculations shows that the most dangerous region (in terms of growth of the areas covered by landslides) is the Precarpathian Depression, where the increase in the landslide damage is predicted by 12.32% for the twenty-year period forecast. For the Folded Carpathians, an increase in damage is predicted by 12.08%; for the Transcarpathian Depression region, the increase in the landslide damage is predicted by 11.72%.

Conclusion

The growth of the environmental risk from landslides closely relates to both the area of landslide development and the population density in the region. The calculated ecological and geological risks consider the peculiarities of temporal dynamics (the predicted possibility of landslide development), the spatial distribution of landslides (considering the differences in geological, tectonic, lithological structure, seismic, hydrological and climatic factors), and the population density within engineering and geological regions. Forecasting the possible intensification of the landslides and assessment of their spread should be considered while adopting the managerial decisions at the regional level in order to reduce the negative impact of landslides on the environment in terms of the economic and social consequences. Given the dynamics of landslide intensification and the growth of negative impact on the population while considering the time probability, the development of tourism infrastructure and its management need special planning

and scientific assessment. Engineering and geological conditions, combined with climate change, are crucial in the assessment of risks to human life and critical infrastructure in the Carpathian region. Intensive development of the tourism industry, poor planning and non-compliance with the requirements for construction in complex engineering geological conditions require the assessment of solutions based on a scientific approach that revolve around:

1. Understanding the risk as an ecological and economic basis for sustainable development of the region;
2. Creating a forecast time model of life risk, as a basis for building a system to prevent the negative consequences of the activation and development of landslides; and
3. Development of a geo-informational model of spatial forecast based on a time model of life risks at the local level as a basis for sustainable development in the future.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	No
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	No	Yes
Editing of the article/paper	Yes	Yes
Supervision	No	Yes
Project Administration	Yes	Yes
Funding Acquisition	Yes	Yes
Overall Contribution Proportion (%)	50	50

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During the research, the authors followed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Yes

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M – 00244 | Review Article

Articulating Fragrant Agarwood Formation as an Outcome of the Interaction between the Insect *Zeuzera conferta* and *Aquilaria* trees – A Review

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Abstract

Agarwood is the resinous infected wood obtained from *Aquilaria* species, which is a highly priced product in the flavour and fragrance market. Its formation is a complex process of interaction between the plant, insect, and microorganisms. Multiple studies concerning the interaction of microorganisms with the *Aquilaria* tree have been reported. However, the significant interaction between the insect *Zeuzera conferta* Walker (Lepidoptera: Cossidae) with *Aquilaria* has been overlooked, and only exiguous studies have been accomplished. Considering the dearth of available literature on this interesting phenomenon a review has been attempted. The taxonomical and morphological descriptions proffered by researchers and the insect life cycle are discussed. The review lays emphasis on the chemical ecology of the interaction between *Z. conferta*, *Aquilaria* and associating microorganisms as a possible continuum operating in the form of complex chemical signalling via release and sensing of Volatile Organic Compounds (VOCs), Herbivore Induced Plant Volatiles (HIPVs) and Microbial Volatile Organic Compounds (MVOCs). The review also scrutinizes the future perspectives of understanding the interaction in devising suitable management strategies to prevent uncontrolled infestation and, simultaneously, develop artificial rearing technology for the insect *Z. conferta* as a strategy for ensuring sustainable livelihood of farmers dependent on agarwood production.

Keywords

Insecticides; Frass; Taxonomy; Artificial rearing; Interaction; Lepidopteran

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Introduction

Zeuzera conferta Walker (Lepidoptera: Cossidae) is one of the principal insect pests that has been found to associate with the *Aquilaria* trees. It is also known as *Neurozera conferta* Walker (Syazwan *et al*., 2019). It belongs to the Class Insecta, Order Lepidoptera, and Family Cossidae in a systemic classification. It is widely distributed in Southeast Asian countries, Eastern Himalayas, Sri Lanka, Bangladesh, Taiwan, Andaman & Nicobar Islands and the Philippines. The insect is particularly prevalent in the agarwood plantations of the north-eastern part of India, particularly in the state of Assam, and is known to influence the formation of the rare resinous and fragrant agarwood by infesting *Aquilaria* trees. In fact, agarwood from Assam is regarded as a high-quality material in the global agarwood market. The borer insect is known locally as "Pukh" in Assamese and "Emphu" in Bodo languages, with both the terms meaning insect, which is used as a general nomenclature by the cultivators, traders, and people conversant with the *Aquilaria* trees in Assam. The *Aquilaria* trees, which belong to the Thymelaeaceae family, are commonly known as Agarwood, Eaglewood, or Aloes wood besides various other regional names. Agarwood is the dark-coloured resinous fragrant wood that has a high commercial value. Further, the formation of agarwood involves a complex process of interaction between the plant, insect, and microorganisms. The process of formation of agarwood is a defense response that is connected to this response to injury, created through natural and artificial means. To prevent or to recover from the injury, the *Aquilaria* trees produce oleoresins at the site of the injury as a product of plant defense response (Zhang *et al*., 2012). The site of the injury is colonised further by microorganisms leading to the accumulation of the oleoresin which is called agarwood.

So far, a total of 19 insect pests have been recorded to associate with the *Aquilaria* trees belonging to 16 families and 5 orders of which the preponderance of the sap-sucker is found higher, followed by leaf defoliators and lastly wood borers (Syazwan *et al*., 2019). However, the wood borer and the leaf defoliator form the major pest of the *Aquilaria* trees causing a serious damage to the *Aquilaria* trees (Ong *et al*., 2014). The larvae of the wood borer *Z. conferta* Walker (Figure 1) infest the woody stem of the *Aquilaria* trees and facilitate subsequent microbial infections. The larvae make vertical tunnels inside the trunk of the *Aquilaria* trees as they feed and move up spreading the microbial infection where the oleoresin accumulates (Kalita *et al*., 2015). From brown streaks to dark brown and finally to black coloured wood are the changes that occur in the healthy wood where the initial infestations occur. Successively, these lead to stunted and poor development, formation of cankers on the trunk, swelling, symptoms of dieback on the top and outer branches of the trees (Nath and Saikia, 2002). Subsequently, the scenario of a visible wound, stem distortions, decayed branches, uneven and irregular trunk, and odoriferous dispenses evidence of agar formation inside the tree. The incidence of *Z. conferta* is, however, not observed in all the *Aquilaria* trees that are grown. Its selectiveness in infesting the *Aquilaria* trees is interesting, as significant differences are being observed in the infestation process among the *Aquilaria* trees that are grown separately at a distance of a few meters with one area being completely infested and the other area with none. These variations in the infestation process have led the traders to practice artificial process of injury and induce infections through physical, chemical, and biological means or by their combinations as a method of treatment in the *Aquilaria* trees where insect incidence is not usually observed. However, the increase in commercial demand and slow natural process of agarwood formation have also pressurized the traders to execute the process of artificial infections (Chippa and Kaushik, 2017). Despite its success in producing agarwood through the application of artificial techniques, the quality of the agarwood remains an issue and is found incommensurate in comparison to naturally occurring ones (Kalita *et al*., 2015). Moreover, the price of the agarwood, the durability of the fragrance, long shelf life, and the extent of the microbial attack are all found to be higher in agarwood that is induced only after the insect (*Z. conferta*) infestation (Hoque *et al*., 2019).

Even with these evidence about the importance of the *Z. conferta* in the formation of agarwood, studies are yet to elucidate its actual role. There is a possibility of insect- microorganism in relation which it might have a role in the superior quality agarwood formation (Hoque *et al*., 2019). However, literature is deficient concerning *Z. conferta* and, therefore, in the present review, efforts have been made to compile the

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information scattered in diverse domains and bring out the perspectives that require a closer study to improve agarwood production in future.

Figure 1: Larva of *Zeuzera conferta* Walker: The process of extracting larvae from the *Aquilaria* trees firstly involves selecting the trees with the help of frass. The texture of the frass is checked to differentiate between the old and the new infestations. Dimmed coloured and dry frass indicates the old infestations whereas brightly coloured and wet with moisture intact indicates the new ones. The newly infected trees are selected and cut off and are brought into the agarwood processing centres. The stems are first cut into sections horizontally with the help of the chainsaw, few centimeters below and above the infestation point. The later are split into many symmetrical parts from top to the bottom edge vertically, thoroughly until the larvae comes out. [*Source*: Field trip, 2021]

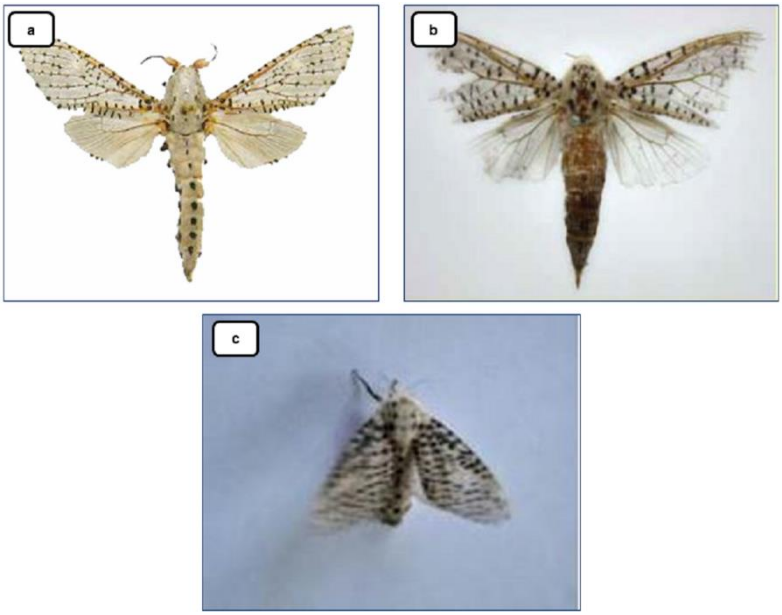

Figure 2: Morphology of Adult *Zeuzera conferta* Walker. (a) Male (♂) *Z. conferta* Walker specified by Yakovlev (2011) from Sylhet region of Bangladesh, host plant unspecified. (b) Female (♀) *Z. conferta* Walker specified by Ong et al. (2010) from *Rhizophora apiculata* plant in Malaysia. (c) *Z. conferta* Walker specified by Borthakur et al. (2021) from *Aquilaria malaccensis* plant in India, gender (♂/♀) Unspecified. [*Source*: Photographs reproduced with permission from respective publishers]

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Taxonomy, Morphology and Development

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Cossidae
Genus:	*Zeuzera*
Species:	*Zeuzera conferta*

The genus *Zeuzera* was classified based on the external characters only, for instance, the presence of the crossvein Subcosta (Sc)- Radius Sector (Rs), the shape of the humeral plate, and the length of the anal plate (Sutrisno, 2015). From a total of 52 species across the world, only 5 are reported to occur in the Indian Subcontinent (Arora, 1976). According to the original illustration given by Walker (1856) on the *Z. conferta*, the female is whitish with black antennae. The thorax possessed two interrupted green stripes and three rows of green spots in the abdomen. Legs are reported to be mostly green and wings with innumerable tiny transverse green or aeneous streaks with green dots down the border. The fore wings are without streaks at the parts of the disk. The length of the body has 13 lines and wings having 28 lines. The species is known from the Sylhet region of Bangladesh and Labuan and Luzon of the Philippines. It is reported to be close to *Zeuzera indica* Herr. -Sch regarding the origin of the vein in the fore wing and the evenly rounded outer margin in the hind wing. However, phylogenetic studies based on the Cytochrome Oxidase subunit I gene (COI) sequence revealed *Z. conferta* to be closely related to the *Z. lineate* (Sutrisno, 2015). The COI gene is regarded as highly conserved and felicitous in identifying a species due to its low variability (generally less than 1-2%). Even for closely associated species, its value is found to be less than 1%. Furthermore, for Lepidoptera the COI gene is one of the most common to be used in inferring the relationship among the closely related species. Yakovlev, (2011) stated the species to be medium in size with males possessing cup-shaped antennae and filiform in females (Figure 2a). Dorsally the thorax of the species is white and patternless, with minute black dots on the lateral surface, rounded minute segment on the abdomen, and laterally minute pair of black dots on every segment. Further, elongated forewings, apically acute, white to coffee-coloured, dark bright dots on wings margins, with minute rows of black dots on veins and patternless hindwing with indistinct dark spots on the outer margin characterize the species morphology. The uncus of the male genitalia was long, with middling thickness, with a minute acute apex of the beak in shape. Separately, thick gnathos, a leaf-like smooth valve at margins of middling thickness, and juxta with a well-developed lateral process. The saccus was small and semi-circular and aedeagus short, thick, and slightly curved in its proximal third with no cornutes. Nevertheless, the genitalia of the female were not studied. The pupae and adults have been recorded by Ong *et al*. (2010) concerning *Rhizophora apiculata* plant. Furthermore, Senthilkumar and Murugesan (2015) reported the male forewings to have black spots being strongest on the vein and opaque white zone, free of black spots, at the end of the cell and in female presence of typical transverse black striae and again black spots free zone at the end of the cell. Adult females are, however, found to be larger than males, possessing long ovipositor at the end of the abdomen, enabling them to position their egg in the bark crevices (Ong *et al*., 2010) (Figure 2b). However, the latest studies carried out by Borthakur *et al*. (2021) on the *Z. conferta* biology, revealed the adult to be of medium in size with a wing expanse of 27 to 35 mm. The arrangement of the forewings was found to be flickering bluish to black in colour with asymmetrical striations or white pellucid background. The hindwings were also reported to be spotty and translucent. The abdomen was brownish in colour and beard black dots which was covered with fur (Figure 2c).

Overall, the genus *Zeuzera* has been actively studied by Roepke (1955; 1957), based on New Guinea and Malayan fauna, and Holloway (1986), based on Bornean fauna. The latter suggested the genus to be similar and well-defined sections of *Xyleutes*, a genus of moths that belongs to the Cossidae family. Schoorl (1990) also conducted a detailed study on the morphological aspects of the genus *Zeuzera*. The genus was

interpreted based on the presence of crossvein Sc-Rs, humeral plate triangular in shape and anal plate comparatively long to short. Based on his hand cladogram, various characteristics believed to be apomorphies of genus *Zeuzera* and its relationship within its genus were also presented. However, it was felt that his study needed further assessment due to the growing evolution of understanding in the field of study to testify its validity (Sutrisno, 2015).

The species of the *Zeuzera* mostly live as a larva in plants (Sutrisno, 2015). Eggs are laid by the female moth chiefly in groups directly in cracks, crevices of the stem and larger branches of the host plant (Moaty *et al*., 2019). A total of 180-250 eggs are laid by the single female *Z. conferta* in one batch with the size ranging from 0.2 mm in length to 0.1 mm in breath (Borthakur *et al*., 2021). The caterpillars emerge out from the egg after its development and are called first instars till it molts. It enters the second instars after the molt and increases in size. Every stage of molting distinguishes another instar. Typically, a caterpillar passes through a total of five instars as it eats and grows, wherein each instar its general appearance changes from one to the next. According to Borthakur *et al*. (2021), the size of the larvae increased from 0.03 cm to an average of 4.5±0.7 in length and from 0.02 cm to 0.06 cm in breath from first instars to fifth instars. The change was also observed in the colour pattern of the larvae form light reddish pink to light pinkish from first instars to fifth instars. Before entering the stage of the pupation, the matured larvae prepare the pupal tunnel and also the exit hole near the bark surface. The pupa measured 1.9 to 2.5 cm in length and 0.05 cm in breath and weighted 0.46 gm and completed its pupal period within 14-30 days and emerged out as an adult moth. In conclusion, they reported that *Z. conferta* have two generations in a year that was also earlier reported by Baksha and Islam (1999), with regards to *Sonneratia apetala* trees in Bangladesh.

Ecology and Interactions

Diversity of Hosts

Besides *Aquilaria* trees, the *Z. conferta* has a broad range of host of different families such as *Sonneratia apetala, S. alba, S. ovate* of family Lythraceae, *Aegiceras corniculatum* of Myrsinaceae, *Avicennia lanata*, *A. marina*, *A. officinalis* of Avicenniaceae, *Ochroma lagopus* of Bombacaceae, *Eucalyptus deglupta* of Myrtaceae, *Rhizophora apiculata, R. mucronata* of Rhizophoracaea, *Theobroma cacao* of Sterculiaceae, *Coffea* of Rubiaceae, *Erythroxylum* L. of Erythroxylaceae, *Elettaria cardamomum* of Zingiberaceae and *Tamarix indica* of Tamaricaceae family (Islam, 2004; Yakovlev, 2011). The preferential habitat of the majority of these host trees are coastal mangrove forest, moist, lowland with few from the tropical forest (Ong *et al*., 2010; Senthilkumar and Murugesan, 2015). The larvae target the stems, trunks, twigs, and shoots of the host plant for the infestation. The association of *Z. conferta* with *S. apetala* is extensively studied in Bangladesh where the larva of *Z. conferta* is also termed as “bee hole borer”. The tree *S. apetala* is largely utilized as a plantation species to construct a shelter belt along with the coastal areas and offshore islands of Bangladesh. The larva is reported to bore in the barks and later make large, profuse, oval, and ramifying tunnels in the stem rendering the tree to wind breakage. Later, the larvae and pupae of the *Z. conferta* are found to be eaten by woodpeckers such as *Dinopium benghalense* and *Picoides canicapillus* and small black ants (Islam, 2004). In *Avicennia* spp., the infestation by the larvae *Z. conferta* is reported to occur at an interval of 7 years in natural mixed forest of Brazil (Vannucci, 2002). Few other host plants of the *Z. conferta* includes Cocoa (*Theobroma cacao*), Balsa, Coca (*Erythroxylum* P. Br), and *Barringtonia* (Arora, 1976; Schoorl, 1990). It is however interesting to note that with regards to these hosts of *Z. conferta*, only in *Aquilaria* trees it is reported to have a productive role i.e., in the formation of resinous wood called as agarwood.

Interactions: Insect-plant-microorganism

Plant and its biotic interactions in natural environment have diverse manifestations. In nature, plant interacts with the insect by attracting pollinators for sexual reproduction on one side and, on the other, protecting

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itself from herbivores, pathogens and even other plants by synthesizing various chemical compounds (Schiestl, 2010). Plants, being sedentary organisms use volatile compounds as a vernacular to communicate and interact with the surrounding environment (Dudareva *et al*., 2006). Volatile organic compounds (VOCs) are released by the plants constitutively that herbivores utilize for host location (Penaflor and Bento, 2013). The chemical signals are perceived by the herbivores with the aid of olfactory system and commence the behaviours for communication with the host (Field *et al*., 2000; Fatouros *et al*., 2008; Leal, 2013). The attraction of the insect towards the host plant is due to the volatile phytochemicals, which are perceived by specialized chemoreceptor neurons on the antenna (Loon, 1996). Herbivores are recognized by the plants through damage-associated molecular patterns (DAMPs) and herbivore-associated molecular patterns (HAMPs), also called as elicitors that include extracellular protein fragments, nucleotides, peptides, glucose oxidase, fatty acid-amino acid conjugates (FACs), β-glucosidase, inceptins, and caeliferins (Giron *et al*., 2018; Hogenhout and Bos, 2011). The herbivore attack on the host plant releases a large diversity and a greater amount of VOCs, called as Herbivore Induced Plant Volatiles (HIPV) (Paré and Tumlinson, 1999; Howe and Jander, 2008; Penaflor and Bento, 2013). HIPVs are important olfactory cues produced by the plants under herbivores attack, in a manner that they reveal indirect information about the presence of the herbivores (Aartsma *et al*., 2019). Parasitoids, specifically carnivorous insects use HIPVs in locating and regulating the herbivores as their natural enemies (Forbes *et al*., 2018; Kessler and Heil, 2011) resulting in tritrophic interaction. Terpenoids, aromatics, green leaf volatiles (GLVs—C6 aldehydes, alcohols, and their esters), and amino acid volatile derivatives are some of the volatiles emitted by herbivore-damaged plants (Dudareva *et al*., 2006). The recognition of the DAMP and HAMP by the plants activates the diverse defense mechanism in the plants aiming to reduce the damage caused by the herbivorous insect (Giron *et al*., 2018). Plants respond to the herbivores attack by two mechanisms known as Direct and Indirect defense. Direct defense includes all plant traits enhancing the resistivity of the plant and, thereby, changing the insect's behaviour or physiology. Indirect defense, on the other hand, includes all the plant traits but does not have a direct effect on attacking herbivores but it can attract the natural enemies of the herbivores that can be any carnivorous insects (Aljibory and Chen, 2018). The metabolites of lipoxygenase (LOX) pathway, the shikimic acid pathway, and product of the terpenoid pathway are the prevalent volatile signals involved in direct and indirect defense (Pichersky and Gershenzon, 2002). However, some herbivores have developed resistivity to such a response and alter plant metabolism by injecting effectors into the host plant and repress the plant defense system (Hogenhout and Bos, 2011; Kaloshian and Walling, 2016; Giron *et al*., 2018). Secondary metabolites of the plant also act as the defense system towards the insect herbivory and also several classes of secondary products are produced through infection, wounding, or herbivory. Insect, however, becomes immune or develops an adaptation mechanism to such a defense mechanism of plants due to feeding on or infecting a particular plant (Bennett and Wallsgrove, 1994). Throughout the phase of feeding or during egg deposition, the herbivores alter the phenotype of the plants through changes in the production of central and specialized metabolites, morphological traits, and architecture (Dicke and Baldwin, 2010; Hilker and Meiners, 2010; Howe and Jander, 2008; Mithofer and Boland, 2012).

The oviposition of the insect has also been found as a threat to the plants. Similar to herbivory induced volatiles, the oviposition by the herbivores also activates the release of oviposition induced volatiles (Hilker *et al*., 2002; Fatouros *et al*., 2005b; Salerno *et al*., 2013). The female wound the trees prior to the egg deposition and the elicitors which is procured from the secretion attaching eggs to plants, forge contact with the inner plant tissues through this wound inflicted (Hilker *et al*., 2005). The female has the aptitude to acknowledge the finest plant or host quality for the fine growth of larvae. The mechanism of specific site preference for oviposition by the female is also a master plan to procure defense against predation on premature stages of development. The oviposition is a critical step, peculiarly in Lepidoptera, owing to the relative immobility of the hatching larvae and thus depending on the judicious choice of food plant by the adult female (Fenny *et al*., 1983; Renwick, 1989). Various events leading to oviposition follows a sequence of searching, orientation, encounter, landing, surface evaluation, and acceptance (Renwick and Chew, 1994). All these stages of the sequence depend on the sensory cues of the insect; however, definitive experiments of the sequential mechanism are difficult to perform (Morris and Kareiva, 1991). After the

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insect gets descend on a plant, it determines its site suitability for oviposition through the physical and chemical contact perception on the various surface of plants. Tarsi, antennae, proboscis, and ovipositor of lepidopterans are the sensory receptors involved. The Central Nervous System (CNS) acts as the final processing of information provided by the various sensory inputs received by the insect acceptance or rejection of a site for oviposition (Renwick and Chew, 1994).

The microorganisms also interact with the insects through the production of microbial volatile organic compounds (MVOC). The MVOCs have been found to closely associate with the behaviour of the insects (Davis *et al*., 2013). Insects are sensitive to odours and highly responsive to microbial volatile emissions (Ezenwa *et al*., 2012; Price *et al*., 2011). MVOCs have ecological functions such as some MVOCs that can attract or repel insects, stimulate oviposition, inhibit the growth of microorganisms competing the associate insects, mimic plant hormones or induce defense resistance (Davis *et al*., 2011; Ryu *et al*., 2003, 2004). The microbial associates are also responsible for the important physiological functions of the insects (Haine *et al*., 2008; Rozen *et al*., 2008) and the interaction of the insect-microbes might even play a significant role in quorum sensing (Lowry *et al*., 2008; Ma *et al*., 2012; Tomberlin *et al*., 2012a). Symbiotic microorganisms associated with the insect also play a role in finding a suitable host and food resources for the insect (Davis *et al*., 2013).

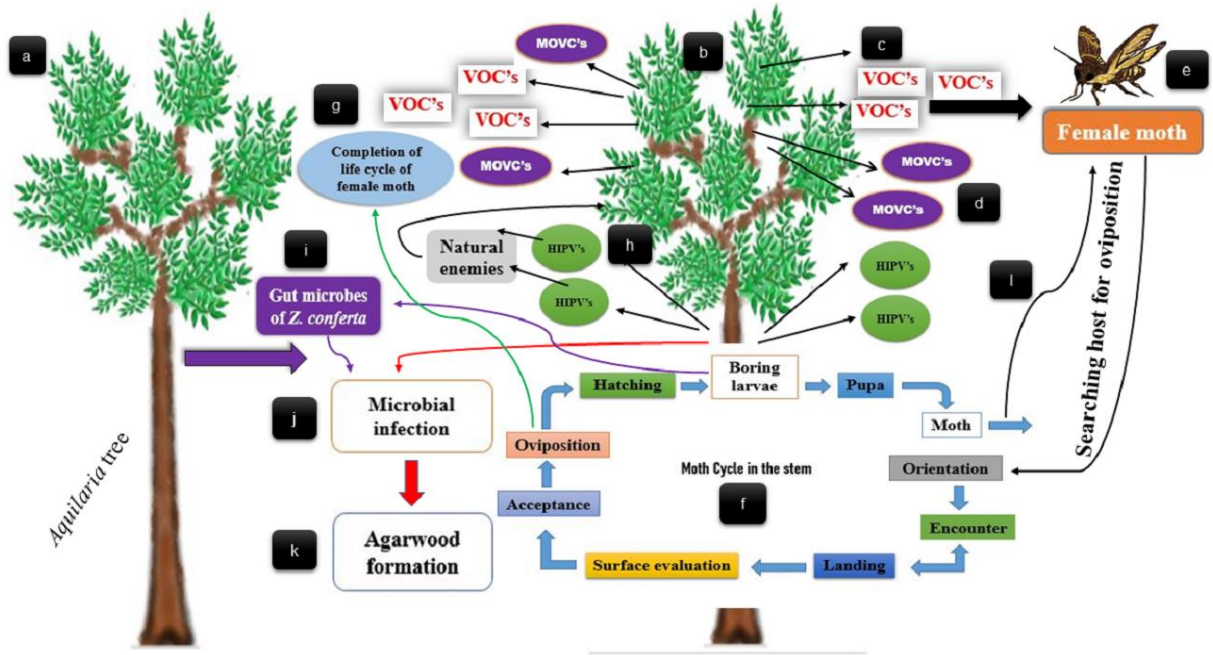

Figure 3: Interactions of *Zeuzera conferta* Walker linked in agarwood formation: (a) *Aquilaria* tree (b) Insect mediated agarwood formation in the *Aquilaria* tree through series of interactions between insect (*Z. conferta*)-plant (*Aquilaria*) and microorganisms. (c) The *Aquilaria* tree releases VOCs (Volatile Organic Compounds) (d) Microorganisms from the host tree also releases MOVCs (Microbial Organic Volatiles Compounds). (e) The female moth perceives the volatile compounds through their olfactory system from the surroundings. (f-g) Using volatile compounds the moth seeks for the host location and undergoes different series of events preceding the oviposition, checking the suitability for oviposition at the favourable site in the stem. On finding the suitable site the female moth lay eggs and completes its life cycle. The hatched larvae then commence the activity of the infestation by forming tunnels in the stem. (h) The tree releases HIPVs (Herbivore Induced Plant Volatiles) after the infestation to attract the natural enemies (e.g., carnivorous insects) of the larvae and establish a mutualistic relationship with the tree. (i-j) Microbial infection occurs along the tunnels created by the larvae, where the accumulation of resin occurs. The gut microbes of the *Z. conferta* also act as a source of microbial infection. (k) The accumulated resins across the tunnels are later called as agarwood. (l) The larvae emerge out as an adult moth from the exit hole after completing its life cycle.

Till date there is no scientific evidence and no experimental studies have been executed to explain about the mechanism of interaction between the *Aquilaria* tree and *Z. conferta*. Moreover, meagre studies have been accomplished on the biology of *Z. conferta*. Based on the analogous strategy of insect-plant interaction, therefore, the insect *Z. conferta,* and *Aquilaria* tree might also trail a similar pattern of interaction (Figure 3a- l). The *Aquilaria* tree (Labelled a) might produce aroma related volatiles such as Volatile Organic Compounds (VOCs) to attract the herbivore, *Z. conferta* (c) as the plant volatiles are the significant molecules in the insect-host recognition (Qiao *et al*., 2012). The adult moth, *Z. conferta* then possibly detect the signals of the various volatiles released by the *Aquilaria* trees through their olfactory system and receives through the chemoreceptors (e). As VOCs possess the potential to trigger the behaviour of the insects, it might stir up the adult *Z. conferta* to look for the host plant for the oviposition. On finding the host plant, the adult female moth then undertakes various sequence of events preceding the oviposition in order to confirm the suitability of the oviposition at a favourable site in the host plant (f). On obtaining the suitable site the female moth lay eggs and completes its life cycle (g). The larvae which emerged from the eggs then initiates the phase of infestation in the *Aquilaria* trees by chewing the wood. Throughout the period of infestation, the larvae might inject various elicitors into the woody stem of the host plant. The host plant then activates its diverse defense mechanism to combat the herbivory by synthesizing disparate secondary metabolites and also releasing various HIPVs. The HIPVs are released by the *Aquilaria* trees to attract the natural enemies of the *Z. conferta* and accordingly maintain a mutualistic relationship with the trees (h). Hitherto, however there has been no literature available with reference to the natural enemies of the *Z. conferta*. The injection of the elicitors represses the defense mechanism of the *Aquilaria* trees and the larvae of *Z. conferta* might survive the phytochemicals released by the *Aquilaria* trees. The microorganisms present in the tree might also emit the Microbial Volatile Organic Compounds (MOVCs) triggering the behaviour of the insect *Z. conferta* (d). Fungi of the genera *Fusarium* and *Lasiodiplodia* have been reported to produce two compounds, δ-lactones and mullein that releases an odour having the potential to act as an insect attractant (Nago and Matsumoto, 1994). The interesting finding is that both these fungi are associated with the *Aquilaria* trees (Mohamad *et al*. 2010; Chippa and Kaushik, 2017). Therefore, such microorganisms might also be releasing the volatile compounds and alluring the insect *Z. conferta* towards the *Aquilaria* trees. In a chemometric evaluation of interaction study carried out by Sen *et al*. (2017), between the agarwood and fungus *Fusarium*, revealed the appearance of ecologically important semio-chemicals (e.g., Pheromones). Semio-chemicals are the organic compounds that have the potential to stimulate the activity of organisms used by insects and other animals for the purpose of biological communications. The role of semio-chemicals, however, in the fungal colonization in *Aquilaria* trees through the insect *Z. conferta* intervention needs further investigation. Consequently, after the infestation of the larvae in the *Aquilaria* tree, spiral, oval, or ring-shaped injury or wound (Figure 4a) is developed serving as the gateway for initiation of microbial infection (Kalita *et al*., 2015) and the tree response to it by the formation of resinous wood called agarwood along the zone of infestation as a mechanism of defense reaction (Figure 4c) (j-k). The size of the tunnel increases as the larvae grow and also the metamorphosis from larva to pupa takes place inside the tree. The pupa partially moves out from the exit hole before finally attaining its maturity as a moth (Ong *et al*., 2010). The larvae then complete its life cycle and emerges out as adult moths through the exit hole leaving the exuvia intact (l). However, the release of the HIPVs by the *Aquilaria* trees to attract the natural enemies of the *Z. conferta* and to prey on it might debarred it from completing its life cycle. Research carried out on the antennal and behaviour response of the *Heortia vitessoides*, one of the major leaf defoliator pest of the *Aquilaria* tree also showed that the female moth was attracted to the volatiles of the green leaves possessing the compounds such as nonanal, decanal, hexanal, and (Z)-3-hexenylacetate rather than the dry leaves, forming the vital constituent for the minimal attraction of the insect (Qiao *et al*., 2012; Syazwan *et al*., 2019). Finally, as the *Aquilaria* tree matures, it closes its exterior entry and exit hole leaving a distinct lesion (Figure 4b).

The microorganisms present in the gut of the *Z. conferta* might also have an indispensable role in infecting the *Aquilaria* trees as they are assigned with various significant roles in their host metabolism, physiology, growth, reproduction (Breznak, 1982; Chen and Purcell, 1997; Lemke *et al*., 2003). The larvae might act as

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vectors and release potential microbes to induce the infection through the excretion process during the tunnelling pursuit. Study on the diversity of the microorganisms associated with the gut of the larvae and comparative analysis with the microbes associated with *Aquilaria* trees and in resinous agarwood might help us understand and correlate the mechanism of insect-plant and microorganism's interactions. Analysis on the potential role of the endophytic microbes associated with the *Aquilaria* trees in producing odorous compounds will help us in a deeper understanding of its capability of alluring the *Z. conferta* towards *Aquilaria* trees. Furthermore, the study of the difference between the insect-infested and non-insect infested *Aquilaria* trees will also contribute to a broader way of understanding of the mechanism of insect infestation, as *Z. conferta* is not found to invade all the *Aquilaria* trees in the same environment.

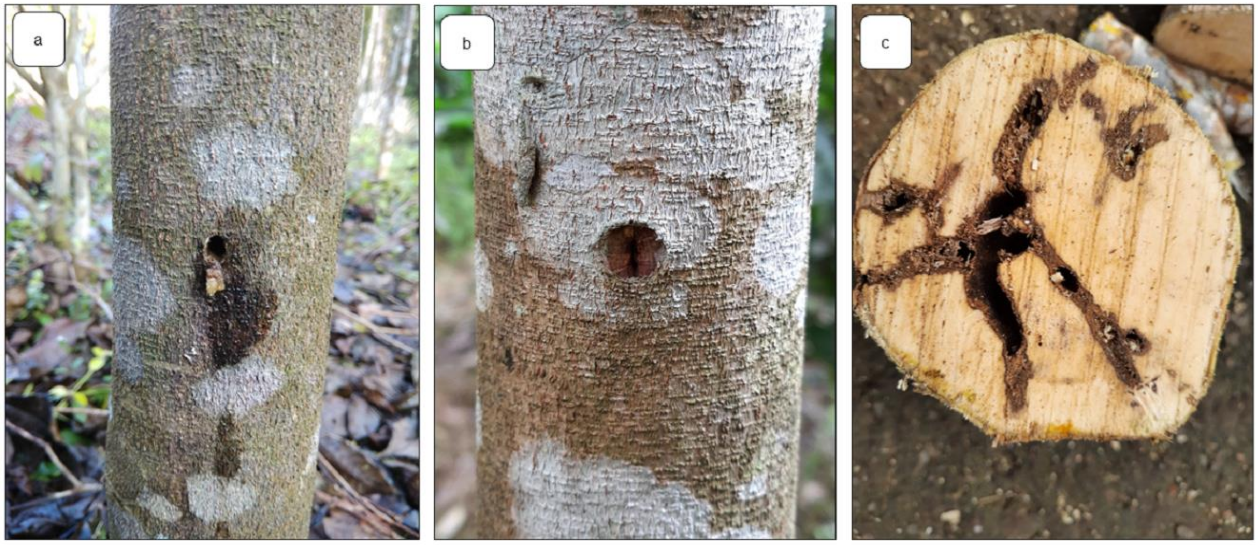

Figure 4: Resin formation at the site of infestation: (a) Spherical wound created by *Zeuzera conferta* infestation. (b) Closure of the wound as the tree attains maturity. (c) Formation of agarwood along the tunnels created by *Zeuzera conferta* inside the stem of the *Aquilaria* tree. [*Source*: Field trip, 2021]

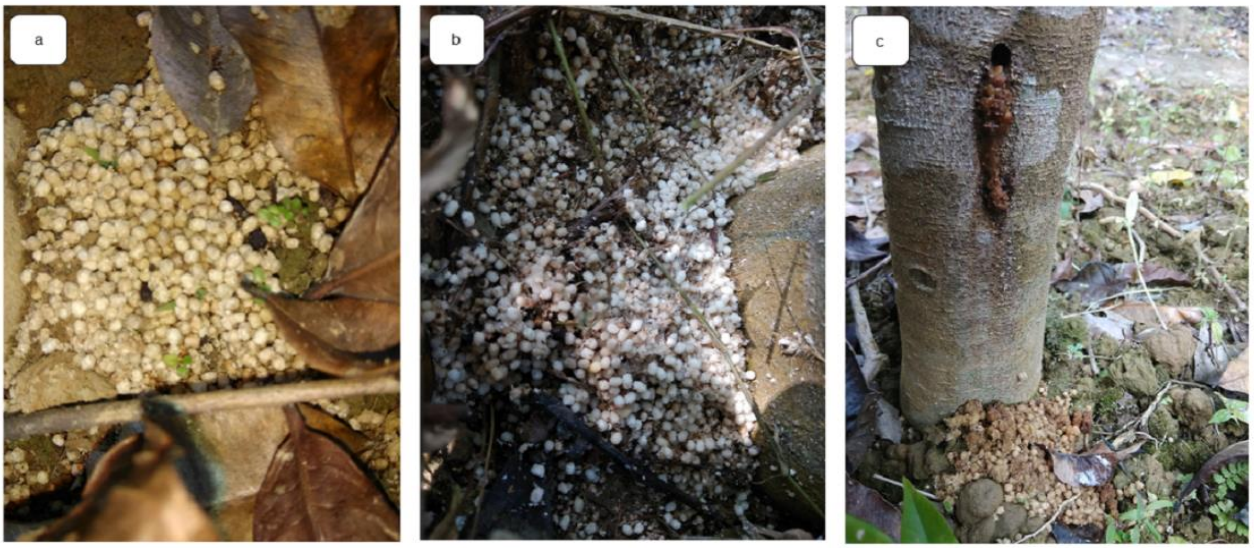

Figure 5: Insect frass as indicator: Frass or faecal pellets emancipated after the *Zeuzera conferta* infestation in the *Aquilaria* trees. (a) Dry, dimmed coloured frass (b) Whitish, freshly released frass (c) Sticky, brownish coloured frass. [*Source*: Field trip, 2021]

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Present and Future Perspectives

Zeuzera conferta – a pest?

The association of the *Z. conferta* with the *Aquilaria* trees can be referred to as "necessary evil". The infestation by the borer in the young *Aquilaria* plants causes a major threat to its survival as the activity of tunnelling by the borer damages the tissues of the plants. However, its desideratum cannot be ruled out, as agarwood of good grades is obtained only when the trees are infested by it (Hoque *et al*., 2019). The damage caused by the *Z. conferta* in *Aquilaria* trees is still considered as moderate level apart from the other 19 pests that are found to associate with the trees (Syazwan *et al*., 2019). The people familiar with the *Aquilaria* habitats and plantations are very much cognizant of the necessity of its association with the *Aquilaria* trees. Even people in the locality who are not directly associated with agarwood farming are also familiar with its essentiality. Yet, the scientific knowledge of different mechanisms of formation of agarwood is unknown to them.

Despite having a prominent role in assisting fine agarwood formation, it remains as a major drawback for most of the *Aquilaria* cultivators owing to the damage it causes by infesting in the young *Aquilaria* plants leading to the stunted growth and sometimes death of the plants. The term pest is reckoned for an insect or a microbe in the agricultural practices if it interrupts the progression or the development of the plant (Syazwan *et al*., 2019). The commencement of the infestation of the pest *Z. conferta* is observed in the plants attaining 5 years, and maximum in the trees of age group 8-16 years and moderately above 16 years (Kalita *et al*., 2015). The cultivators have, therefore, taken quite a few measures to protect the *Aquilaria* plants from infestation by the *Z. conferta*. Some of the measures are (i) spraying of the insecticides on the surface of the tree, (ii) spraying of the insecticides directly on the holes made by the borer on trees, (iii) killing of the insect directly when found, and (iv) killing the female moth before oviposition. The measures taken are performed seasonally based on the availability of the insects. The event of killing is intermittent as it is performed only when the insects are found. However, the spraying of the insecticides is performed when the rate of an infestation is found to be higher based on the observation. Few other management practices that have hitherto been executed are trimming and removal of the infected branches, shutting off the hole made by the insect with plasticine (liquid-based pesticides), and application of the granule-systemic based pesticides (Syazwan *et al*., 2019). Pheromones, mass trapping, mating disruption, entomopathogenic fungi, and nematodes are other control measures that have been successful in controlling the lepidopteran pest (Ibrahim *et al*., 2019; Ong *et al*., 2010). The practise of spraying insecticides is carried out when the trees are young and are heavily infested by *Z. conferta.* However, when the trees attain its maturity, the incidence of the *Z. conferta* is not much of a concern and the practice of spraying insecticides lessens as the tree becomes less vulnerable to breakage and damage. The insecticides used and their effectiveness in controlling the incidence of *Z. conferta* is needed to be analysed in detail. However, the application of the pesticides in controlling the incidence of the pest has become increasingly knotty due to concern about human health hazards, environment and pest resistance (Atreya *et al*., 2012). Furthermore, the obscure habitat of the larvae inside the trees and prolonged ovipositional period makes the chemical treatment less successful (Shamseldean *et al*., 2009).

Frass

The frass of the *Aquilaria* trees acts as an indicator of the incidence of the *Z. conferta* (Figure 5). Frasses are the excrement or the excreted pellets which are released by the larvae after feeding on their food source. In wood borers the frass from the tunnelling activity is expelled out from the entry and exit hole on the ground (Ong *et al*., 2010). The expelled frass helps the seeker, seeking the activity of *Z. conferta* in the *Aquilaria* trees for confirmation about the infestation just by scrutinizing the presence or absence of the frass on the ground surrounding the *Aquilaria* trees. The frass varies in shape and colour with some spherical or oval in shape and white in colour and some wet sticky powdered with brownish appearance. In assessing

between the old and the new infestations by the *Z. conferta*, frass plays a prominent role through its morphological appearance. Dry frass and dimmed coloured (Figure 5a) indicate old infestation, whereas wet and bright coloured indicates the new ones (Figure 5b). According to the cultivators, the trees which expels brownish coloured frass after the insect infestation produces a better grade of agarwood (Figure 5c). Ants and spiders are later reported to occupy the abandoned stem to take refuge (Ong *et al*., 2010). According to Reynold and Hunter (2004), frass also provides important source of nutrients in the soil system increasing the diversity of the soil invertebrates. The deposition of the frass in the forest floor increased the nitrogen content excessively. Collembola, fungal-feeding nematodes, bacterial-feeding nematodes, and prostigmatid mites are some of the soil invertebrates that have significantly increased in the Southern Appalachians due to the depositions of the frass in the forest floor (Reynolds *et al*., 2003). Careful investigations on frass can lead to future diagnostic mechanisms on staging insect infestations leading to agarwood resin formation. Biochemical, microbiological and image analysis of frass appear to be suitable initial analytical candidates in this regard.

Artificial Rearing

The incidence of *Z. conferta* is not observed in all the *Aquilaria* trees that are cultivated. The incidence or the prevalence of the pest attack in the *Aquilaria* trees is mostly observed in monocultures (Ong *et al*., 2014). The practise of growing as monocultures by the farmers into small or a large-scale came into existence due to the overexploitation outside of their natural habitat (Irianto *et al*., 2011). However, there are some regions where the incidence of the insect is not observed despite being grown as monocultures or mix cultures. Owing to those innumerable artificial techniques are applied for production of agarwood, as naturally the formation of agarwood very much relies on the insect and microorganism's interactions (Syazwan *et al*., 2019). Despite its success in production of agarwood through artificial means, quality has always been a matter of concern for the cultivators as the superior grades are only harvested from the insect infected ones (Kalita *et al*., 2015; Hoque *et al*., 2019). The technique of artificially rearing the insect might be a key alternative to overcome this hurdle. The artificially reared *Z. conferta* larvae can be introduced in the *Aquilaria* trees where the incidence is not generally observed. Consequently, the larvae might select suitable site in the tree introduced and initiate its tunnelling activity and execute its role in insect-plant and microorganism's interaction leading to the agarwood formation. The latest study carried out by Borthakur *et al*. (2021) on the life cycle of the *Z. conferta* bestows hope of artificially rearing the insect and making it available in close proximity. This technique can be an alternative source of livelihood and also helps in catalysing the production of quality agarwood, generating more advantage to the cultivators. Moore and Navon (1966) were the first researchers to develop artificial medium for the wood borers, specifically for the leopard moth, *Zeuzera pyrina* L. The artificial media of their preparation comprised of a basal medium of three variants, composed of full fat soya meal (30.0 g), sucrose (48.0 g), Brewer's yeast (24.0 g), agar-agar flakes (24.0 g), nipagin (1.5 g), acetic acid 20% v/v (30.0 ml); sodium ascorbate 10% w/v (30.0 ml), pear bark homogenate (10 g/ 70 ml H_2O), and distilled water. The media was successful in raising the successive generation of the leopard moth considerably within a short duration of 3-4 months than in nature where it takes a year. However, the artificially bred larvae were found glabrous, and they differed in colour as compared to those developed in woods. Moreover, apart from the laboratory conditions the rearing can also be tried in its natural state by providing the cambium portion of the *Aquilaria* stem as the larvae depends on it as food source (Borthakur *et al*., 2021). Therefore, the introduction of the larval stage of the *Z. conferta* at the right age of the *Aquilaria* plant might be a solution to the problem of lack of insect incidence and also might be less susceptible to breakage and death as matured trees are less vulnerable to pest (Ong *et al*., 2014).

Conclusion

Agarwood resin formation which is a unique phenomenon is still not clearly understood by science. The study of the insect should secure equal eminence with other areas of research associated with *Aquilaria* trees. The superior quality of agarwood garnered after the insect infestation makes the need to study the

insect *Z. conferta* highly significant. Since the accumulation of the oleoresin is observed along the tunnels generated by the insect, there is also a possibility that the microbes existing in the gut of the larvae might as well initiate the microbial infection through the excrement of the larvae. The possibility of the involvement of chemical signalling in the ecology of the insect and its interaction with the plants and microorganisms further strengthens the argument that *Z. conferta* plays a pivotal role in the famous agarwood aroma development. Future studies are likely to unravel the intricacies of this involvement. The phrase "necessary evil" parallels in describing the *Z. conferta*, as the infestation is a critical necessity to fine agarwood formation but also remains a major threat for the plantation when infestation occurs at early age. The selectiveness in infesting a particular *Aquilaria* tree, environmental conditions, and soil quality of the regions where the insect infestation is observed could be interesting themes for future research. Possibly the insights from the future research on *Z. conferta* and the plant-insect-microbe continuum can help understand the aroma of agarwood better.

Abbreviations

VOCs: Volatile Organic Compounds.
HIPVs: Herbivore Induced Plant Volatiles.
MVOCs: Microbial Volatile Organic Compounds.
COI: Cytochrome Oxidase subunit I gene.
DAMPs: Damage-Associated Molecular Patterns.
HAMPs: Herbivore- Associated Molecular Patterns.
FACs: Fatty acid-Amino acid Conjugates.
LOX: Lipoxygenase.
CNS: Central Nervous System.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	No	Yes
Editing of the article/paper	Yes	Yes
Supervision	No	Yes
Project Administration	Yes	Yes
Funding Acquisition	Yes	Yes
Overall Contribution Proportion (%)	60	40

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Research involving human bodies (Helsinki Declaration)
Has this research used human subjects for experimentation? No

Research involving animals (ARRIVE Checklist)
Has this research involved animal subjects for experimentation? No

Research involving Plants
During the research, the authors followed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Yes

Research on Indigenous Peoples and/or Traditional Knowledge
Has this research involved Indigenous Peoples as participants or respondents? No

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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Ecosystem Approach in Dealing with Invasive Alien Species: International, European and Ukrainian Experience of Legal Regulation

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Abstract

This article is devoted to highlighting the international, European and Ukrainian experience encompassing legal regulation dealing with the invasive alien species that represent the second largest threat to global biodiversity, right after habitat destruction. It has been proved that, at the international level, primarily within the framework of the Convention on Biological Diversity, the ecosystem approach is recognized as the basis in dealing with such species. It is also gradually being reflected in the regulatory framework of the European Union. The provisions of the EU on nature protection and the relevant regulations of the European Commission define invasive species, which are prohibited from activities that may contribute to their dissemination in the environment. In the Ukrainian environmental law, a positive trend towards the recognition of the ecosystem approach in dealing with invasive alien species is observed primarily among national strategic documents, while in current national environmental legislation, these issues are regulated fragmentarily and inconsistently, which indicates the need for its early reform.

Keywords

Environmental law; Biological diversity; Invasive alien species; Ecosystem; Ecosystem approach

Introduction

One of the main environmental problems of today is the loss of biodiversity. Over the past 400 years 120 species of amphibians, 94 species of birds and 63 species of mammals have disappeared from the face of the Earth due to unreasonable human activities. Although each of the extinct species is a final and irreplaceable loss for the biosphere (evolution knows no turning back), many more of them are under the threat of extinction (Danilov-Danil'jan, Losev, Reif, 2005).

There are various causes of biodiversity loss. According to the American biologist, naturalist and writer, E. O. Wilson, they can be abbreviated as 'HIPPO', where the first letter means the most significant cause, and the following letters are arranged accordingly as the significance of the factor decreases. The letter 'H' comes from 'habitat', so the primary reason for the reduction of biological resources is the destruction of habitats of the organisms. The letter 'I' comes from 'invasion' and indicates the widespread impact of the invasion of alien species, as the introduction of these species, even with good intentions, is a biological contamination. Introduced from other parts of the world, some species are rapidly spreading and displacing native species of ecosystems. The first 'P' letter means the third problem – 'pollution', while the second 'P' letter is associated with the 'population' of humans – with the overpopulation of the planet. The last letter 'O' indicates the 'overexploitation' of biological resources – the destruction of species by hunting and fishing (Puzanova, 2010).

Thus, the second most important cause of biodiversity loss is the invasion of alien species. These are plants, animals, or other organisms that are not native to an ecosystem but introduced largely through human action, either deliberately or by accident. They can become competitors, predators, parasites, and hybridizers of native plants and animals, ultimately threatening the survival of endemic species (The Ecology Book, 2019).

In 2014, the Global Invasive Species Database compiled a list of the invasive alien species (IAS) titled '100 of the World's Worst Invasive Alien Species' (Luque *et al.*, 2014), which included the organisms that had the greatest negative impact on human activities and native species. The list includes 56 animal species, 36 plant species, 5 fungal species and 3 microbial species, some of which are the European rabbit *(Oryctolagus cuniculus)* and the cane toad (*Rhinella marina*) that caused significant damage to the endemic Australian ecosystem.

Widely known examples of IAS are also the Nile perch (*Lates niloticum*), which was introduced into Lake Victoria and caused the extinction of some 200 endemic fish species; the Caulerpa seaweed (*Coulerpa taxifolia*) invaded the Mediterranean and severely damaged the endemic aquatic flora and fauna. The introduction of the Polynesian rat into Easter Island is thought to have contributed to the deforestation of that island, with severe consequences for the human populations (Krämer, 2021).

The IAS pose a threat to biodiversity and natural ecosystems of Ukraine. Today there are about 90 invasive species reported, including over 40 transformer species. Generalist mollusk species have spread in the Sea of Azov and the Black Sea (*Mya arenaria, Anadara inaequivalvis*), and such species as *Deroceras caucasicum* and *Krynickillus melanocephalus*, as well as *Arion lusitanicus* slug, which is rapidly spreading in Ukraine, are a cause of major concern for the country's biodiversity. Among the common alien mammals are the muskrat, American mink, and raccoon dog.[1]

Considering the negative impact that IAS have on biodiversity and ecosystems, an urgent need is the legal regulation fighting against such species, based on the implementation of the ecosystem approach.

[1] Sixth National Report of Ukraine on the Implementation of the Convention on Biological Diversity (English version), December 2018, 83. Available online: https://www.cbd.int/doc/nr/nr-06/ua-nr-06-en.pdf [Accessed on 25 June 2021]

The IAS are investigated by many scientists, that include Smith, Bazely, Yan (2000), Genovesi, Shine (2004), Essl, Bacher, Roy (2019), Krämer (2021) and others. The ecosystem approach is developed by Smith, Maltby (2003), Morgera (2015), Platjouw (2016), De Lucia (2019), etc. From legal standpoints, the authors of this article also studied these issues in different contexts. However, it should be noted that scientific research combining such areas as the legal regulation of the implementation of the ecosystem approach and the prevention of the negative impact of IAS on the environment, unfortunately, has not been carried out to date. Such a comprehensive study is relevant for national environmental legislation in the context of the latest international legal norms, and is also promising for environmental and legal science in general. Taking this into account, the purpose of this article is to highlight certain aspects of the international, European and Ukrainian experience of legal regulation of the implementation of the ecosystem approach in dealing with IAS.

IAS-Linked Ecosystem Approach in International and European Environmental Legislation

At the international level, there are many legal documents devoted to the conservation of biodiversity and ecosystems, among which leading is the Convention on Biological Diversity[2] (CBD), adopted in 1992, having objectives to conserve biodiversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (Art. 1).

The CBD defines the terms 'biological diversity' (the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part) and 'ecosystem' (a dynamic complex of plant, animal, micro-organism communities and their non-living environment interacting as a functional unit) (Art. 2). The CBD also establishes a number of provisions for the protection and conservation of biodiversity and ecosystems, in particular: establish a system of protected areas or areas where special measures need to be taken to conserve biodiversity; promote the protection of ecosystems, natural habitats and the preservation of viable populations of species in the wild; take measures to rehabilitate and restore degraded ecosystems; prevent the introduction of alien species that threaten ecosystems, habitats or species, and control or destroy such alien species, etc. (Art. 8 a, d, f and h).

The key provisions of the ecosystem approach are reflected in the decisions of the meetings of the governing body of the CBD – the Conference of the Parties (COP). At the First meeting (Nassau, Bahamas, 1994), it was confirmed that the planet's essential goods, ecological functions and services depend on a variety and variability of genes, species, populations and ecosystems (para. 1 of Annex to Decision I/8)[3], and at the Second meeting (Jakarta, Indonesia, 1995), the ecosystem approach was recognized as the basis for action under the CBD (Decision II/8).[4] The Fifth meeting of the COP (Nairobi, Kenya, 2000) was of particular importance for the development of the ecosystem approach, as it adopted Decision V/6,[5] which contains a description of the ecosystem approach, a list of its principles and practical recommendations for their application (sections 'A', 'B' and 'C').

Thus, the ecosystem approach introduced by the CBD is a means of examining the relationships within ecosystems with other systems and people for whom ecosystems are habitats and livelihoods. It involves moving from a one-sided view of marketable species – for example, accessing forests solely as a source of timber – to a multifaceted view, working on different spatio-temporal scales, using all available knowledge

[2]Convention on Biological Diversity (adopted on 5 June 1992). Available online: https://www.cbd.int/convention/text [Accessed on 25 June 2021]
[3] CBD (1994). Report of the First Meeting on the COP to the CBD (UNEP/CBD/COP/1/17).
[4] CBD (1995). Report of the Second Meeting of the COP to the CBD (UNEP/CBD/COP/2/19).
[5] CBD (2000). Report of the Fifth Meeting of the COP to the CBD (UNEP/CBD/COP/5/23).

and involving relevant stakeholders. This approach aims to ensure the long-term sustainability of biodiversity and the significant development of today's understanding of sustainable nature (Perelet, 2006).

Returning directly to IAS, it should be noted that at its Fourth meeting (Bratislava, Slovakia, 1998), the COP invited the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to develop guidelines for the prevention of the introduction of alien species and mitigation of its consequences and report on it at its Fifth meeting (section 'C' of Decision IV/1)[6], and in Annex II to Decision IV/16[7] it announced a comprehensive consideration of alien species as one of the items on its Sixth meeting.

In turn, at a meeting in Montreal (Canada), 2000, SBSTTA developed draft of the above guidelines,[8] which are fully reflected in the Annex to Decision V/8 of the COP.[9] This Annex establishes a definition of the terms 'alien species', which refers to a species that occurs outside its normal distribution, and 'alien invasive species', an alien species that threatens ecosystems, natural habitats or species, and declares that all measures to deal with IAS should be based on the ecosystem approach, in line with the relevant provisions of the CBD and the decisions of the COP (Guiding principle 3 'Ecosystem approach').

The most thorough provisions on IAS in general and the ecosystem approach as the basis in dealing with such species, in particular, were enshrined in Decision VI/23 'Alien Species that Endanger Ecosystems, Habitats or Species',[10] adopted at the Sixth meeting of the COP (the Hague, the Netherlands, 2002), and in the Annex of which 'Guiding Principles of Preventing Invasions and Mitigating the Influence of Alien Species that Endanger Ecosystems, Habitats or Species' are contained.

Decision VI/23 sets out the basic framework for the legal regulation of the prevention of the negative impact of IAS on ecosystems. As stated in the Preamble to it, such species are a major threat to biodiversity, especially in geographically and evolutionarily isolated ecosystems, such as small island developing States, and that the risk may increase with the expansion of world trade, transport, tourism and climate change.

In accordance with the 'Guiding Principles', 'alien species' refers to a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce, while 'invasive alien species' means an alien species whose introduction and/or spread threaten biological diversity (note 57). Some of the measures envisaged by Decision VI/23 on the prevention of the harmful effects of IAS on ecosystems can be proposed. So, in the process of implementing the 'Guiding Principles' and developing, reviewing and implementing national strategies and action plans for biodiversity conservation in order to address threats of IAS to the biodiversity, it is necessary to raise awareness among policy makers at all levels of government and in the private sector, officials in quarantine, customs and other border services, as well as among the general public, about the threats posed to biodiversity by IAS, goods and services provided by ecosystems, and the means to deal with such threats, and interact with trading partners and neighboring countries, at the regional level, and, as appropriate, with other countries to address the threats posed by IAS to the biodiversity of ecosystems located in two or more countries and to migratory species, as well as to address issues of common regional interest (paras 'e' and 'g' of part 10).

It also emphasizes that priority measures should consider the need to include IAS provisions in national biodiversity strategies and action plans, as well as in sectoral and intersectoral policies, strategies and plans, in order to take into account, the ecosystem approach and ensure the comprehensive implementation of

[6] CBD (1998). Report of the Fourth Meeting of the COP to the CBD (UNEP/CBD/COP/4/27).
[7] CBD (1998). Report of the Fourth Meeting of the COP to the CBD (UNEP/CBD/COP/4/27).
[8] SBSTTA (2000). Item 3.4 of the Provisional Agenda. Alien Species: Guiding Principles for the Prevention, Introduction and Mitigation of Impacts (UNEP/CBD/SBSTTA/5/5).
[9] CBD (2000). Report of the Fifth Meeting of the COP to the CBD (UNEP/CBD/COP/5/23).
[10] CBD (2002). Report of the Sixth Meeting of the COP to the CBD (UNEP/CBD/COP/6/20).

national strategies and IAS action plans in accordance with the calls set out in decision V/8 of the COP (para. 'd' of part 12). A special place in Decision VI/23 is given to recommendations to facilitate research and assessments on: the parameters of invasive species and the vulnerability of ecosystems and habitats to IAS, and the impact of climate change on these parameters; measures to increase the capacity of ecosystems to resist IAS and recover from their invasions; criteria for assessing the risks associated with the introduction of IAS into biological diversity at the genetic, species and ecosystem levels (paras 'a', 'g' and 'i' of part 24). In addition, the application of these 'Guiding Principles' should pay due attention to the fact that ecosystems are dynamic over time and, therefore, the natural distribution of species can change without human intervention. One of the main guidelines is that measures to deal with IAS should be based accordingly on the ecosystem approach described in Decision V/6 of the COP (Principle 3). Research on IAS should include careful detection of IAS and documentation of: a) history and ecology of the invasion (origin, routes of entry and time frame); b) biological characteristics of IAS; and c) the associated effects on the ecosystem, species and genetic level, as well as the social and economic consequences and the nature of their changes over time (Principle 5).

Thus, emphasis is placed on cooperation with relevant organizations, which will facilitate the further implementation of Art. 8 h) of the CBD, including through the development of guidelines, sound methods and pilot projects to address the threats posed by IAS to certain habitats, including means to enhance the capacity of ecosystems to resist or recover from IAS (part 16).

Issues against IAS were discussed at almost all subsequent meetings of the COP to the CBD, in particular, the Seventh (Decision VII/13), the Eighth (Decision VIII/27), the Tenth (Decision X/2), the Eleventh (Decision XI/28), the Twelfth (Decision XII/17), the Thirteenth (Decision XIII/13) and the Fourteenth (Decision XIV/11) meetings. For example, the Tenth meeting (Nagoya, Japan, 2010) approved the Strategic Plan for Biodiversity 2011-2020 'Living in harmony with nature' and the Aichi Biodiversity Targets (Annex to Decision X/2).[11] The Plan contains a list of strategic objectives in this area, including taking measures to address the causes of biodiversity loss, as well as reducing the direct burden on it (paras 'a' and 'b' of part 10). Targets 8 and 9 of 'Strategic Objective B. Reduction of direct pressures on biodiversity and promotion of sustainable use' envisage that by 2020 environmental pollution, including from excess nutrients, should be brought to levels that do not cause harm the functioning of ecosystems and biodiversity, and the identification and prioritization of IAS and their distribution routes, priority species will be regulated or destroyed, and measures will be taken to regulate movement routes to prevent their introduction and implementation.

Additionally, a number of acts have been developed to implement the CBD and to actively combat harmful species at the international level, including: The Global Invasive Species Programme, 1999, The Global Strategy on Invasive Alien Species, 2001, The European Strategy on Invasive Alien Species, 2002, etc. For instance, the Global Strategy on Invasive Alien Species states that these species are currently recognized as one of the greatest biological threats to the ecological and economic well-being of our planet, as IAS are alien species whose creation and distribution threaten ecosystems, plant species or their habitats, harm the economy or the environment (McNeely *et al.*, 2001). That is why the European Strategy on Invasive Alien Species states that transboundary and subregional cooperation is a priority, as many of these territories cross the national borders. That is, ensuring the application of a precautionary approach to IAS decision-making in accordance with international law, as part of a risk analysis that takes into account the possible effects on internal biodiversity and ecosystem functions, and the need to promote an ecosystem approach as an appropriate basis for assessing planned actions and policies applies to IAS (Genovesi and Shine, 2004).

At the regional level, common legal procedures ensure the control of pests and diseases that adversely affect the condition of plants, animals, life and human health, in contrast to IAS that threaten biodiversity and

[11] CBD (2011). Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. Decision X/2 (UNEP/CBD/COP/10/27).

ecosystem functions. The above document provides for a number of key actions, including: empowering the competent authorities to take appropriate mitigation measures; revision of lists of species and conservation strategies to ensure legal protection against IAS; make better use of existing legal measures (for example, to control the spread of weeds); establishing responsibilities within reasonable limits for landowners, users and relevant stakeholders to prevent or control the further spread of IAS, etc.

Since an ecosystem is a set of species of living organisms that have adapted to living in a certain environment, that is why legal regulation and measures to regulate the negative impact of IAS on ecosystems should be based on the main types of ecosystems. It will be recalled that the CBD distinguishes terrestrial, marine and other aquatic ecosystems. The division into main types of ecosystems corresponds to the thematic areas studied under the CBD. The use of these spatial units for analysis ensures consistent reporting under the CBD and also allows for thematic, regional and global reviews. It is expected that countries will use more detailed data on key typical ecosystems for practical purposes. Such a hierarchical ecosystem allows for general reviews at different levels, both in individual countries and at the inter-State level. The main types of ecosystems include: marine and coastal areas, forests, freshwater bodies, tundra, arid and sub-humid lands, meadows, agricultural lands, and built-up lands, etc.[12]

It should be noted that issue of preserving ecosystems from IAS at the international level has been consolidated not only in the CBD and decisions of its COP, but also in other important international agreements. For example, the Framework Convention on the Protection and Sustainable Development of the Carpathians,[13] which in the context of implementing ecosystem approach has established certain requirements for many spheres, including preservation and sustainable use of biological and landscape diversity (Art. 5). Protocols to this Convention have been adopted in various years, which also reflect certain aspects of the ecosystem approach, in particular the control of IAS. Thus, in the Protocol on Conservation and Sustainable Use of Biological and Landscape Diversity[14] IAS are recognized as the cause of deterioration of quality and value of environmental functions, its degradation, their next definition is provided ('non-native species introduced intentionally or unintentionally outside their natural habitats where they have settled, reproduced and disseminated in ways that harm the environment into which they have been imported') (Art. 2 f and j), and the Parties are obliged to cooperate in order to prevent the import, control or destruction of IAS that threaten ecosystems, habitats or local species of the Carpathians (para. 'b' of Art. 1), prevention of their introduction or release (Art. 13), etc.

The regulatory framework for IAS is also being actively developed by the European Union, which is a Party to the CBD and has certain obligations under Art. 8 h) to prevent the introduction of alien species that endanger ecosystems, habitats or species. Thus, Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora (the Habitats Directive)[15] aims to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, emphasizing the need to adopt provisions for additional measures for the re-introduction of certain natural species of flora and fauna and the possible introduction of alien species.

[12] CBD (2003a). Monitoring and indicators: designing national-level monitoring programmes and indicators. (UNEP/CBD/SBSTTA/9/10).
[13] The Framework Convention on the Protection and Sustainable Development of the Carpathians (signed on 22 May 2003). Available online: http://www.carpathianconvention.org/text-of-the-convention.html [Accessed on 25 June 2021]
[14] The Protocol on Conservation and Sustainable Use of Biological and Landscape Diversity to the Framework Convention on the Protection and Sustainable Development of the Carpathians (adopted on 19 June 2008). Available online: http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/01%20The%20Convention/1.1.2.1%20BiodiversityProtocolFinalsigned.pdf [Accessed on 25 June 2021]
[15] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, OJ L 206, 22.7.1992, p. 7–50.

In support of the achievement of the aims of the Habitats Directive, as well as the Water Framework Directive[16], the Marine Strategy Framework Directive[17] and the Birds Directive[18], EU Regulation 1143/2014 of 22 October 2014 (on the prevention and management of the introduction and spread of invasive alien species)[19] approved the relevant requirements for risk assessment, procedures for measures to prevent the penetration of IAS into the EU, rapid identification and removal of new IAS, management of species that are already widespread in the EU, etc. The document states that a significant proportion of alien species can become invasive and have a serious negative impact on biodiversity and related ecosystem services, as well as other social and economic consequences that should be prevented. About 12,000 species in the EU and other European countries are alien, of which about 10-15% are invasive.[20] In accordance with this regulation, a list of IAS for EU countries was subsequently adopted Commission Implementing Regulation *(*EU*)* 2016/1141 *of* 13 *July* 2016 adopting a list of invasive alien species of Union.[21]

It is worth noting that the EU Regulation 1143/2014 and its monitoring were discussed in detail by Krämer (2021), in order to see, what lessons can be learnt from the cooperation and concertation of the different states with regard to IAS. The author concludes that in order to reach results, within the EU or at international level, close cooperation between neighbouring countries is necessary. It is not sufficient to leave the implementation and effective application of international agreements or of EU legislation to the goodwill of the countries concerned. The COP to the CBD as well as the European Commission will, therefore, have to do more to ensure an effective application of the existing provisions (Krämer, 2021).

To date, a group of scientists was a comprehensive work on developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union. They present these species highlighting the potential negative impacts and the most likely biogeographic regions to be affected by these potential IAS. Furthermore, researchers recommend conducting regular reviews of both the species rankings and future potential IAS that could threaten the EU, as demanded by the EU Regulation (Roy *et al.*, 2019). For this purpose, dedicated species accounts should be considered and kept updated in the species data repository formally endorsed by the EU Regulation i.e., EASIN – European Alien Species Information Network (Roy *et al.*, 2019).

Concluding the common review of international and European experience in the legal regulation of the introduction of the ecosystem approach in the fight against IAS, it should be mentioned that an extraordinary event in the field of EU biodiversity and ecosystems was the adoption on 20 May 2020 by the European Commission (2020) of a new EU Biodiversity Strategy for 2030: Bringing nature back into our lives,[22] which is called 'the most ambitious environmental document in human history' and according to which EU countries seek not only to preserve their biodiversity and related ecosystem services, but also to become a world leader in nature conservation and restoration for a decade (EU Biodiversity Strategy, 2020). The Strategy contains specific commitments and actions to be implemented in the EU by 2030, including control

[16] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327, 22.12.2000, p. 1–73.
[17] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy, OJ L 164, 25.6.2008, p. 19–40.
[18] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds, OJ L 20, 26.1.2010, p. 7–25.
[19] Regulation (EU) No. 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species, OJ L 317, 4.11.2014, p. 35–55.
[20] Regulation (EU) No. 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species, OJ L 317, 4.11.2014, p. 35–55.
[21] Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council C/2016/4295, OJ L 189, 14.7.2016, p. 4–8.
[22] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity Strategy for 2030 Bringing nature back into our lives, COM/2020/380 final

of IAS. It is noted that IAS can significantly undermine efforts to protect and restore nature, facilitate the outbreak and spread of infectious diseases, posing a threat to humans and wildlife. Of the 1,872 species now considered threatened in Europe, 354 are under threat from IAS. Without effective control measures, the rate of invasion and the risks it brings to nature and health will continue to rise.[23]

Ecosystem Approach in dealing with IAS in the Environmental Legislation of Ukraine

The main problem in developing legal mechanisms to regulate the prevention of IAS in national legislation is not taking into account all existing species of different ecosystems. The type of ecosystems to be invaded include freshwater, marine, terrestrial, etc., and the type of invaders include plants, animals, microorganisms, etc. In this context, it would be useful to give examples from some countries of the introduction of an ecosystem approach to the regulation of IAS at the national level.

For example, one of the means of public awareness used in USA is a list of IAS called 'The Dirty Dozen', which are some of the least desirable alien species in USA. Although these 12 species differ from each other in many ways, they all have one thing in common: they cause problems to native species and ecosystems. The species on this list represent many different organisms, a variety of ecosystems, and a wide geographical range, from Hawaii to Florida and from Maine to California (Wittenberg and Cock, 2001).

The next example is Canada, which in pursuance of Art. 8 h) of the CBD, that, in 1995, developed the Canadian Biodiversity Strategy, and in 2004, the Invasive Alien Strategy for Canada. Subsequently, the national IAS strategy led to the development of two action plans for terrestrial IAS plants and plant pests and aquatic IAS, respectively, as well as a national strategy for wildlife diseases (Smith, Bazely and Yan, 2013).

Particular attention needs to be paid to marine and freshwater ecosystems, which are considered very vulnerable to the invasion of alien species. That is why international instruments relating to the aquatic environment emphasize the need for precautionary measures related to the introduction of alien species (Shine, Williams and Gündling, 2000). Geographically isolated ecosystems are particularly vulnerable to invasive species. That is why it is necessary to cite the example of island States, for which the provision of an ecosystem approach is extremely important for the conservation of all biological diversity. The IAS is a major threat to the vulnerable marine, freshwater and terrestrial biodiversity of the Caribbean and to the people whose livelihoods depend on it. The Caribbean States have recognized the need for a regional strategy and have expressed interest in pooling their national efforts to implement Art. 8 h) of the CBD, which will lead to the joint development of the Global Environment Facility (GEF) funded project entitled 'Mitigation the Threats of Invasive Alien Species in the insular Caribbean'. The aim of the project is to mitigate the threat to local biodiversity and the economy from IAS in the Caribbean islands, including terrestrial, fresh and marine ecosystems (Krauss, 2010). Therefore, the legal framework should provide a basis for regulating the invasion of alien species into any type of ecosystem, as well as for monitoring and managing their use wherever this occurs. However, today the legal regulation of terrestrial ecosystems is much broader than for coastal and marine environments or inland water ecosystems (Shine, Williams and Gündling, 2000).

While exploring the foundations of legal regulation of this issue in Ukraine, it should be noted that Ukraine, ratifying the CBD[24] and other environmental treaties, has undertaken international legal obligations to

[23] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity Strategy for 2030 Bringing nature back into our lives, COM/2020/380 final
[24] Law of Ukraine (1994). On Ratification of the Convention on Biological Diversity, Law of Ukraine 257/94-VR of 29 November (1994), Verkhovna Rada of Ukraine, 1994. Available online: https://zakon.rada.gov.ua/laws/show/257/94-вр#Text [Accessed on 25 June 2021]

preserve and restore natural ecosystems and the implementation of the ecosystem approach in national environmental policy and law, including dealing with IAS. Ukraine also has certain obligations for the conservation of biological diversity and natural ecosystems in the framework of the Association Agreement with the European Union,[25] including the implementation of the Habitats, Birds and Water Framework Directive (Annex XXX). However, according to experts, in the light of the newly adopted EU Biodiversity Strategy 2030, the full implementation of all objectives set by the Agreement will be insufficient to achieve Ukraine's indicators relevant in the EU after the adoption of the Strategy. Therefore, this document can be considered without achieving indicators of which further European integration steps will be difficult to imagine (EU Biodiversity Strategy, 2020).

The main strategic document of environmental orientation in Ukraine is the Law 'On Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030',[26] which was adopted on 28 February 2019, and came into force on 1 January 2020. Adoption of this document was an important step towards the formation of a modern national environmental policy, as it is aimed at reviewing its priority tasks related to the signing of the Association Agreement between Ukraine and the EU, and ensuring gradual approximation of environmental legislation with the EU directives. This Strategy should become a reference point for further systematization of environmental legislation in the context of European integration processes (Getman *et al.*, 2019).

A comprehensive analysis of the provisions of the Strategy indicates that significant attention is paid in it to the conservation and restoration of ecosystems and the implementation of the ecosystem approach, since the ecosystem component is clearly manifested as the goal of the state environmental policy, as well as among the expected results of its implementation, since in accordance with Section VI in 2030 year, Ukraine must achieve such a level of balanced (sustainable) development, in which dependence on the use of non-renewable natural resources and environmental pollution will be reduced to ecosystemically acceptable levels.

The Strategy does not explicitly indicate the need to implement an ecosystem approach in dealing with IAS, but it states that one of the tasks to reduce environmental risks in order to minimize their impact on ecosystems (Objective 4) is the prevention of the spread of invasive species and the control of their occurrence and distribution in natural ecosystems, including marine ones.

Thus, it can be assumed that the application of the ecosystem approach in the fight against IAS follows from a broad formulation of the goal of the State environmental policy, which is based on the need to implement this approach in all spheres of socio-economic development. Nevertheless, it is obvious that this wording needs further clarification, which, incidentally, is stated in the recommendations of the parliamentary hearings approved on January 14, 2020 on the topic: 'Priorities of environmental policy of the Verkhovna Rada of Ukraine for the next five years',[27] in which it is recommended that the relevant Ministry together with the central executive authorities should consider the specification and clarification of the above Law, mechanisms to ensure its implementation, as well as streamlining environmental legislation of Ukraine by systematizing it for each of the natural resources with the ecosystem approach.

[25] Association Agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part, Official Journal of the European Union L 161/3, 29.5.2014. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22014A0529(01)&from=EN [Accessed on 25 June 2021]
[26] Law of Ukraine (2019). On Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030, Law of Ukraine 2697-VIII of 28 February (2019), Verkhovna Rada of Ukraine, 2019. Available online: https://zakon.rada.gov.ua/laws/show/2697-19#Text [Accessed on 25 June 2021]
[27] Resolution of the Verkhovna Rada of Ukraine (2020). On the Recommendations of the Parliamentary Hearings on the Topic: 'Priorities of the Environmental Policy of the Verkhovna Rada of Ukraine for the Next Five Years, Resolution of the Verkhovna Rada of Ukraine 457-IX of 14 January (2020), Verkhovna Rada of Ukraine, 2020. Available online: https://zakon.rada.gov.ua/laws/show/457-20#Text [Accessed on 25 June 2021]

Issues of IAS control, albeit briefly, are enshrined in the Concept of the National Biodiversity Conservation Program for 2005-2025.[28] It provides for measures to preserve flora and fauna, along with their groups, complexes and ecosystems, and notes that the implementation of this Program will allow to recreate degraded ecosystems, promote the conservation of endangered species, prevent the introduction of species characteristic of other natural regions that may adversely effect on ecosystems, local species or public health.

The latest strategic document, which is likely to replace or supplement the previous one, should be the Biodiversity Strategy to 2030, which is currently being developed and will be the basis for all environmental decisions. This strategy will not only become a comprehensive document aimed at biodiversity conservation but will also demonstrate a European approach to nature protection in Ukraine.[29] The objectives of the Strategy are: ensuring monitoring of the state of biodiversity in Ukraine; introduction of the concept of ecosystem services; formation of an integrated approach to the conservation of species and the fulfillment of international obligations for the conservation of biodiversity. We hope that due attention in the Strategy is paid specifically to the issues of conservation and restoration of ecosystems and the implementation of the ecosystem approach in dealing with IAS.

Equally important in this area is the draft order of the Cabinet of Ministers of Ukraine 'On approval of the National Strategy for the management of invasive alien species of flora and fauna in Ukraine until 2030',[30] designed to improve state environmental policy to prevent penetration and control of introduction of IAS into natural ecosystems, destruction and mitigation (minimization) of adverse effects of such species on natural ecosystems, economic activity and human health (Art. 2). Within this aim, the following objectives and tasks are identified:

1. Raising awareness and scientific and methodological support of measures for the management of IAS. Tasks within this objective:
   - conducting special research on the ecological and biological properties of alien species and identifying potential IAS;
   - development of criteria for assigning species to the category of IAS and assessing the level of their impacts on biodiversity, ecosystems, public health and economic activity;
   - approval and periodic updating of lists of IAS by level of danger for local species, ecosystems and human health by individual taxonomic units or their groups; and
   - creation of a database on IAS by all taxonomic groups, etc.
2. Improving public policy, regulatory framework and institutional capacity to prevent the intrusion, destruction, control of the introduction of IAS into natural ecosystems and mitigate (minimize) their adverse effects. The following tasks are distinguished within this objective:
   - taking into account in state strategic documents the issues of IAS management;
   - formation of the regulatory framework for the effective prevention of penetration and control over the spread of IAS, their destruction, minimizing the impact or mitigation of the consequences of the invasion;

[28] Order of the Cabinet of Ministers of Ukraine (2004). On Approval of the Concept of the National Biodiversity Conservation Program for 2005-2025. Order of the Cabinet of Ministers of Ukraine 675-r of 29 September (2004), Verkhovna Rada of Ukraine, 2004. Available online: https://zakon.rada.gov.ua/laws/show/675-2004-p#Text [Accessed on 25 June 2021]
[29] V Ukraini rozpochato rozrobku proiektu Stratehii okhorony bioriznomanittia do 2030 roku. Available online: https://spilno.org/news/v-ukraini-rozpochato-rozrobku-proyektu-stratehii-okhorony-bioriznomanittya-do-2030-roku [Accessed on 25 June 2021]
[30] Draft order of the Cabinet of Ministers of Ukraine (2019). On Approval of the National Strategy for the Management of Invasive Alien Species of Flora and Fauna in Ukraine for the Period up to 2030. Official portal of the Ministry of Environmental Protection and Natural Resources of Ukraine (2 May 2019). Available online: https://menr.gov.ua/news/33368.html [Accessed on 25 June 2021]

- approval of criteria for classifying species as IAS, assessment of their impact on biological diversity and economic activity, public health, structural and functional organization of ecosystems; and
- approval of lists of IAS, etc.

3. Development and implementation of practical measures to prevent the penetration, control of the spread, destruction and mitigation of the effects of IAS invasion at the local and state levels, which provides for the following tasks:

- development and approval of a system (plans) of measures to prevent the penetration, control of the spread, destruction and mitigation of the consequences of the invasion of IAS at the local and state levels; and
- development of measures to control the spread and control of IAS within the territories and objects of the nature reserve fund in order to preserve the natural state of ecosystems, rare aboriginal species and groups.
- determination of responsible executors for the implementation of such measures.

It is assumed that the achievement of the objectives of the National Strategy will be carried out in two stages: the first – 2020-2023, and the second – 2023-2030. This Strategy will become a book of rules for the treatment of IAS of flora and fauna in Ukraine. It will establish legal mechanisms for the management of IAS, in particular, regulations, guidelines will be approved, as well as appropriate amendments to existing regulations on agriculture, fisheries, forestry, hunting, housing and communal services, transport infrastructure, natural reserve fund, veterinary medicine, quarantine and plant protection, sanitary and epidemiological well-being of the population, customs.[31]

Thus, it is observed that the National Strategy provides the basic principles for preventing the negative impact of IAS on biodiversity and ecosystems of Ukraine, and, therefore, its adoption will facilitate the implementation of the CBD and other international and European instruments in this area into national legislation. However, the National Strategy, essentially needs further refinement, taking into account the ecosystem approach. Although among the national strategic documents, there is a positive trend towards the recognition of the ecosystem approach in dealing with IAS, the situation with the recognition of this issue at the level of current regulatory environmental legislation of Ukraine is much more complicated.

It should be noted that the key environmental law in Ukraine 'On Environmental Protection'[32] does not contain any rules for the preservation and restoration of natural ecosystems, the introduction of an ecosystem approach and the prevention of negative impacts of IAS on biodiversity and ecosystems. In addition, according to this Law, the ecosystem is not recognized as an object of legal protection at all (Art. 5), just as it not only lacks definitions, but also never mentions the words 'ecosystem' and 'invasive alien species', which are a significant shortcoming that needs to be addressed as soon as possible. Such legal uncertainty creates a significant barrier to the introduction of an ecosystem approach to IAS for all ecosystems, not to mention the need to take into account certain features of legal regulation regarding their different types. Also, the Land Code of Ukraine does not contain any legal norms on ecosystems[33], although the ecosystem definition of 'land' is enshrined in the Law of Ukraine 'On Land Protection'[34], according to which land is a land surface with soils, minerals and other natural elements that are organically combined and function with

[31] Minpryrody rozrobylo Natsionalnu stratehiiu shchodo povodzhennia z vydamy-vselentsiamy invaziinymy chuzhoridnymy vydamy flory i fauny v Ukraini na period do 2030 roku. Available online: https://mepr.gov.ua/news/33369.html#:~:text=Інвазійні [Accessed on 25 June 2021]

[32] Law of Ukraine (1991). On Environmental Protection, Law of Ukraine 1264-XII of 25 June (1991), Verkhovna Rada of Ukraine, 1991. Available online: https://zakon.rada.gov.ua/laws/main/1264-12#Text [Accessed on 25 June 2021]

[33] Law of Ukraine (2001). Land Code of Ukraine, Law of Ukraine 2768-III of 25 October (2001), Verkhovna Rada of Ukraine, 2001. Available online: https://zakon.rada.gov.ua/laws/show/2768-14#Text [Accessed on 25 June 2021]

[34] Law of Ukraine (2003). On Land Protection, Law of Ukraine 962-IV of 19 June (2003), Verkhovna Rada of Ukraine, 2003. Available online: https://zakon.rada.gov.ua/laws/main/962-15#Text [Accessed on 25 June 2021]

it (Art. 1). Neither the ecosystem approach nor IAS are mentioned in the Water Code of Ukraine[35], although in the Procedure for state water monitoring[36] significant attention has been paid to the protection of ecosystems from the negative impact of IAS.

It would seem that the key role in this area should belong to floristic and faunal legislation, especially since the list of activities related to environmental measures includes measures to prevent the introduction and spread of alien plant species in natural ecosystems. Instead, in the Law of Ukraine 'On Flora'[37] there are no references to the ecosystems or ecosystem approach, only the ecosystem definitions of 'flora' (the totality of all plant species, as well as fungi and their groups in a given area) and 'natural plant communities' (a set of plant species that grow within certain areas and are in close interaction with each other and with environmental conditions). This Law provides a definition of 'introduction' (artificial introduction of a species into the plant world outside its natural range) (Art. 3) and states that the requirements for the introduction of wild plants are determined by the relevant Regulation, the responsibility for the development and approval of which rests with the relevant Ministry (part 3 of Art. 33). In a very general way, the ban on the introduction of IAS is provided for the legal protection and use of greenery in human settlements, as in accordance with paragraphs 6 and 7 of Section IV of the Standard Rules for Landscaping a Settlements[38] of aboriginal flora and their decorative forms are used for landscaping such areas, while the use of plant IAS is prohibited.

In contrast to the analyzed acts, the Forest Code of Ukraine[39] shows some tendency to implement an ecosystem approach, in connection with the implementation of some international acts.[40] In Art. 1 of this Code, the ecosystem definition of 'forest' is enshrined, which means a type of natural complexes (ecosystem) combining mainly woody and shrubby vegetation with relevant soils, grasses, fauna, microorganisms and other natural components that are interrelated, and linked in their development, affect each other and the environment. In addition, this article was supplemented by ecosystem definitions of natural forests (natural forest ecosystems), virgin forests (virgin forest ecosystems) and quasi-virgin forests (conditionally virgin forest ecosystems) (parts 7-9). At the same time, only one article in the Code (Art. 85 'Conservation of biodiversity in forests') is devoted to the issue of combating IAS, according to which such conservation is carried out by forest owners and permanent forest users at the genetic, species, population and ecosystem levels by, in particular, prevention of genetic contamination of aboriginal species and invasions of introduced species into natural ecosystems.

A similar situation can be traced with regard to faunal legislation. The Law of Ukraine 'On Fauna'[41] does not contain a definition of 'fauna', but recognizes its ecosystem character, because not only objects of fauna

[35] Law of Ukraine (1995). Water Code of Ukraine, Law of Ukraine 213/95-VR of 6 June (1995), Verkhovna Rada of Ukraine, 1995. Available online: https://zakon.rada.gov.ua/laws/main/213/95-вр#Text [Accessed on 25 June 2021]
[36] Resolution of the Cabinet of Ministers of Ukraine (2018). On approval of the Procedure for the implementation of state monitoring of waters, Resolution of the Cabinet of Ministers of Ukraine 758 of 19 September (2018), Verkhovna Rada of Ukraine, 2018. Available online: https://zakon.rada.gov.ua/laws/show/758-2018-п#Text [Accessed on 25 June 2021]
[37] Law of Ukraine (1999). On Flora, Law of Ukraine 591-XIV of 9 April (1999), Verkhovna Rada of Ukraine, 1999. Available online: https://zakon.rada.gov.ua/laws/main/591-14#Text [Accessed on 25 June 2021]
[38] Order of the Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine (2017). On Approval of the Model Rules for the Improvement of the Territory of a Settlement, Order of the Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine 310 of 27 November (2017), Verkhovna Rada of Ukraine, 2017. Available online: https://zakon.rada.gov.ua/laws/show/z1529-17#Text [Accessed on 25 June 2021]
[39] Law of Ukraine (1994). Forest Code of Ukraine, Law of Ukraine 3852-XII of 21 January (1994), Verkhovna Rada of Ukraine, 1994. Available online: https://zakon.rada.gov.ua/laws/main/3852-12#Text [Accessed on 25 June 2021]
[40] Law of Ukraine (2017). On Amendments to Certain Legislative Acts of Ukraine on the Protection of Virgin Forests under the Framework Convention for the Protection and Sustainable Development of the Carpathians, Law of Ukraine 2063-VIII of 23 May (2017), Verkhovna Rada of Ukraine, 2017. Available online: https://zakon.rada.gov.ua/laws/show/2063-19#Text [Accessed on 25 June 2021]
[41] Law of Ukraine (2001). On Fauna, Law of Ukraine 2894-III of 13 December (2001), Verkhovna Rada of Ukraine, 2001. Available online: https://zakon.rada.gov.ua/laws/show/2894-14#Text [Accessed on 25 June 2021]

(wild animals, their parts and products of their vital activity), but also their habitat and migration routes are under protection (Art. 3). Moreover, Art. 36 of this Law, which determines the content of wildlife protection, stipulates that such protection provides a comprehensive approach to studying the state, development and implementation of measures to protect and improve the ecological systems in which the wildlife is located and is an integral part (part 2). At the same time, one of the ways to protect animals is to prevent the invasion of alien species of wild animals and to take measures to prevent negative consequences in the event of their accidental penetration (Article 37).

Certain reservations regarding IAS are also contained in the Law of Ukraine 'On Aquaculture'.[42] It provides definitions of aquaculture objects (aquatic organisms used for breeding, keeping and cultivation in aquaculture conditions), their introduction (activity on the introduction of aquatic organisms (introducers) into water bodies (their parts) located outside their natural habitat) and alien species of aquatic organisms (species or subspecies of aquatic biological resources that appear outside their natural range and outside the zone of their natural potential distribution) (Art. 1). Also it imposes on aquaculture entities the obligation to prevent unauthorized, including accidental, ingress of alien and non-native species into water bodies (parts thereof) (part 2 of Art. 5), and in the case of use of these species in the field of aquaculture to ensure their uncontrolled spread in new habitats, the absence of negative impact on the state of populations of local species of aquatic biological resources and the conditions of functioning of aquatic ecosystems (part 1 of Art. 20).

Conclusion

The study concludes that, at the international level, the ecosystem approach can rightly be considered as the basis for combating IAS, which is explicitly stated in Decision VI/23 of the COP to the CBD. EU environmental policy also aims to regulate the implementation of the ecosystem approach to the IAS, as evidenced by the Biodiversity Strategy 2030, which pays due attention to the implementation of the ecosystem approach to achieve its objectives, including the control of the IAS.

Having ratified the CBD, Ukraine has taken international legal obligations to preserve and restore natural ecosystems and the implementation of the ecosystem approach in environmental policy and law. Analysis of Ukrainian environmental legislation shows that a positive trend towards the recognition of the ecosystem approach in dealing with IAS is observed primarily among national environmental strategic documents. Also important in this area should be the Biodiversity Strategy until 2030 and the National Strategy for the management of invasive alien species of flora and fauna in Ukraine until 2030, which are currently in the process of development and approval.

In contrast to the specified strategic documents, in other acts of Ukrainian environmental legislation, in particular in the Law of Ukraine 'On Environmental Protection' and resource legislation (Land, Water, Forest Codes of Ukraine, as well as the laws of Ukraine 'On Flora', 'On Fauna', etc.), the issues of IAS control on the basis of the implementation of the ecosystem approach are regulated in fragments and inconsistently and therefore need significant reform.

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[42] Law of Ukraine (2012). On Aquaculture, Law of Ukraine 1593-VI 0f 18 September (2012), Verkhovna Rada of Ukraine, 2012. Available online: https://zakon.rada.gov.ua/laws/main/5293-17#Text [Accessed on 25 June 2021]

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Biomass Production and Nutrient Accumulation by Natural Rubber (*Hevea brasiliensis* Wild. Ex A. Juss.) Müell. Arg. Clones in a Humid Tropical Area in South India

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Abstract

Natural rubber (*Hevea brasiliensis* Wild. Ex A. Juss.) Müell. Arg. is an important commodity crop grown in world over for industrial raw material rubber latex for various products, mainly tyre manufacturing. *Hevea* propagation is through clones evolved by breeding as cultivars with desired characters. This article presented the biomass and nutrient accumulation of four important *Hevea* clones *viz*. RRII 105, RRII 118, RRII 203 and GT1 at 30 years age. Biomass and nutrient concentration of tree components *viz*. trunk, branches, leaf and root were assessed by uprooting the trees in the field and standing trees using allometric equation. Among the different clones, RRII 118 and GT1 recorded higher biomass compared to RRII 105 and RRII 203. Above-ground biomass (88-93 per cent) varied more than below-ground biomass (7-11 per cent). The high yielding clones had higher leaf and root biomass. Drought tolerant and timber clones *viz*. RRII 118 and RRII 203 recorded higher K and high yielding clone RRII 105 had higher Ca accumulation. Biomass removal of these clones may lead to deficiency of K and Ca in soil and hence needs the external supplements. The relation of high Ca content and leaf disease of fungal origin is promising for further studies. The higher accumulation of iron and manganese indicated the tolerance of *Hevea* to these elements and possibility of phytoremediation. The per cent contribution of nutrients to total biomass varied less between clones and was below 3 percent at the age of 30 years and this is evidence of adjustments in proportions of nutrients in *Hevea* irrespective of clonal variations.

Keywords

Biomass; Nutrient accumulation; Tree components; *Hevea* clones

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Introduction

Natural rubber (NR) tree (*Hevea brasiliensis* Wild. Ex A. Juss.) Müell. Arg. is unique in the production of natural rubber, and it contributes almost 99 per cent of the requirements of the natural rubber in the world (Perron *et al*., 2021; Karunaichamy and Rajagopal, 2020). It is an important commercial source of natural rubber latex (Hytonen *et al*., 2019) and is a forest tree species native to Brazil found in the Amazon River basin (Rekha *et al*., 2016). It is included in family *Euphorbiacea* as a monocotyledon and growing in perennial nature with long duration of 30-32 years. The rubber tree is a quick growing sturdy tree with a tall trunk and thick canopy prevailing in tropical conditions. Rubber plants take 4 to 5 years for canopy closure and grow to full sized trees in 15 to 20 years (Karthikakuttyamma, 1997). The harvesting crop is the latex that flows from the bark of the tree by a systematic wounding called tapping. The productive economic life of rubber trees (Joseph and Jacob, 2020) is around 25-30 years. After 30-32 years the trees are cut down and replanted with new clones. Natural rubber (NR) is one of the major commodity crops in the economy of India because of its huge industrial application of which the important ones are the tyre manufacturing and export of value-added products (James *et al*., 2018). In India, NR cultivation and establishment of large plantations were initiated more than one hundred years ago, and rubber cultivation is mainly confined (85 per cent) to the state of Kerala (Pradeep *et al*., 2020). Development of a clone is done by breeding programme (Abraham and Mydin, 2020; Chandra *et al*., 2020) through the selection of the desired characters. The clones are the modified versions of plants to improve latex, the economic produce of the rubber tree, and other secondary characters like drought cold and disease tolerance. Propagation of the rubber tree is vegetative through budding of the scion portion into the stock plant of the earlier raised seedlings from sprouted seeds. The clones are used as the important planting material having different varieties for rubber cultivation. Tree crops are more important for higher biomass production and nutrient accumulation with long residence in the soil (Perron *et al*., 2021). The quantification of biomass, nutrient reserve and partitioning characteristics of trees accounts towards the site productivity, plant activity and nutrient pattern (Jing *et al*., 2020). Beside these, an understanding about the biomass production, partitioning and nutrient accumulation in various plant parts has an important role in nutrient budgeting for the development of crop growth models and crop response for evolving strategies to enhance productivity (Hytonen *et al*., 2019). However, the accumulation for each nutrient is different. Primarily, certain nutrients are rich in concentration in certain plant varieties in accordance with the plant activities. The clone-wise biomass production and nutrient accumulation of rubber are useful in nutrient budgeting and in understanding the nutrient requirements of different rubber clones, role of nutrients to improve crop production, tolerance to biotic and abiotic stress, resistance to diseases, and wood properties of the trees. Biomass and nutrient accumulation data can be helpful in selecting the clones to use soil reserve judiciously. Biomass data is also very important in estimating carbon stock and carbon sequestration capacity and, thereby, in ascertaining the carbon crediting. Biomass and nutrient budgeting in clone RRII 105 at 20 years age in the traditional region of Kerala was reported by Karthikakuttyamma *et al*. (2004). The information on biomass and nutrient accumulation in different rubber clones deserves more attention because the data on this domain is scanty. The clones selected for the present study perform differently in terms of yield potential, stress tolerance, disease resistance and wood properties.

In view of above, the present study was aimed at studying the biomass characteristics, nutrient partitioning and nutrient accumulation in the four important clones of *Hevea* to know the variation between clones for exploring further the possibility of selection of suitable clones. The hypothesis of the study is that the clones selected have variability in biomass production, nutrient characteristics, nutrient partitioning, nutrient accumulation and related plant properties.

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Materials and Methods

Site characteristics

The location of the study was the Central Experimental Station (CES) of The Rubber Research Institute of India, Rubber Board located at Chethackal in Pathanamthitta district, the south-eastern district of Kerala (9º22´ N and 76º50´E and 100 msl), India. The region received average annual rainfall of 3500 mm generally, with mean minimum and maximum air temperature of 22.4º C and 30.8º C, respectively, under humid tropical climate. The soil comes under the classification of clayey-skeletal, kaolinite, isothermic and Ustic Kanhaplohumult is the international classification name of type of a soil with a depth of 100 cm (NBSS-LUP, 1999). The general soil nutrient status was high in organic carbon (2.52 per cent), medium in available P (14 mg kg^{-1} soil) and medium in available K (92.5 mg kg^{-1}). The soil pH was 4.95, which is strongly the acidic.

Experimental design

Four important clones of natural rubber (*Hevea brasiliensis*) Müell. Arg., *viz*. RRII 105, RRII 118, RRII 203 and GT1, were selected for the study. The first three clones were evolved through breeding by the Rubber Research Institute of India (RRII) and the fourth one was an Indonesian clone Gondang Tapen (GT) brought to India under clone exchange programme. The clone RRII 105 is the popular clone included as the category1(officially released for planting after small scale, large scale and multi-locational on-farm evaluations) of the approved clone recommendations of the Rubber Board. It occupies 85 per cent of the total area under cultivation in India. It is widely cultivated in the traditional belt (extending from Kanyakumari district of Tamil Nadu state in the south through Kerala to Coorg district of Karnataka state in the north) and non-traditional region in India (*viz*. North-Eastern, Konkan and Eastern region). Traditional regions are having congenial agro-climatic conditions for rubber cultivation. In the non-traditional region, the soil is suitable but the climatic constraints like severe drought, cold stress and wind events, are the limitations. The clones RRII 203 and GT 1 are included in category 11 (allowed for planting in 50 per cent of the total area along with another 50 per cent under category 1 clones). RRII 118 is in category 111 (superior clones with proven merits and limited for planting for the experimental purpose) as reported by Mydin *et al*. (2017). To evolve the clones for the experiment, the seeds collected from the approved seed garden were germinated and seedlings were raised. The bud patches of scion portion were grafted and multiplied to make plants of each clone for the purpose of planting in the main field. The plants were grown through the immature phase (1-7 years), mature phase (7^{th} year onwards) and latex harvesting stage (7^{th} or 8^{th} year onwards) up to tree felling age at 30 years. The trees were planted at a spacing of 4.9 m × 4.9 m in randomised block design (RBD) with 5 replications during June-July 1985. All cultural operations including establishment of leguminous ground cover *Pueraria phaseoloides*, regular weeding and spraying for disease management were followed uniformly as per the recommendations of the Rubber Board (1980). Since this is a clone evaluation trial, the management practices were identical for all the clones. Rubber has specific manurial practices for the immature phase (1-7 years after planting) and a mature phase (from 5^{th} year onwards). Accordingly, the plants were dosed with 10-10-4-105 NPKMg fertilizer mixture, *viz*. 225 g $plant^{-1}$, three months after planting during September-October, 450 g $plant^{-1}$ (in two equal splits during April-May and September-October during 2^{nd} year and 4^{th} year), and 550 g $plant^{-1}$during 3^{rd} year. From 5^{th} year onwards, uniform fertilizer dose of 30:30:30 NPK by urea (65 kg), rock phosphate (150 kg) and muriate of potash (150 kg) on per hectare basis for mature trees (recommended dose) were applied annually in two equal splits during April-May and September-October, covering all clones in the productive yielding phase up to 25 years. Thereafter, no fertilizer was given to all the clones when they reached to tree felling stage at 30 years age.

Tree sampling and analysis

Two trees of four different clones at 30 years age in the same location of an experimental field of clone trial were selected for the study. Trees were uprooted and total height and girth at 150 cm from the bud union

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were taken as the basal parameters. Trees were divided into four morphological units as tree components, *viz*. trunk, branches, leaf (small twigs and petiole) and root in each clone. This was used for the biomass estimation and nutrient accumulation of clones. To assess the biomass, fresh weight of each component was recorded immediately after felling by using appropriate weighing balance in the field itself to avoid moisture loss. Representative sub-samples were taken from each component that were oven-dried at 65^0C for 72 hours and the dry weights were recorded. Using this, the total dry biomass of trunk, branches, leaves, and root of each clone was estimated. A portion of trunk, branches, leaves and roots were taken for chemical analysis to know the variation in nutrient concentration of these components. The per cent content of major- and micronutrients of all these components was estimated using a known quantity of the ground samples dried at 105ºC for constant weight by applying standard procedures, *viz*., nitrogen (N) estimation by micro-kjeldhal method using acid digestion and distillation, phosphorus (P) estimation and potassium estimation by stannous chloride method using spectrophotometer and direct reading flame photometry respectively. The calcium (Ca), magnesium (Mg), and micronutrients, *viz*. zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe), were estimated by direct reading atomic absorption spectrophotometer.

To determine the biomass and nutrient accumulation in more trees, 10 replicates of standing trees of each clone. Thus, total 40 trees were selected at the same location. Girth (trunk) at 150 cm from the basal bud patch of the trees was recorded. Using the girth values, the aboveground biomass of these standing trees was determined by the Shorrock's equation (Shorrock *et al*., 1965). Total above ground dry biomass (kg) was 0.002604(G) ^ 2.7826), where 'G' is the girth (trunk) at 150 cm, which was validated (Ambily *et al*., 2012) for the rubber clones in India. Similar method of the estimation of biomass using allometric equation was reported for the coniferous and broadleaved mixed forest in north-eastern China (He *et al*., 2018) and among *Poplar* SRC clones (Dinko *et al*., 2017). The allometric equation for biomass estimation was also reported in *Olea europaea*, L. Subsp. *cuspidate* in Mana Angetu forest (Kebede *et al*., 2018) and mountain moist evergreen forest in Mozambique (Lisboa *et al*., 2018). Using the per cent contribution of biomass to the components (trunk, branches and leaf) of the uprooted trees, the corresponding biomass of the tree components in standing trees were estimated. Root biomass was around 10 per cent irrespective of the clones in the uprooted trees. Hence, to estimate the root biomass of standing trees, the corresponding root dry biomass per cent of uprooted trees of each clone were used. From this, the total biomass (above-ground + root) of standing trees of clones were calculated. A portion of sub-samples were collected from trunk, branches, leaves and roots of the standing trees (10 numbers each) of every clone to determine the nutrient concentration as per the method used for the uprooted trees. Nutrient accumulation was worked out by multiplying the nutrient concentration with dry biomass derived for the standing trees. Contributions of nutrients to the total dry biomass of the tree in each clone were also calculated.

Statistical analysis

Data were statistically analysed by one way analysis of variance (ANOVA) to compare the growth parameters, biomass, nutrient accumulation and distribution in plant components. Total nutrient accumulation in whole tree basis and contribution of nutrients to total biomass were also compared between clones using one-way ANOVA. When the data were significant at the 5 per cent significant ($p<0.05$) level, a multiple comparison by Duncan multiple range test (DMRT) were performed to describe the significant level of the clones for all parameters. All values shown are mean values for each clone. Means with different letters are statistically different ($p<0.05$). All analyses were conducted by OP stat (Sheorm, 1998).

Results

Growth

Growth characteristics (Table 1) were significantly different ($p<0.05$) among *Hevea* clones. Height recorded were 10.9 m for RRII 105 and 14.7, 14.8 and 15.3, respectively, for RRII 118, RRII 203 and GT 1. The

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RRII (p=0.0001) height was recorded of the clone RR 105, and the height of other three clones was on par. Girth was higher (p=0001) in RRII 118 (146.8 cm) and GT 1 (138.7 cm) than in RRII 203 (111.8) cm and RRII 105 (103.8 cm). Moreover, it was observed that the same ratio of girth and height, which comes to 1:10, was observed for each of the clones except RRII 203 (of which the ratio was recorded slightly higher, i.e., 1:13 (p=0.0001)).

Table 1: Growth characteristics (Height, Girth, Girth: height ratio, Shoot: root ratio and Root: shoot ratio of clones *viz*. RRII 105, RRII 118, RRII 203 and GT1. All values showed are mean values. Means with different letters are significantly different (p<0.05).

Clone	*Height (m)*	*Girth (cm)*	*Girth: height ratio*	*Shoot: root ratio*	*Root: shoot ratio*
RRII 105	10.9^{b}	103.8^{d}	$1:10^{b}$	8.01^{c}	0.12^{a}
RRII 118	14.7^{a}	146.8^{a}	$1: 10^{b}$	10.62^{a}	0.09^{a}
RRII 203	14.8^{a}	111.8^{c}	$1:13^{a}$	12.06^{d}	0.08^{a}
GT1	15.3^{a}	138.7^{b}	$1:11^{b}$	14.39^{b}	0.07^{a}

Biomass and partitioning

The variation in biomass was observed in the clones. The biomass production and the yield potential, as per the approved classification (Saraswathyamma *et al.*, 2000), were found different in four clones under study. The growth characteristics of RRII 105 was observed with tall trunk having good branches along with strong union. On the other hand, RRII 118 was a vigorous clone with short trunk having prominent branches like trunk along with secondary branches. In RRII 203, the trunk was long and straight with well distributed and balanced canopy; but in GT1, the trunk was upright and slightly kinked with main branch long and acute angled along with light secondary branches. The yield potentials of the clones *viz*. RRII 105, RRII 118, RRII 203 and GT1 reported by Saraswathyamma *et al.* (2000) were 2400, 1164, 1818, and 1400 $kg^{-1}ha^{-1}$ per year. It was observed that the high biomass accumulating clones was not good in yield.

Significant biomass difference (Figure 1) and biomass partitioning per cent to the total biomass (Figure 2) in plant components were observed between clones. The total dry biomass was 1214.43, 2489.09, 1102.29 and 2055.58 kg/tree for the clone RRII 105, RRII 118, RRII 203 and GT 1, respectively. Among the clones, RRII 118 and GT1 recorded higher biomass (p=0.0001) compared to RRII 105 and RRII 203.

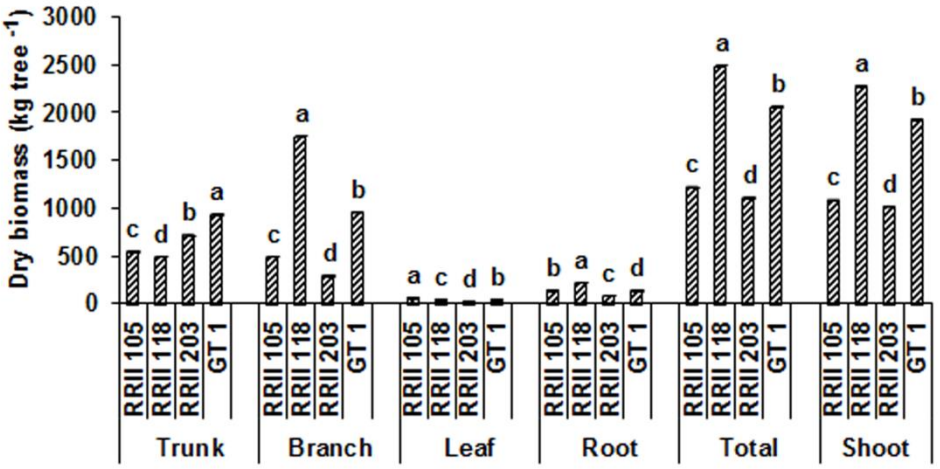

Figure 1: Dry Biomass accumulation (kg $tree^{-1}$) (Total, Shoot and in plant components (Trunk, Branches, Leaf and Root) of clones (RRII 105, RRII 118, RRII 203 and GT1). All values showed are mean values. Means with different letters are significantly different (p<0.05).

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The clone RRII 203 recorded higher (p=0.0001) biomass (709.76 kg tree^{-1}) and per cent contribution (64.13 %) in trunk and recorded less biomass (289.31 kg tree^{-1}) and per cent contribution (26.14 %) in branches, compared to the clone RRII 118. RRII 118 recorded less biomass (489.67 kg tree^{-1}) and per cent contribution (19.67 %) in trunk and higher (p=0001) biomass (1752 kg tree^{-1}) and per cent contribution (70.39 %) in branches. But GT 1 and RRII 105 recorded an equal distribution: around 40 per cent in trunk and branches. Higher (p=0.0001) leaf dry matter was recorded in RRII 105 (54.17 kg tree^{-1}) and lowest in RRII 203 (18.81 kg tree^{-1}). Higher per cent leaf dry matter was observed in RRII 105 (4.46%), whereas other clones recorded leaf dry matter of less than 2 per cent. Root biomass was higher (p=0.0001) in RRII 118 (214 kg tree^{-1}) and lower in RRII 203 (84.41 kg tree^{-1}). However, the per cent contribution was higher in RRII 105 (11.1), while other clones recorded less than 10 per cent contribution of root biomass. When comparing the clones, 88-93 per cent shoot biomass and 7-11 per cent root biomass was observed at the age of 30 years. Shoot to root ratio in RRII 203 (12.1), GT 1 (11.1), and RRII 118 (10.6) is higher (p=0.0001) than RRII 105 (8.1).

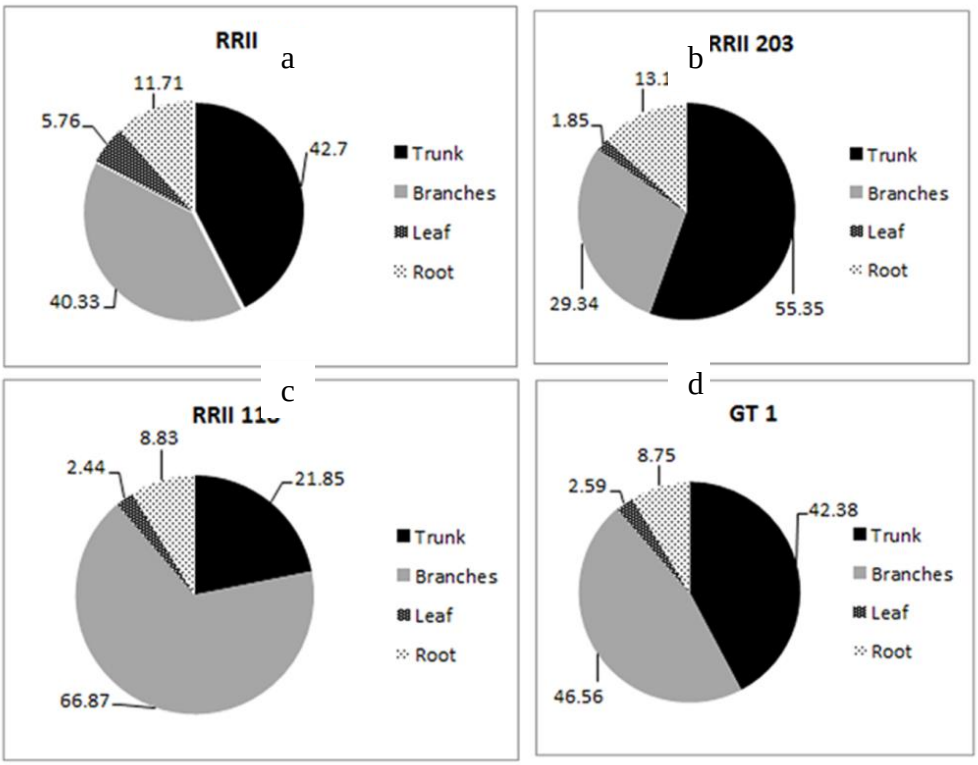

Figure 2: Biomass partitioning (%) of tree components in clone, RRI 105 (a), RRII 118 (b), RRII 203 (c) and GT 1(d). The data label denotes the per cent values of plant components in each clone.

Nutrient concentration

Nutrient concentration in tree components (Figure 3a-i) varied among different clones. Significant variation (p=0.0001) in nutrient concentration in tree components and between clones except N concentration in branches and Fe concentration in root were observed. Some indications such as high K (p=0.0001) in trunk, branches and leaf of RRII 118 and trunk of RRII 203 and high Ca (p=0.0001) in trunk and branches of RRII 105 is to be investigated further. Because RRII 118 and RRII 203 were known drought tolerant clones and RRII 105 is the popular high yielding clone, the difference in K and Ca content observed in these clones may be related to drought tolerance and yield, respectively. Therefore, this is to be considered for detailed studies to investigate whether there is any relation of these nutrients with the drought tolerance or yield. For the micronutrients also, there was significantly higher (p=0.0001) variation in Mn and Fe concentration in

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leaf of different clones. The clone RRII 118 recorded the highest (p=0.0001) Fe and Mn content in leaf. The clone RRII 105 also recorded higher (p=0.0001) Fe content in leaf. This is an indication of tolerance of these nutrients in rubber. The detailed study of the role of nutrients in rubber will enlighten further.

Table 2: Nutrient accumulation (N, P, K, Ca, Mg, Zn, Cu, Fe and Mn) of clones *viz*. RRII 105, RRII 118, RRII 203 and GT1 on per tree basis in kilogram per tree (kg/tree) All values showed are mean values. Means with different letters are significantly different (p<0.05). Nutrient accumulation in plant components (trunk, branches, leaf and root) in g/kg.

Clone & Tissues)	*Nutrient accumulation (kg/tree)*								
	N	*P*	*K*	*Ca*	*Mg*	*Zn*	*Cu*	*Fe*	*Mn*
RRII105	7.91^{b}	0.59^{d}	5.88^{d}	14.79^{a}	1.45^{c}	0.03^{c}	0.01^{c}	0.04^{c}	0.08^{b}
(Trunk)	(4.29)	(0.36)	(4.24)	(12.74)	(1.34)	(0.02)	(0.01)	(0.29)	(0.05)
(Branch)	(4.11)	(0.33)	(3.87)	(15.14)	(0.81)	(0.02)	(0.01)	(0.18)	(0.07)
(Leaf)	(36.19)	(2.68)	(10.56)	(5.63)	(2.46)	(0.15)	(0.02)	(0.83)	(0.45)
(Root)	(6.06)	(0.09)	(8.45)	(1.84)	(1.49)	(0.03)	(0.01)	(0.48)	(0.03)
RRII118	9.79^{a}	1.12^{a}	26.29^{a}	7.11^{c}	3.8^{b}	0.05^{a}	0.03^{a}	0.47^{b}	0.21^{a}
(Trunk)	(3.84)	(0.35)	(6.83)	(4.37)	(1.89)	(0.02)	(0.05)	(0.33)	(0.04)
(Branch)	(3.21)	(0.40)	(7.23)	(2.31)	(1.39)	(0.01)	(0.01)	(0.12)	(0.11)
(Leaf)	(38.58)	(2.79)	(18.62)	(7.51)	(2.51)	(0.18)	(0.12)	(0.91)	(0.78)
(Root)	(4.71)	(0.16)	(12.41)	(2.66)	(1.68)	(0.01)	(0.02)	(0.32)	(0.03)
RRII203	5.01^{c}	0.84^{c}	10.41^{b}	3.24^{d}	1.58^{c}	0.02^{d}	0.01^{c}	0.04^{c}	0.04^{c}
(Trunk)	(4.11)	(0.71)	(11.7)	(3.19)	(1.67)	(0.15)	(0.01)	(0.48)	(0.03)
(Branch)	(3.52)	(0.52)	(3.17)	(1.81)	(0.54)	(0.01)	(0.02)	(0.14)	(0.03)
(Leaf)	(34.04)	(2.41)	(14.74)	(9.59)	(5.01)	(0.11)	(0.08)	(0.63)	(0.51)
(Root)	(5.09)	(0.14)	(13.15)	(3.21)	(1.66)	(0.02)	(0.02)	(0.42)	(0.03)
GT1	9.65^{a}	1.02^{b}	7.55^{c}	9.87^{b}	4.07^{a}	0.04^{b}	0.02^{b}	0.63^{a}	0.03^{d}
(Trunk)	(4.41)	(0.55)	(4.89)	(5.94)	(3.06)	(0.16)	(0.01)	(0.42)	(0.41)
(Branch)	(3.81)	(0.24)	(1.38)	(3.71)	(1.11)	(0.01)	(0.01)	(0.19)	(0.06)
(Leaf)	(34.95)	(2.57)	(11.93)	(11.29)	(3.32)	(0.19)	(0.04)	(0.36)	(0.19)
(Root)	(3.83)	(0.!7)	(7.61)	(1.86)	(1.23)	(0.01)	(0.02)	(0.24)	(0.03)

(Values in parenthesis represents the nutrient content of tissues (g/kg)

Nutrient accumulation

The major and micronutrient accumulation, except Fe in root, in tree components (Figure 4a-i) varied among different clones. Of the major nutrients, *viz*. N, P and Mg accumulation in trunk was higher (p=0.0001) in GT 1. Similarly, higher (p=0.0001) K and Ca accumulation in trunk was recorded in RRII 203 and RRII 105, respectively. In branches, the higher (p=0.0001) accumulation of all nutrients compared to other clones was observed in RRII 118. Since the accumulation of nutrients is also a function of the biomass of components, the large biomass of branches in RRII 118 contributes to the higher accumulation of corresponding nutrients. In leaf, N, P and Mg were higher (p=0.0001) in RRII 105; whereas lower K and Ca were observed in RRII 203. In root, RRII 118 recorded higher (p=0.0001) N, K, Ca and Mg. Among the clones, micronutrients *viz*. Zn, Fe and Mn accumulation in trunk was higher in GT1. The Cu was lowest in RRII 105. In branches, all micronutrient accumulation was higher (p=0.0001) in RRII 118. In leaf, Zn and Fe were higher (p=0.0001) in RRII 105 with higher (p=0.0001) Cu in RRII 118. In root, Zn, Cu and Mn were higher (p=0.0001) in RRII118 compared to other clones. The nutrient accumulation is related to the biomass characteristics and nutrient concentration of the plant components, and both contribute to the observed differences among the clones. The role of nutrients to plant activities is to be further studied.

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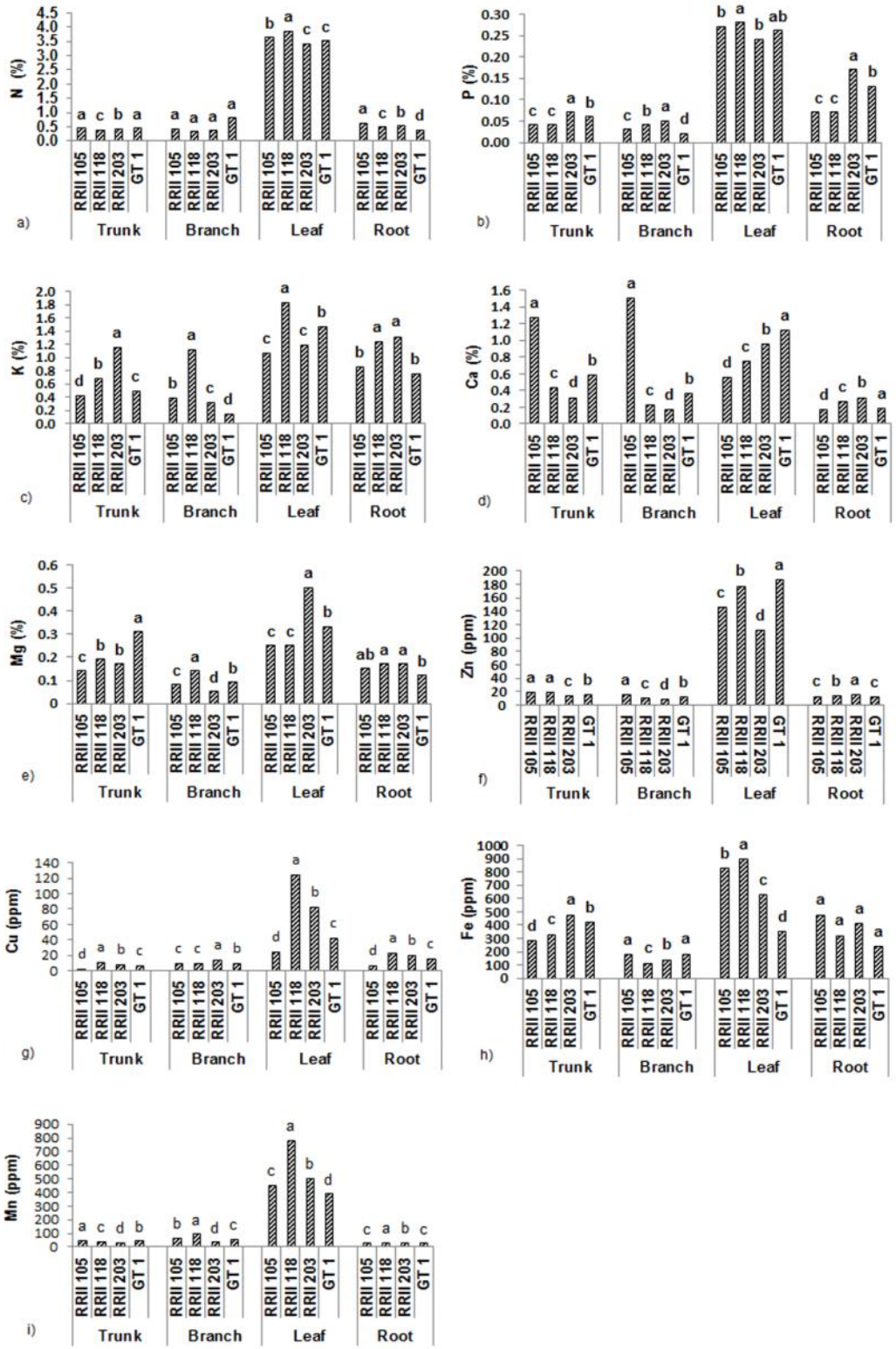

Figure 3: Nutrient concentration (N, P, K, Ca, Mg, Zn, Cu, Fe and Mn) in plant components (Trunk, branches, leaf and root) of clones *viz*. RRII 105, RRII 118, RRII 203 and GT1.All values showed are mean values. Means with different letters are significantly different (p<0.05).

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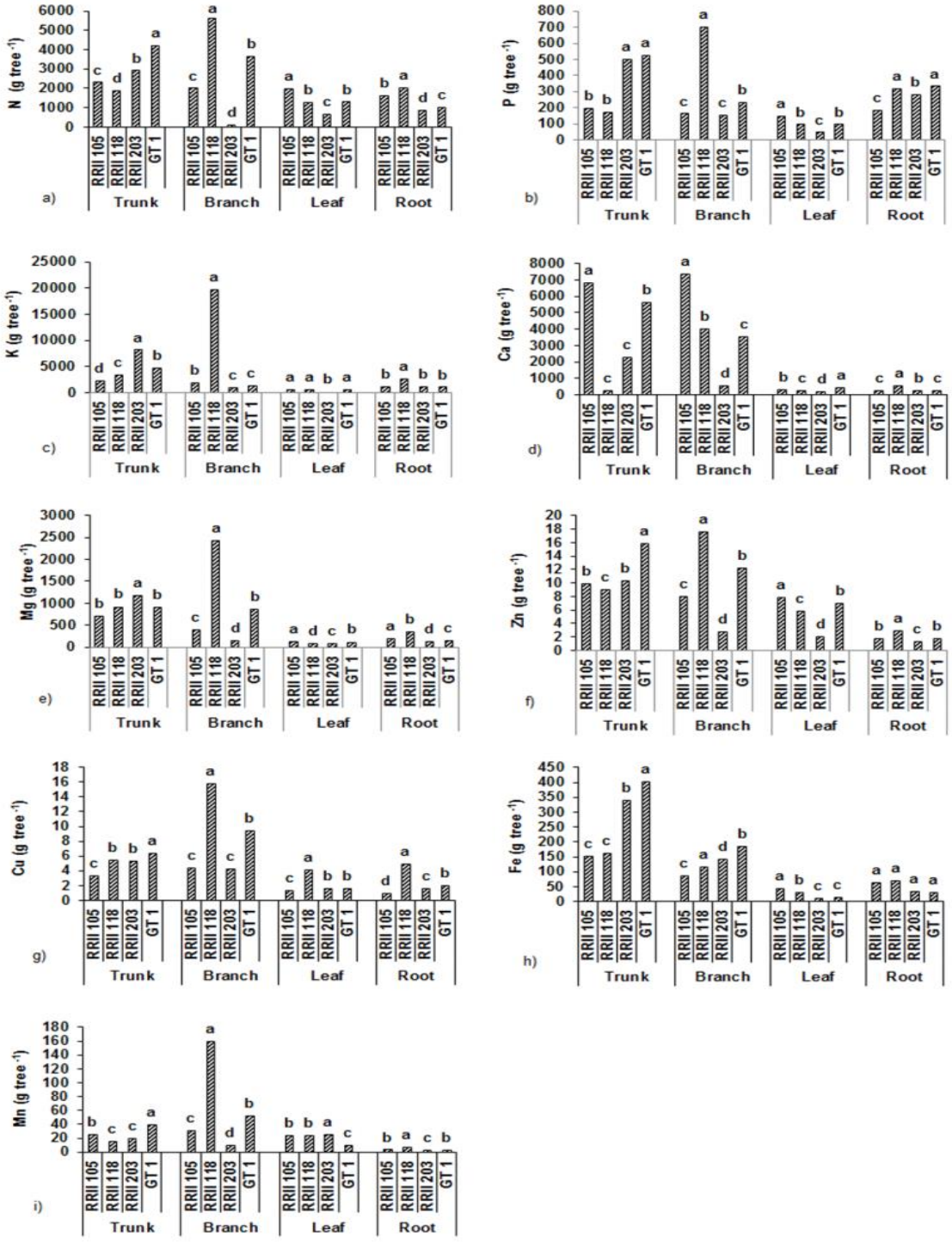

Figure 4: Nutrient accumulation (N, P, K, Ca, Mg, Zn, Cu, Fe and Mn) in plant components (Trunk, branches, leaf and root) of clones *viz*. RRII 105, RRII 118, RRII 203 and GT1.All values showed are mean values. Means with different letters are significantly different (p<0.05).

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Nutrient accumulation in the whole tree (Table 2) showed variation between clones. The values of major and micronutrient accumulation in the whole tree were N (5.01-9.79), P (0.59-1.129), K (5.88-26.29), Ca (3.24-14.79), Mg (1.45-4.07), Zn (0.02-0.05), Cu (0.01-0.03), Fe (0.04-0.63) and Mn (0.03-0.21) kg tree^{-1}. Higher (p=0.0001) Ca accumulation was found in RRII 105. But RRII 118 and RRII 203 accumulated higher (p=0.0001) K than Ca. The nutrient order found in the studied clones was Ca>N>K>Mg>P (except in RRII 118 and RRII 203). Micronutrients were in the order of Fe>Mn>Zn>Cu in *Hevea* clones. Higher (p=0.0001) Zn, Cu, Fe and Mn accumulation was observed in clone RRII 118. The highest (p=0.0001) Fe accumulation was recorded in GT 1. Furthermore, detailed studies are required to know the role of these elements or any toxicity due to these elements in rubber. Is it a genetic character contributing to low yield in different cultivars?

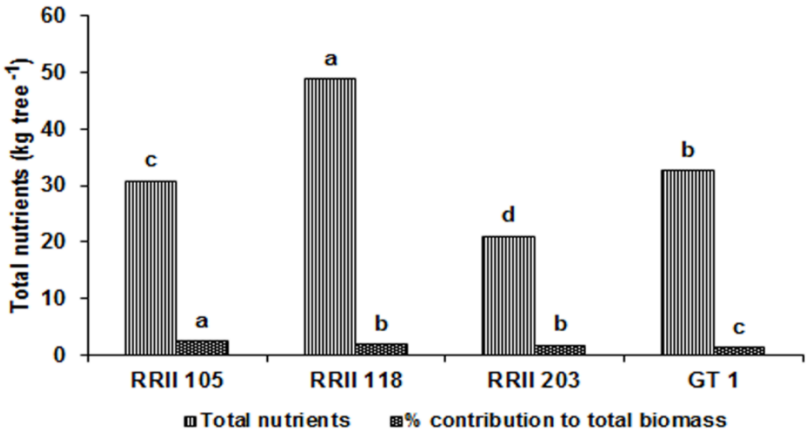

Figure 5: Total nutrients and per cent contribution of nutrients to total dry biomass in different clones. The bar in grey colour with vertical lines denotes the total nutrients and bar in black colour with dots denotes per cent contribution of nutrients to total dry biomass. All values showed are mean values. Means with different letters are significantly different (p<0.05).

Total of all nutrients in the clones and per cent contribution of nutrients to total dry biomass are presented in figure 5. Total of all nutrients in RRII 105, RRII 118, RRII 203 and GT1 were, respectively, 30.96, 48.86, 21.19 and 32.85 kg tree^{-1}. Total nutrients varied much as these were related to the biomass of the clones. But per cent contribution of nutrients was 2.55 for RRII 105, 1.96 for RRII 118, 1.92 for RRII 203 and 1.61 for GT 1. Among the clones under study, RRII 105 had higher (p=0.0001) per cent contribution of nutrients, whereas the nutrient concentration was lower (p=0.0001) in GT 1. RRII 118 and RRII 203 were on par. The yield potential of these two clones was also very much different. Even though the total nutrients showed much variation between clones, the per cent contribution was not varied correspondingly and was observed as below 3 per cent at the age of 30 years.

Discussion

In *Hevea*, the evolution of clones through breeding with improved qualities is ultimately for achieving enhanced productivity and environmental sustainability. There are different reports that clones were different in their performances (Mydin *et al*., 2017; Reju *et al*., 2020; Ambily *et al*., 2012; Meenakumari *et al*., 2013) including the girth, biomass especially above-ground biomass, yield, stress, disease tolerance and wood properties. Shorrock (1965) reported the historic initial time studies on girth and above-ground biomass of clones in Malaysia and found a variation between clones. Swamy *et al*., (2006) had observed around 1.5 times increase in girth among two clones of *Populus deltoids* in agrisilviculture plantation. The growth variation of *Eucalyptus* clones was observed by Saravanan (2019). In the present study, the clones studied were different in girth and above-ground biomass. The reason for a similar girth:height ratio observed for all clones except one

clone being a timber clone with long straight trunk is found as a clone characteristic of *Hevea.* In the present study, the root biomass was only slightly different as compared to the above-ground biomass, and the root biomass was about 10 per cent irrespective of the clones. In earlier studies (Karthikakuttyamma, 1997), the shoot to root ratio was reported to be 5.92 for the clone RRII 105 at 20 years age. Jessy (2008) reported that the shoot to root ratio to be 4.81 for the clone PB 217 at 19 years age. The root to shoot ratios in these studies were 0.17 and 0.21, respectively, which are different from the clones (0.1-0.12) at 30 years age used in the present study. This indicated that there is age-wise difference existing in the shoot to root and root to shoot ratios in rubber clones. Biomass partitioning of rubber is a species character as reported in other species where the partitioning was in a different manner (Albaugh *et al*., 2006) having root to stem ratio of 0.7-0.5, 0.4 and 0.47 in *Pinus taeda* trees at three sites. Thus, shoot to root ratio is around 50 per cent in *Pinus taeda* trees. Ludovici *et al*. (2002) reported that the root: stem ratio of 0.43 in loblolly pine was 30 per cent root and 70 per cent shoot mass. In agrisilviculture plantations, the root to shoot ratio of *Populus deltoids* was different (0.2 to 0.35) between clones (Swamy *et al*. 2006). In rubber, a different pattern of partitioning was observed in the present study. In *Picea likiangensis*, 14.8 per cent root biomass was reported at 32 years age in Southern China (Davidson *et al*., 1999). The high biomass accumulated clones, *viz.* RRII 118 and GT 1, had lower yield potential as reported in approved cultivar classification (Saraswathyamma *et al*., 2000). Therefore, the inverse relation of biomass and yield was observed in clones of the present study.

The variation in biomass production, partitioning and per cent contribution to plant components of clones was reported by many workers (Dinko *et al*., 2017; Swamy *et al*., 2006; Saravanan, 2019). Similar observation of the higher branch biomass in the highest biomass accumulated clone was found in the hybrid aspen (*Populus tremula* × *P. tremuloides*) clone (Hytonen *et al*., 2020). Variations in biomass partitioning and per cent contribution to total biomass in clones was also found in *Eucalyptus* clones (Saravanan, 2019).

The clonal difference in nutrient concentration was reported in hybrid aspen (*Populus tremula* × *P. tremuloides*) in Finland (Hytonen *et al*., 2020) and natural rubber *Hevea* in Thailand (Hytonen *et al*. 2019; Hytonen *et al*., 2020) and was found different from the present study. This may be attributed as species and location-wise difference. General order of macronutrient content of rubber tree observed (Karthikakuttyamma, 1997; Jessy, 2008) was Ca>N>K>Mg>P and the difference in the nutrient of two clones of the present study can be attributed as a clonal character related to the different plant activities in these clones. The different pattern of nutrient distribution in the tree *Picea likiangensis* in Southern China was reported by Liu *et al*. (2004). Nagaraju *et al.* (1997) reported that the plant species differ in their nutrient elements in plant components. Kleiber *et al*. (2019) have reported that the per cent nutrient content of Lime tree and Horse chestnut tree differed in their health indicated the species specificity in nutrient pattern. In the present study, there was variation in nutrient concentration in different plant components. The higher Ca in the trunk and branches in the clone RRII 105, high K in all the plant components of clone RRII 118, high K in the trunk and root of RRII 203 and high Ca and K in the leaf of clone GT1 may relate to different plant activities like yield variation, drought tolerance, disease resistance and timber properties. Higher leaf K was reported as an index of adaptation to drought stress in *Hevea* (Ambily *et al*., 2020). The observation of higher K in the clones of the present study indicated the role of K in drought tolerant property in *Hevea* and can be further studied for breeding for drought tolerant clones. The clone RRII 105 is a high yielding clone and RRII 118 and RRII 203 are drought tolerant. This may be a clone specific difference due to that the Ca content of plants is, to a large extent, genetically controlled and little affected by the Ca supply in the root medium (Lungstrom and Stjernqust, 1993). Higher Ca may be attributed as the higher plants often contain Ca in appreciable amounts. Calcium is largely immobilized in cell walls and would be expected to accumulate with age (Lungstrom and Stjernqust, 1993). It was reported (Fromm, 2010) that Ca and K application was beneficial for the formation of wood in trees. The role of Ca and K is in cambial activity, xylem development and xylogenesis. The clones already identified as timber clones had a high K in the present study; it is also somewhat related to the role of K in wood formation in *Hevea*. The higher K content also relates to the drought tolerance and the observed high leaf K and root K in RRII 118 and RRII 203 may be due to drought tolerant property of these clones. The drought tolerant property of *Hevea* clones based on the physiological properties was reported by Neethu *et al*.

(2021). Antony *et al*. (2018) reported that RRII 203 showed high K in leaf and root in the present study, which had better performances in dry areas in Karnataka. This is also evidence of a relation of K and drought tolerant properties of this clone. However, the clone RRII 105 with low K content was found as susceptible to more leaf drying to drought stress also support the role of high K in drought tolerance of clones. As far as the leaf diseases are considered, abnormal leaf fall and powdery mildew caused by *Phytophthora palmivora* and *Oidium hevea steinm*, respectively, are the major crop loss resulting diseases in India (Mazlan *et al*., 2019). Among the clones studied, the clone RRII 105 and GT1 were reported as resistant clones to *phytophthora* leaf fall on prophylactic spraying (Edathil *et al*., 2000). In a recent report (Khompatara *et al*., 2019), *Sargassum polycystum*, a seaweed extract, was found effective to increase resistance to the *Phytophthora* mediated leaf fall disease in rubber seedlings. Bharat *et al*. (2018) reported that an alga, *Sargassum polycystum*, has the elemental concentration of sodium (85.3 mg L^{-1}), chlorine (75.02 mg L^{-1}) and calcium (69 mg L^{-1}) in higher quantity and among this Ca was in appreciable quantity. This pointed out the role of Ca in controlling *Phytophthora* leaf fall disease. The enhanced resistance may be due to high Ca content in these clones. Disease control using chemical fertilizers usually have an adverse effect on the environment, soil and a reason for toxicity of living beings associated (Khompatara *et al*., 2019). In consideration of these, the identification of inherently resistant clones is more beneficial and easier as a control measure. Therefore, the observation of high Ca in the clones can be a basis for the detailed study of the elemental role of Ca and further in the breeding and selection of resistant clones. The nutrient order of macronutrient content of rubber clone RRII 105 and PB 217 observed was Ca>N>K>Mg>P (Karthikakuttyamma, 1997; Jessy, 2008). But the nutrient order in the present study varied among clones even though clone RRII 105 and GT1 had similar order of macro nutrient concentration. Similar order of nutrient elements was reported in orange trees (Mattos *et al*., 2003). Species difference is evident as reported by Davidson *et al.* (1999) in the nutrient accumulation of the two species *viz*., *Inga dens flora* and *Pollalesta discolor*, in which nutrient order is N>K>Mg>P>Ca. This was different from *Hevea* clones studied. Similar concentration pattern of *Hevea* clones except RRII 118 was reported in Apple trees in Himachal Pradesh (Sharma and Bandari, 1995). Kumar *et al*. (2005) reported the nutrient concentration in bamboo (*Bambusa bambos*) tree in a different manner from observed in *Hevea*.

Species difference was observed in the case of micronutrients also. The significant clonal difference in the concentration of Zn and Cu was reported by Hytonen *et al*. (2020). In two tree species *viz*., *Inga densiflora* and *Pollalesta discolor*, the micronutrient concentration was in the order of Mn>Fe>Zn>Cu (Davidson *et al*., 1999), which was different from that observed in rubber. This may be attributed to the differences in the uptake and metabolism, according to the requirement of the crops. Generally, Fe toxicity is happening when Fe concentration exceeds 1,000 ppm. But in rubber, Fe concentration in the leaf itself was 899 ppm in clone RRII 118 without toxicity symptoms. Mn is also very important in the sense that it is having biochemical functions. Mn exceeding 160 ppm causes toxicity (Alejandio *et al*., 2020). In acidic soils high in manganese availability, plants can take up considerable amounts of Mn so that levels in the order of 1,000 ppm Mn in the dry matter are not uncommon (Alejandio *et al*., 2020). But when it exceeds 2,000 ppm, toxicity is often observed. In the clone RRII 118, Mn concentration in the leaf was 780 ppm and in other three clones it ranged from 387 to 499 ppm. Higher level of Fe and Mn in leaf in *Hevea* clones indicates that *Hevea* is tolerant or accumulates these elements. Yan *et al*. (2020) reported the recent development of phytoremediation, an eco-friendly technique for the removal of metal pollutants by growing plants having ability to accumulate these elements. This indicated that the tolerance of higher Fe and Mn concentration in *Hevea* may have the possibility for phytoremediation. The Zn and Cu concentration is comparatively less in rubber. Usually, copper is taken up by plants in only a very small quantity. Pietrini *et al*. (2019) reported that, in most of the plants, Cu is important in physiological functions in a concentration range of 3-20 ppm. The nutrient requirement and role of nutrients is to be further explored in *Hevea*.

The total dry biomass (t/tree) in rubber tree in Thailand had 2.4, 0.2, 3.4, and 4.8 kg N, P, K, Ca, respectively, and 380–700, 36–64, 530–980 and 750–1,360 kg per hectare basis (Hytonen *et al*., 2019). This was different from the nutrient accumulation in plant components, total nutrients and per cent contribution of nutrients to total dry biomass observed in *Hevea*. Usually in plant composition, C, H and O comes to around 94-99.5

and nutrient composition is 0.5-6.0 per cent (Mills and Jones, 1996). In the present study, the nutrient contribution was below 3 per cent and within this limit. The total nutrients and per cent contribution of nutrients to total dry biomass in clones indicated that there were adjustments in the nutrient proportions as a species characteristic of *Hevea* and related to the clonal characteristics like variation in growth, yield, and disease and stress tolerance. This is to be further studied in detail to obtain confirmed results to relate the biomass and nutrient accumulation with clonal characteristics. In the present study, clones were different in biomass, nutrient concentration and nutrient accumulation. This is evidence of clonal variation in biomass and nutrient accumulation in *Hevea* clones. The biomass and nutrient budget of the clone RRII 105 was reported by Karthikakuttyamma *et al*. (2004), but the data for different clones is useful for the further detailed study of the role of nutrients in rubber tree and for the nutrient management to clone-wise recommendations judiciously for productivity enhancement and sustainability of rubber ecosystem.

Conclusion

The present study indicates that natural rubber (*Hevea brasiliensis*) clones differ in their biomass production and nutrient accumulation. Biomass partitioning and nutrient distribution pattern was also varying in different clones. Highest yielding clones (RRII 105 and RRII 203) recorded higher leaf and root biomass compared to low yielding (RRII 118 and GT1) clones. The inverse relation of biomass and yield potential was recorded in these clones. While above-ground biomass showed much variation, the below-ground biomass not varied much and, irrespective of clones, about 10 per cent root biomass was observed. This was found as a clone characteristic of *Hevea*. There were no characteristic variations in leaf concentration between clones. High K content in the drought tolerant clones RRII 118 and RRII 203 may be related to drought tolerance and timber properties. High Ca in high yielding clone RRII 105 is a relation of Ca to high yield and high Ca in RRII 105 and GT 1 may be due to a tolerance to *phytophthora* leaf disease in *Hevea*. The observed nutrient relation is pertinent in the relation of these nutrients in yield, wood properties, and drought and disease tolerance. During biomass removal of these clones, there is a possibility of deficiency of K and Ca in the soil. The per cent contribution of nutrients to total biomass varied less between clones and was below 3 per cent at the age of 30 years for all clones and this is evidence of adjustments in proportions of nutrients in *Hevea*. Higher accumulation of iron and manganese indicated that *Hevea* is tolerant to these elements and is a potential for phytoremediation. Detailed study may provide more insight into the relation of biomass and nutrient accumulation to various plant activities in rubber tree and different clones of *Hevea* so as to utilize the soil reserves more efficiently and for further breeding to improved varieties and selection of clones to increase the productivity of rubber.

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Authors' Contributions (in accordance with ICMJE criteria for authorship)

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Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	No
Critical revision of the article/paper	Yes	Yes
Editing of the article/paper	Yes	No
Supervision	No	Yes
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The Potential Role of the Artificial Intelligence in Combating Climate Change and Natural Resources Management: Political, Legal and Ethical Challenges

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Abstract

The aim of the article is to study the role of artificial intelligence (AI) in solving current issues of climate change, environmental protection and natural resources management. The advantages and threats of using AI for the development of political and legal parameters for ensuring the safe and effective implementation of technological system, as well as ensuring sustainable control over its functioning and development trends, are analyzed. The relevance of the topic is substantiated by the fact that the legislative basis in this area is at the early stage of formation, while the scale of the impact of AI on all the aspects of social life may be impossible to accurately foresee. A special attention is paid to the analysis of the legal regulation of these issues in the context of European Union and Ukraine. The present work is one of the few that addresses three issues: climate change, the growing influence of artificial intelligence, and the possibility of legal regulation of the use of AI to solve urgent environmental problems without threatening the fundamental human rights and freedoms.

Keywords

Climate change; Artificial intelligence; Environmental policy; EU law; Adaptation of Ukrainian legislation

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Introduction

Climate change is among the most urgent global problems of the present. The founder of Microsoft Bill Gates declared climate change the main threat to humanity after the COVID-19 pandemic, which can cause even higher death rates (Gates, 2020).The United Nations Intergovernmental Panel on Climate Change (IPCC) issued a Special Report in October 2018 about global warming, identifying its catastrophic consequences, such as rising levels of seas and oceans, melting glaciers and flooding coastal areas and islands, abnormal events such as hurricanes, floods, more frequent and intense droughts and storms, desertification of land and a decrease in crop yields due to the depletion of water supplies, which, in turn, will exacerbate regional tensions and conflicts (IPCC, 2018).

In order to avoid the extreme impacts of a 2°C global temperature rise, the IPCC calls for a 45% decrease of greenhouse gas emissions by 2030 and 100% by 2050, which can be done only by unprecedented changes in all aspects of social life. The case of the United States of America should be highlighted. It has the highest carbon emission from transport (29%), energy (28%), industry (22%), commercial and residential construction (12%), and agriculture (9%) (United States Environmental Protection Agency, 2020). Thus, certain options of reducing negative consequences and adaptation to them were proposed by the joint effort of experts and politicians (Mulvaney, 2019).

Several international negotiations on possible solutions of the climate change problem have taken place together with the framework international laws have been adopted. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) laid the foundation for international cooperation to minimize extent of the climate change. In 1997, the Kyoto Protocol on the Reduction of Greenhouse Gas Emissions was approved (United Nations, 1997). In 2015 the Paris Agreement was adopted (the first universal instrument in order to transit to a low-carbon global economy), where from 2020 a global action plan was fixed in order to limit the warming, which is a lot below 2°C (United Nations, 2015). In 2019, the World Meteorological Organization published a report on state of the climate from the period of 2015 till 2019.It clearly demonstrated that countries are not meeting their international commitments to reduce greenhouse gas emissions, and climate change is happening faster than scientists have predicted (WMO, 2019).

The current search for the solution for the climate change, which is happening in information society (Raban, Gordon and Geifman, 2011; Duff, 2015; Martins *et al.*, 2019; Filippova, 2021), is impossible without the development of cognitive bases and systemic technologies of AI, including the field of ecology, environmental policy and law. The EU High-Level Expert Group on Artificial Intelligence declare that the artificial intelligence is "a software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. The AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing the environment which is affected by their previous actions". Moreover, "AI refers to systems that display intelligent behavior by analyzing their environment and taking actions with some degree of autonomy to achieve specific goals. The AI-based systems can be purely software-based, acting in the virtual world (e.g., voice assistants, image analysis software, search engines, speech and face recognition systems) or the AI can be embedded in hardware devices (e.g., advanced robots, autonomous cars, drones or Internet of Things applications)" (European Commission, 2019).

Considering the civilization significance of the AI and its growing role in solving the key problems facing mankind nowadays, it is vitally important to legally define the status of AI for ensuring its effective management system and regulate its functions. Legitimization of the AI as a new level of social organization presupposes its unconditional control by the society with a continuous legal and technical correction of the virtual reality, which has become its derivative. It is undisputable that AI should be trustworthy as it has

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enormous social impact and, thus, it is a matter of great importance that the use of AI is grounded on fundamental human rights and values. It is also necessary to analyze the problem of climate change and the way the AI technologies affect it. There are many different ways AI can be used for combating climate change. However, a number of environmental, ethical and political issues arise. One of the key issues that will be reviewed in this article is the need for an integral system of legislative acts that should regulate a universal conceptual and categorical apparatus, fundamental principles and rules of the creation, testing, implementation, application and closing of such projects and the establishment of legal responsibility for possible negative consequences.

Methodology

This article presents an analysis of publications on various aspects of the AI use for combating climate change and the implementation of behavioral models that optimize the relationship between humankind and nature, minimizing the negative impact of AI. The examples of successful use of artificial intelligence to deal with the urgent issues of climate change are provided. This is followed by an overview of the challenges of AI use in the context of environmental protection, with an emphasis on those factors that directly affect the climate, as well as the political and ethical issues related to the problem of climate change. This research is based on the general scientific methods of analysis, systems approach, synergetic and modelling. Finally, the issue of legal regulation of the AI use in the European Union and Ukraine and the development prospects of legislation in this area are considered in detail. Particular scientific methods of specific sociological research and comparative legal research were used in order to collect, analyze, and process the legal information and to optimize the legislative regulation of the AI's use for solving current environmental issues.

Results and Discussion

Using the Artificial Intelligence to Tackle the Problem of Climate Change

The Artificial intelligence is considered the most important game-changing factor in global politics and economics. The results of 2017 Geneva UN Artificial Intelligence Summit revealed that the AI may cause positive changes to all aspects of human life. Additionally, it has been proposed to reorient AI's application options used for self-driving car, smart phones with voice and face recognition. This is seen as a means for fundamental improvement of mankind supporting comprehensive actions to eradicate the lack of the food and essential commodities, and to safeguard the natural environment (Muraleedharan, 2021). AI can predict climate and provide global and individual weather reports more precisely by covering vast challenges such as forecasting hurricanes, floods, droughts, simulation of former climatic situation and their social and economic consequences. Recent research (Rasp, Pritchard and Gentine, 2018) showed that the artificial intelligence and artificial neural networks successfully help in regulating difficult and local atmospheric processes. For example, processes taking place at the origin and development of convective clouds and, consequently, help with clarifying details, which ongoing models of climate metrics do not consider.

AI opens up some new possibilities for understanding the vast array of data obtained from many component modellings of climate. Monteleoni *et al*. (2011) and McQuade and Monteleoni (2012) combine the predicted situation of about 30 climate models the IPCC uses via computer learning algorithms. Improving the accuracy of global climate simulations, the AI algorithms reduce and manage natural disaster (such as extreme atmospheric events) risks, which are predicted to become more frequent and severe (McGovern *et al.*, 2017). Better forecasts are needed to develop effective climate policies, enable governments to adapt to change and identify opportunities to cope with negative impacts. The AI algorithms increase preparedness for environmental risks when quick and smart decisions are critical. The AI algorithms are used not only for local natural events, but also for more global ones, as predicting coordination of the measures taken at actual 2°C increase in global temperature. For example, Ise and Oba (2019) described the results of

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providing a neural network with global monthly temperatures over the past 30 years. The neural network successfully predicts the changes of heat over the next 10 years with an accuracy of 97%. AI may also be used to clarify the causes of climate change. Thus, in case of using satellite images, it is possible to identify and map significant sources of CO_2 emissions in countries that do not have reporting obligations.

One other sphere of using AI is managing droughts and other hydrological risks. UNESCO's G-WADI Geoserver application uses an artificial neural network (ANN) algorithm to obtain the value of precipitation for current moment. This product is called 'Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System' (G-WADI PERSIANN-CCS). It is used for informing, emergency planning and managing hydrological risks of natural causes. One can enter the system by means of the iRain mobile application, which was designed to facilitate citizens' participation to collect local data for global rainfall monitoring (UNESCO, 2019). This application shows rainfall satellite observations in real time, tracks extreme rainfall around the world, and gives local rainfall information by using crowd sourcing data augmentation. AI can also be applied for demonstrating extreme weather effects (Snow, 2019). In order to demonstrate comfortably visualized form for the community, experts at the Montreal Institute for Learning Algorithms (MILA), Microsoft, and Conscient AI Labs used a GAN (a kind of the AI) to model the probable looks of houses after damages by the sea level rise and more severe storms. The plan includes launching an application in order to show people what their homes and neighborhoods might look like in the future, with the various impacts of climate change.

Additionally, AI can be used for measuring and reducing CO_2 emissions by optimizing existing systems. Carbon Tracker, an independent financial analytical tank, tracks emissions from coal-fired power plants by means of data, obtained from satellites, and convinces that such an industry is financially sub-optimal. This technology can be used all over the world in places where monitoring is not carried out and there is no need to obtain a permission. AI is also introducing new ways to measure the impact of factories by analyzing data about local infrastructure and electricity being used. It is convenient for gas-fired power plants having no readily measurable plumes like coal-fired power plants. Carbon Tracker is going to be used for analyzing emissions for 4,000-5,000 power plants and is expected to create the largest data bank making information publicly available. If a carbon tax is imposed in the future, Carbon Tracker can help set the price for emissions and can find the emission producers.

Microsoft Company has found another solution by creating autonomous underwater data centers, which are controlled by the artificial intelligence. Ocean is used for cooling, while energy of the waves is used for powering (Roach, 2020). Also, the AI can accelerate research of nuclear fusion reactors, which could provide a safe and carbon-free alternative to unsustainable power generation. The AI can regulate and optimize energy consumption with smart buildings that use built-in sensors for energy efficient consumption. Such energy consumption can be significantly reduced with the help of the AI, by taking into account the predicted weather, building congestion and other environmental conditions to adjust the needs of a local indoor infrastructure. Moreover, such buildings are capable of regulating the energy consumption if low-carbon electricity is in short supply. These innovations are especially relevant to urban spaces, as they are projected to ensure that at least 60% of the humanity in the world will live in such houses by 2050 and are extremely resource intensive. The AI is also used for optimizing electricity-required processes. One of such cases is Google's Deep Mind artificial intelligence that helped organizations reduce their data center's energy consumption by 40% and to become more energy-efficient by cutting greenhouse gas emissions. Further, the AI can be successfully used for the industrial emission control and waste management. With the help of advanced learning tolls and intellectual networks, deviations from industry standards and government regulations can be traced. For example, IoT technology has been implemented in some industrial plants, connected with low temperature keeping devices.

Other similar AI-powered Earth applications are iNaturalist and eBirds, which gather information from a wide range of experts on species' populations, ecosystems, and the ways of migration. These products are

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important for improving the findings and saving of freshwater and marine ecosystems. Intelligent agricultural solutions are also worth mentioning. Namely, the agricultural technology startup PEAT in Berlin created the Plantix application, which detects probable problems in soil. American companies AWhere and FarmShots use self-learning program in conjunction with satellites to obtain weather forecast, to investigate crop resilience, and to assess farms for disease and pests.

It is noteworthy that AI is already being used to optimize clean energy development. In the Amazon Basin, hydroelectric dam constructors usually develop one dam at a time without a long-term strategy. A group of experts created an AI simulation to find dam sites that can produce the lowest greenhouse gas emissions. The AI model has identified more complex and surprising set of proposals for reducing greenhouse gas emissions than ever before (Cornell University, 2019). In the current situation of more than one billion people having no electricity, the AI can help with electricity supply by giving the possibility to use it and organizing zero-carbon electrification by means of isolated micro-grids (Ritchie, 2019). In 2019, AI and machine learning experts published a document titled "Tackling Climate Change with Machine Learning" (Rolnick *et al*., 2019). The authors of the report were consulted by renowned experts (Hao, 2019). The document suggests 13 areas in which machine learning can be deployed: electricity systems, transportation, buildings and cities, industry, farms and forests, carbon dioxide removal, climate prediction, societal impacts, solar engineering, individual action, collective decisions, education, finance. Several points from the report are considered as under:

- *Improving energy forecasts and collecting infrastructure data* is especially relevant to the transition for more renewable energy sources. The AI can identify construction marks and properties from satellite data to use computer self-learning program to detect how much energy is consumed at the city level. These techniques can determine buildings to be upgraded in order to make them more effective.
- *Creation of the new materials.* Machine learning accelerates the development of materials that store, collect and use energy more efficiently by researching new chemical structures with the properties which are required. The AI can take into account all limits, look through all known materials and combinations and suggest the best available variation. For example, Airbus has developed a new 3D printed aircraft detail which is not as heavy as the original one, but requires less raw materials, and is stronger, and also reduces CO_2 emissions during flight (Autodesk, 2016).
- *Optimization of cargo delivery routes and supply chain.* Machine learning can help to find the ways to combine as many cargoes as possible and to minimize overall travel and some emissions. Better forecasts of supply and demand for goods may reduce wastage during their production and transportation.
- *Advancing electric vehicles.* The AI can improve battery management (charging life and fill-up times) and optimize the transportation system due to more environmentally friendly driving and cars' use for reducing carbon footprint.
- *Improving tracking of deforestation.* The satellite images and programming products may process information on tree cover loss on a much larger scale as well as chainsaw sound detection algorithms may cause the law enforcement agencies to stop illegal activities faster.

The AI is already a common thing in our daily lives, and it is already beneficial for environmental management. All of the abovementioned examples are only some of many possible ways AI can drive the transition to green sustainable development. With the growing demand for automating solutions to environmental problems, it is the obligation of the government, private and public organizations to fund research and development associated with such technologies and ensure standardization, which is required for their production and application. However, the AI is not the only universal method of combating climate change. Nevertheless, while technology is undoubtedly helping generate solutions to the climate change problem, it is not a magic wand and requires joint international action, taken by climate, technical and AI experts as well as politicians, engineers, AI specialists, entrepreneurs and

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governments. By tracking environmental impacts and linking them to human performance, the AI may be of a high importance for designing, implementing and enforcing environmental laws, regulations and policies.

Problematic Aspects of Using Artificial Intelligence in the Context of Environmental Protection

The Artificial intelligence can and must help create more nature-friendly and sustainable environment as well as combat climate change. However, this potentiality raises some questions related to ecological, political and ethical issues (Coeckelbergh, 2020b).

The problem of materials and energy consumption. Machine AI learning requires a large amount of data, and energy that is used to process it and store. Some computing types use more power than others. According to the study by the University of Massachusetts, single NLP (natural-language-processing) model can emit the equivalent of about 300,000 kg of carbon dioxide, which is five times more than a car produces in its lifetime (Strubell, Ganesh and McCallum, 2019; Matheson, 2020). Although AI has a great potential to minimize consumption and make grid-related efficiency optimized, it will still be a major consumer of electricity. According to research, data centers now require more than 2% of the world's electricity (Pearce, 2018), and scientists predict that, by 2025, this amount is expected to grow between 8% and 21% (Andrae and Edler, 2015; Andrae, 2017; Giles, 2019). A study by Belkhir and Elmeligi (2018) indicates that the estimated global footprint in 2020 may be compared to the impact of the aviation industry and greater than that of Japan (the fifth largest pollutant in the world).

In response to criticism, data centers were transformed into more efficient form and now they run, at least partly, from renewable energy sources. Google, Amazon and Microsoft have begun investing in renewable energy and AI to improve energy efficiency. The introduction of AI server farms powered by renewable resources, the development of general-purpose artificial intelligence neural networks, and more are the ways researchers are reducing their carbon footprint (Gent, 2020). But is this investment sufficient to offset the impact of these technologies on the environment and climate at all levels? The vast majority of big companies still relies on fossil fuels and is not subject to environmental control in the pursuit of efficiency. For example, the report from the "Green Peace Clicking Clean" revealed that all of the major streaming companies, namely, Amazon Prime, HBO and Netflix use less than 22% renewable energy. And Northern Virginia, being the base for the largest number of data centers on the planet, is operated by a utility company with only 1% of its electricity coming from renewable sources (Cook *et al*., 2017). With the appearance of wasteful cryptocurrency mining (Hern, 2018) and 5G networks forced on realizing the Internet of Things, data and traffic collection is already accelerating (Hazas *et al*., 2016). Moreover, production of electrical devices requires not only big energy expenditure but also intensive mining of raw materials, the same as plastic used for producing devices and its packaging.

The artificial intelligence and the fossil fuel industry. Some large tech companies are selling their carbon-intensive AI services designed to do easier and more efficient oil and resource production. Amazon attracts new clients through programs such as Predicting the Next Oil Field in Seconds with Machine Learning. Microsoft hosted "Empowering Oil & Gas with AI" (Microsoft News Center, 2018) and Google Cloud works with companies in fossil fuel field. C3 IoT, an artificial intelligence actor, that initially helped drive the transformation to a renewable energy society, is now helping major oil and gas companies accelerate fossil fuel extraction (C3 AI, 2019). The Guardian recently explored the role of large technologies in supporting the fossil fuel market, highlighting that the huge recourses technology companies are investing into actions that oppose climate legislation and advocate climate change denial (Kirchgaessner, 2019).

Non-transparency of information. When researchers and policymakers tried to account for the impact of technology on climate, they faced the problem of extremely small amount of available information. The authors of the Greenpeace report (Cook *et al*., 2017) say that very few companies are revealing new metrics

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concerning the use of dirty and clean energy. Amazon WebServices serve nearly 50% of the global cloud services market. The report stated that the company remained "almost completely opaque about the energy footprint of its massive operations." This gives millions of organizations using AWS the ability to measure and report their own energy and carbon footprint. This non-transparency not only makes it difficult to hold large companies accountable, but also creates a critical barrier for efficient energy in all fields where digital technology is used.

As the AI has to be more ecologically responsible and safe for the climate it is required to increase awareness among its users and data working specialists to support additional method surveys, which will make an ecosystem of energy around the AI more visible. Wolff-Anthony, Kanding and Selvan (2020) have suggested that energy and carbon print have to be showed together with usual producing standards. Among the ethical problems of AI use, it is the lack of privacy and protection of data security, lack of clarity about responsibility, lack of ability, and irreproachability. The ethical principles were suggested and discussed by scientists (Floridi *et al*., 2018; Dignum, 2019; Coeckelbergh, 2020a). Special consultation organizations flagged, for example, collaboration of experts in the AI and professional community (e.g., IEEE), which performed according to the global initiation in ethics. These problems have to be solved, no matter how the artificial intelligence can be used, including improving situation with climate change. Many reports emphasize that humans need to be responsible for self-learning systems. Thus, nowadays, the focus on the way the machine learning can produce or exacerbate the desired results for specific individuals and groups - the effect which is of high importance to the ethics of machines in general (Guzman, 2021). It is worth mentioning that some of the use of AI in environmental sphere can cause certain political problems, some of which are further reviewed.

Political issues regarding freedom and behavior change. The AI can "nudge" people to behave more climate-friendly, leading to a change in the "architecture of choice" (Thaler and Sunstein, 2008). Climate nudging can become the basis for improving the environmental situation in the world. However, nudging while maintaining freedom of choice does not save autonomy and rationality of people. But it is quite questionable whether society is willing to pay such a big price for the sake of the probable environmental benefits.

Using the AI to control humanity. To solve the climate change problem, it is proposed to establish a "green government" which, with the help of the AI, may manage humanity and regulate countries and individuals to achieve climate goals. This looks like a direct threat to human rights and freedoms. However, there are examples of States that have managed to introduce environmental regulation, which, to some extent, introduces certain limitation to improve the climate change situation, but leaves enough freedom. To give the exact definitions for "to some extent", "enough" and "middle" is a complicated issue when democracy determines the way of life. Especially at the global level when one deals with significant differences in understanding what are the fundamental rights and reference points for different countries. Therefore, States will have to face the challenge of human freedom and learn to combine nudging and governance. However, it may result in the situation when some States tackle climate change, while others ignore the problem. This directly leads to the global and intergenerational justice.

Political issues related to the global and intergenerational justice are also noteworthy. Globally, not everyone is under the threat of climate change, and one generation can be affected by the effects of climate change caused by a previous generation. The COMEST report shows that "failure to act can be disastrous, but responses to climate change that are not well organized, with ethical implications, can destroy entire communities, create new paradigms of inequality and uneven distribution, and make even more vulnerable those people who have already been torn away by other man-made political and ideological struggles" (COMEST, 2010). It means that the climate AI interventions need to be more than ethical and take into account the principles of justice when influencing different societies, people of different age, countries and cultures in light of political considerations.

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The Anthropocene problem. One of the reasons for climate change is associated with the desire of modern man to control everything, which was a consequence of such a planetary state as the "Anthropocene" (Crutzen, 2006). Climate change may be considered as a result of strong human grasp on the planet. Instead of increasing planetary control by using AI, it would be more reasonable to reduce the pressure when implementing existing technologies. Additionally, one should consider how climate policy may incorporate the necessary technologies. In this respect, a study by Dobbe and Whittaker (2019) deserves attention, which provides recommendations for launching and improving technology-oriented climate policies and climate-sensitive technology policies. *Mandate transparency* means that the regulators must force all actors to achieve clear and transparent documentation concerning energy and carbon emission.

Account for the "full-stack supply chain". In an essay by Crawford and Joler (2018) and a large-scale map "Anatomy of an AI System" examined one Amazon Echo and highlighted the natural and human resources, which are needed to design, manufacture, keep and at the end get rid of this simple facility. The results were not entirely optimistic. The attention should be paid not only to the possible efficiency but also to the accompanying effects. There is a danger that efforts to improve efficiency in the field of computing may result not in improving the climate, but in increasing dependency on it (Coulombel *et al*., 2019). Relative efficiency is definitely important, but for practical energy metering absolute values are required.

Making "non-energy policy" analysis standard practice. A study of non-energy sectors led Selby, Cox and Royston (2016) to conclude that the AI policy proposals in non-energy sectors often fail to account for climate impacts. Therefore, when the AI is used by usual policy domains, its impact on ecology and environment may be counted as a regular policy instrument.

Implementation of technology regulation and new ecological transactions policy. Given the impact of technology on climate, the integration of climate technology and policy is urgent and ongoing.

Restriction of AI using to speed up fossil fuel extraction. According to researchers McGlade and Ekins (2015), "one third of the oil reserves, a half of gas reserves and more than 80% of current coal reserves must remain unused from 2010 to 2050 to reach the 2°C target." Therefore, a legal regulation is needed to restrict the use of AI for the extraction of fossil fuels. If AI is implemented to neutralize the climate change, one should check and be sure that the positive impact of AI on the environment outweighs the negative one. In this aspect, two points should be considered to deal with a number of objections against AI use. The Allen Institute has proposed certification (Stein, 2020) of the artificial intelligence techniques, differing carbon-neutral from non-carbon neutral AI. However, it is important that these labels are not "green washing", which happens with some other eco-certification regimes (Vos, 2009). Standards can influence the design and deployment of specific AI systems through product certification and serve to disseminate the AI best practices, as in the case of cyber security or environmental sustainability. The "data exchange" approach is to span the exchange of data used in climate computer programs. For example, for the electricity sector, the countries may lead to minimum duplication of tasks associated with climate by using AI as a repository of open data on electricity (St. John, 2018). Centralizing these steps will allow to access data more efficiently while avoiding prohibitive costs and minimizing the impact on the AI learning environment.

Despite the growing awareness of the climate change problem, sufficiently effective solutions, needed to reduce carbon emissions, has not been found yet. Thus, AI is expected to enable the development of some climate strategies without a corrosive carbon budget. However, it is worth recognizing that the use of AI also generates negative impacts on the environment. The AI technology is still extremely energy consuming and material intensive, and the corporations, responsible for this, provide little information about the ecological footprint of their activities. It is also worth mentioning problems such as danger of data's confidentiality protection, distribution of responsibilities, explaining ability, justness, etc. Additionally, political problems related to human freedoms, global justice and fairness between generations, the impact

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of the AI on people's behavior (up to the idea of using direct coercion), as well as the problem of the "anthropogenic" are of a great concern.

Not only companies and rulers are responsible. Until consumers are buying new devices and using oil-powered transport, all economics will stay the way they are. Therefore, it is necessary to develop the climate-friendly AI, making all technological processes more efficient while meeting environmental and climate protection priorities. This will definitely transform everyday life, which will lead to the transformation of economy and society. Special attention should be given to increasing climate awareness among the AI users and technicians, and make the ecosystem of the AI energy and materials transparent.

To address a number of challenges in this area, researchers propose a technology-oriented climate policy strategy and a climate-sensitive technology policy. Recognizing the limitations of the AI should not lead to the exclusion of its use where it is needed to solve complex climate problems. Some tech companies are investing in the machine algorithms to create new AI products for combating climate change. The machine learning systems can improve the ability to display and understand the size and value of underground oil and gas reservoirs, which makes it easier to develop these resources at a lower cost. The AI is also used for developing principally new fuels (Kates-Harbeck, Svyatkovskiy and Tang, 2019). The same logic applies not only to traditional hydrocarbons, but also to new options for the supply of non-hydrocarbon energy. The implementation of AI products is of high importance for achieving Sustainable Development Goals and support democratic processes and social rights. Additionally, the AI technologies are the most important means of achieving the goals of the European Green Deal. It is noteworthy, that users and developers should check first and be sure that results obtained from the AI are understandable and verifiable, unbiased and trustworthy. As well, as a new technology, AI should withstand tests and initial unprofitability.

Legal Regulation of AI Use in the EUand Ukraine

For the effective, understandable and safe use of AI, an integral system of legislative acts is needed. Such acts would regulate a single conceptual and categorical apparatus, fundamental principles and rules for the creation, testing, implementation, application and closure of such projects, the establishment of legal responsibility for possible negative consequences and the procedure for compensation for possible damage.

First studies and activities devoted to various features and peculiarities of the AI and law appeared in the 1970s-1980s. Anne Gardner's thesis "Artificial intelligence approach to legal reasoning" (Gardner, 1984) is a remarkable work in this field. In addition to individual studies, the scientific cooperation in this area emerged. In 1987, the first International Conference on the Artificial Intelligence and Law took place. In 1991, the International Association for Artificial Intelligence and Law was established. In 1992, publishing of "Artificial Intelligence and Law" was started (Rissland, Ashley and Loui, 2003). However, the legal framework in this area has begun to form only recently in the most progressive countries, where the rapid development of information technologies is taking place and requires appropriate regulation. For example, in countries of East Asia, the EU and the United States of America. Notably, the most efficient legal measures in this area are being taken in the European Union.

The AI products and services are the object of many areas of law, including privacy, data security, product liability, intellectual property, and antitrust laws. In addition, these areas of law are expected to be modified according to the new circumstances connected with the AI. As the AI is a principally new technical application and the diligence on legal risks has not become a commonplace yet, the efforts to comply require non-standard approach and the drive to understand what society needs at the moment. A sign of acceptance of exceptional capabilities of AI is the creation of regulatory framework on the AI, which some leading businesses are actually demanding. For now, the proposals are grouped as principles and guidelines, but a regulatory framework should merge to be followed. Progress towards building the structure is taking place fast, though in slightly different ways for different industries and in different jurisdictions (Mitchell *et al*.,

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2020). Despite the fact that AI is used in various fields, there should be a single legislative foundation for all with further industry development. Unified legislation should establish a regime for the creation and use of AI, which ensures human rights, protection of confidentiality, compliance with all ethical standards, open access to information on the impact of AI on humans and the environment.

The European Parliament Resolution on Civil Law Rules on Robotics. On February 16, 2017, the European Parliament adopted a resolution on legislative initiative, according to which a number of legislative and non-legal initiatives concerning construction, operation, and application of robots and artificial intelligence was advised to the European Commission. The Resolution, among other things, encouraged the European Commission to adopt a proposal for a legislative instrument, that would provide civil law rules on the responsibility of robots and AI, "to propose common Union definitions of cyber physical systems, autonomous systems, smart autonomous robots and their subcategories" a special EU agency for robotics and artificial intelligence prepared a charter which includes a code of conduct for robotics engineers, a code for research ethics committees at reviewing robotics, protocols and model licenses for designers. Additionally, the Commission is addressed to "create a specific legal status for robots in the long run, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons responsible for making good any damage they may cause, and possibly applying electronic personality to cases where robots make autonomous decisions or otherwise interact with third parties independently".

The Resolution highlights the need for legal regulation in order to create predictable and clear conditions for enterprises to develop their own projects and plan their own business models; ensure that control over the setting of legal standards is maintained so that the EU and member States are not forced to adapt and live by standards set by other States. The document emphasizes that such regulations "should not influence the processes of research, innovation and development" and that future regulatory initiatives about construction and use of robots and AI "do not restrict innovation in the field". The Resolution can be divided into several main blocks: social, economic, ethical and legal issues and issues with the development of robotics and AI; regulation of the development and use of robotics at the present stage; requirements for standardization in the development of relevant technologies; issues of controlling how actors make their decisions concerning using robotics and AI technologies; creation of an institutionalized control system in the field of robotics and artificial intelligence; issues of civil liability concerning the development and use of robotics and AI; ensuring the protection of personal data exploitation and application of robotics and AI. It is worth noting that the Resolution is one of the first real steps towards legislative consolidation of standards for the development and use of AI. Despite the fact that Resolution is advisory in nature, it provides an opportunity to form an idea of what will underlie the rules that will regulate the relevant activity in the near future (European Parliament, 2017).

In 2018, the European Commission adopted the Artificial Intelligence for Europe (Communication), by which the approach of the EU to harnessing and addressing the AI was contoured (European Commission, 2018a). From 2014 to 2017, the EU invested € 1.1 billion in the AI research and innovation through the Horizon 2020 program. The Communication highlights that AI is being created and used on the grounds of the EU values and fundamental rights. It also revises existing safety and civil liability regulations. The Commission later released a further communication and adopted a plan based on the initial communication in 2018 (European Commission, 2018b, 2018c).

In 2019, the European Commission published Ethics Guidelines for Trustworthy Artificial Intelligence, which sets out a framework for developing and using the trusted AI (European Commission, 2019a). The guidelines set out requests that AI must respond to be considered trustworthy. The set of assessments is intended to help verify meeting each of the key requirements: human agency and oversight, privacy and data governance, robustness and safety, diversity, nondiscrimination and fairness, societal and environmental well-being, transparency, accountability. The AI must "respect fundamental rights,

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applicable regulation and core principles and values, ensuring an ethical purpose and be technically sound and reliable, since even with good intentions, lack of technological prowess can lead to unintended harm". These Guidelines, together with the General Data Protection Regulation, give to the EU the possibility to establish high standards for business in the EU and possibly worldwide.

The European Commission also created the Robotics and Artificial Intelligence Unit, which aims to develop a competitive robotics and artificial intelligence industry in Europe. In April 2018, the EU member States signed a Declaration of Cooperation on Artificial Intelligence to develop a European approach to AI (European Commission, 2018b). In February 2020, the European Commission (2020b, 2020c) published the "White Paper on Artificial Intelligence: a European approach to excellence and trust", which outlines and identifies the standard form of the regulatory framework. The aim of the book is to seek information and suggestions for the creating a common EU field for AI regulation. Due to the high-level nature of AI White Paper, the following important questions remain unanswered: 1. The exact legal violations, which AI Whitepaper is intended to eliminate, are not clearly stated; 2. It is suggested to divide AI applications into high and low risk categories, but very often companies do not know which category is applied until this happens; 3. There is a significant risk of regulatory overlap with existing laws that are already applied to many AI technologies (for example, GDPR).

The Commission's report on safety and liability implications of the AI, the Internet of Things and robotics has been published, which gives more information on the gaps the Commission has detected in existing laws (European Commission, 2020a). The Commission Report identified legal gaps, which include security risks due to connectivity and openness of AI systems; a certain autonomy of the AI decisions; the need of neural and accurate data for the AI training; the complexity of products, systems and of value chains; the opacity of operating systems; gaps in product liability laws; general fault-based liability rules, which don't fit autonomously deciding the AI systems (Feindor-Schmidt, 2020).If the White Paper is implemented, companies will have to deal with a number of challenges. However, there are some positive outcomes. The White Paper states that AI may be a benefit for society and ensuring AI coherence in the EU can reduce compliance with the requirements that companies currently face due to different requirements from one EU member state to another (Mitchell *et al.*, 2020).

After identifying the gaps, the EU intends to release a comprehensive AI legislative package that will include new rules for those who create and implement the AI. A part of this package may include 3 resolutions adopted by the European Parliament on October 20, 2020: Framework (Basis) for ethical aspects of artificial intelligence, robotics and related technologies; civil liability regime for artificial intelligence and intellectual property rights for the development of artificial intelligence technologies, the Framework of ethical aspects of artificial intelligence, robotics and related technologies; the Civil liability regime for artificial intelligence and the intellectual property rights for the development of artificial intelligence technologies (European Parliament, 2020a, 2020b, 2020c).

It is also necessary to emphasize the huge role of civil society organizations (CSOs) in the creation and use of AI technologies. The White Paper on AI states that the European AI governance framework should guarantee the maximum participation of all stakeholders (including civil society organizations), as well as mandatory consultations with them on the implementation and further development of the structure (European Commission, 2020b). The CSOs should be aware of the AI potential to create new social problems in the future. By taking up the challenge now and tackling these issues, civil society organizations can play a key role: in leading the debate about developing AI while minimizing the risks of harm to society; in consultations and decision-making on the formation of the AI regulatory framework; in ensuring the ability of CSOs in the future to solve any problems that cannot be avoided. The CSOs can identify algorithmic bias issues for companies and organizations that implement new algorithms, as well as for those who are responsible for developing relevant new laws and regulations.

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The EU does not have a unified AI regulation system yet. However, there are various laws that are related to the development and implementation of artificial intelligence technologies. These laws include, but are not limited to, intellectual property law, data protection law, consumer protection or product liability laws, computer misuse laws, and human rights laws. At the same time, a number of Resolutions and AI White Paper have already been adopted, which highlight the main problematic issues that require regulation and provide a roadmap, according to which the EU legislation maybe formed. Given the ambitious pace of development in this area, it can be predicted that the EU will be one of the first to create a legislative foundation, which will subsequently be implemented by other countries, including Ukraine.

Analyzing the state of legal consolidation of the application and implementation of the AI in Ukraine, it may be concluded that such legislation is only in its infancy. The process of digitalization in various spheres has actively begun. Thus, the government faces the task of consolidating at the legislative level the strategy of formation and implementation of principally new technology transformation. It should be noted that, in 2018, the government approved the concept for the formation of Ukraine's digital economy and society for 2018-2020 and the formulation of a phased plan for its functioning (Parliament of Ukraine, 2018), and in 2020 the government approved the Concept for the development of artificial intelligence in Ukraine (Parliament of Ukraine, 2020). As the Minister of Digital Transformation points out, “Ukraine has a great potential in the field of artificial intelligence. We have the largest number of companies developing artificial intelligence technologies in Eastern Europe. Companies in the field of AI with Ukrainian roots have already acquired international corporations such as Snap, Google, Rakuten. Therefore, we are now working to create favorable conditions for AI to become one of the key drivers of digital transformation and overall growth of Ukraine's economy. After all, developing the field of artificial intelligence, we ensure the competitiveness of Ukraine in the international market” (Fedorov, 2020).

In December 2020, the Cabinet of Ministers of Ukraine approved the Concept for the Development of Artificial Intelligence in Ukraine with a plan for its implementation until 2030. According to the Concept, artificial intelligence is an organized set of information technologies by using which it is possible to a) perform complex tasks with the help of a system of scientific research methods and algorithms for processing information that was obtained or independently created, as well as b) create and use with the help of their own knowledge bases, decision-making models, algorithms and identify ways to achieve the objectives. Algorithms for processing information are obtained or independently created during the work, as well working with information and identify ways to achieve the objectives.

The goal of the Concept is to define the priority areas and basic objectives of the further use of the artificial intelligence products to meet the rights and legitimate interests of individuals and legal entities, building a competitive national economy, improving public administration a significant component of the development of socio-economic, scientific and technical, defense, legal and other activities in areas of national importance.

Ukraine, which is a member of the Special Committee on Artificial Intelligence at the Council of Europe, joined the Recommendation of the Council on Artificial Intelligence of the Organization for Economic Co-operation and Development in 2019 (OECD, 2019). The Concept enshrines the basis of further implementation and using of AI, compliance with which fully meets the requirements of the Organization for Economic Cooperation and Development on AI, including: development and use of AI systems only subject to the rule of law, fundamental human and civil rights and freedoms, values, as well as providing appropriate guarantees when using such technologies; compliance of the activity and algorithm of solutions of artificial intelligence systems with the requirements of the legislation on personal data protection, as well as observance of the constitutional right of everyone to not interfere in personal and family life in connection with the processing of personal data; ensuring transparency and responsible disclosure of information about artificial intelligence systems; reliable and safe operation of artificial intelligence systems throughout their life cycle and implementation on an ongoing basis of their assessment and management of potential risks;

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placing on organizations and individuals who develop, implement or use artificial intelligence systems, responsibility for their proper functioning in accordance with these principles.

Priority areas, in which the tasks of State policy for the development of artificial intelligence are implemented, are identified as the following: education and vocational training, science, economics, cyber security, information security, defense, public administration, legal regulation and ethics, justice. It is noteworthy that there is no environment-related area in the given list. Although almost every area, to some extent, affects the state of the environment, this issue needs further legislative clarification.

To achieve the goal in the field of legal regulation and ethics, the Concept identifies the following tasks: implementation in the legislation of Ukraine of the norms enshrined in 2019 "Recommendation of the Council on Artificial Intelligence" by OECD, subject to ethical standards set out in Recommendation CM / Rec (2020) 1 of the Committee of Ministers to member States on the human rights impacts of algorithmic systems, approved in April 2020 by the Committee of Ministers of the Council of Europe; elaboration of the issue of compliance of the legislation of Ukraine with the guiding principles established by the Council of Europe on the further implementation and use of AI technologies and its harmonization with the European one; ensuring the functioning and operation of technical committees of standardization in accordance with the requirements of relevant standards concerning AI; ensuring cooperation between the relevant Technical Committees of Ukraine and international subcommittees of standardization ISO / IEC JTC 1 / SC 42 Artificial Intelligence on the joint development of standards in the field of artificial intelligence; support for initiatives to create organizational forms of cooperation between interested legal entities and individuals in the field of AI; formulation of a Code of Ethics for artificial intelligence with the participation of a wide range of stakeholders.

Despite the fact that the first specialized normative act was adopted in Ukraine only in 2020, Ukrainian scientists have already begun to consider the problems of legal regulation of the use of AI in various areas of law and analyze EU norms in this area. Noteworthy scholar is O. E. Radutnyi, who studies criminal liability and legal personality of AI. He notes that in the future the Criminal Code of Ukraine will be supplemented by a section on the responsibility of "electronic person (identity)" for criminal offenses and thus defined AI as a subject of legal relations. According to this scholar, reflections on the liability of the AI makes sense only if humanity retains control over it (Radutnyi, 2018). In turn, N. Martsenko, studying the legal regime of AI in civil law, notes that understanding AI and work as a subject of civil law seems inexpedient and may cause the ambiguity in law. The use of definition "electronic person" in EU regulations, in author's opinion, seems premature, as the spread of this concept in the field of law does not provide a holistic legal understanding of its legal status, civil liability, user protection, data protection. The author also determines that it is more appropriate to understand work and AI as an object of civil rights. Consequently, the regulation of civil liability at the level of consumer relations gives grounds to consider AI as a product (commodity) (Martsenko, 2019). Researchers that study the prospects of legal regulation of artificial intelligence note that European Parliament resolutions serve as a kind of beacon, by highlighting those areas that require legislative regulation, and identifying prospects for such regulation not only at EU level but also for many countries, including Ukraine. The development of certain European legal standards for robotics and AI will contribute to the development of the relevant industry and ensure respect for human rights in the formation of new social relations with the participation of autonomous devices (Pozova, 2017).

It should be noted that in Ukraine the AI technologies are using in a test mode, including its use for improving the environmental situation. But, unfortunately, in Ukraine the legislative regulation concerning using of AI is absent; as well there are too few scientific works that would consider the issues of legal regulation of AI in environmental protection and could become the foundation for the creation of relevant legislation. Therefore, decisive action is needed, which will be of great importance for ensuring human rights in the implementation and exploitation of the artificial intelligence technology, environmental safety requirements and ensuring the sustainable transformation to benefit situation for the country. Taking into

account the course of Ukraine towards European integration, it is obvious that it is the EU standards in this area that will be the initial reference point for the corresponding norms of Ukrainian legislation.

Thus, the use of AI must be properly regulated by law for the benefit of the whole society. Even the legislative definition of the concept of "artificial intelligence" already opens up access to new areas and industries. However, it should be noted that primary norms, which require legal consolidation are the norms for ensuring human rights in the use of AI and the procedure for using AI for environmental purposes, taking into account the principles of expediency and efficiency.

Concluding Remarks

The Artificial Intelligence is an innovative technology that is expected to improve society, business and states. It can help find the solutions for ongoing global problems, including climate change and ecological degradation, at the same time protecting democracy and fighting crime. A human-centered approach to the AI should focus on that AI is designed, implemented, treated and controlled, provided fundamental human rights are respected. The Treaties of the European Union and Charter of Fundamental Rights of the European Union provide respect for people dignity, when a human enjoys a unique and inalienable moral status. At the same time environmental issues and a balanced attitude that ensures the prosperity of mankind in next decades and centuries are taken into account (Madiega, 2019).

There are various ways AI can be used to combat climate change, such as collecting and using data on temperature and carbon emissions, natural and ecological disasters, demonstrating how extreme weather effects on human environment, improving forecasts and energy management, processing endangered species data, transforming the transport landscape for reducing carbon emissions, tracking deforestation and industrial carbon emissions, tracking the ocean ecosystem, predicting periods of dehydration, ensuring precision agriculture, contributing to smart recycling, helping carbon capture and geoengineering, at the same time convincing consumers to be more environmentally conscious.

However, the use of the AI raises various problems concerning negative influence on the nature, which requires careful consideration. The AI technologies consume a lot of electricity and materials, accelerate the fossil fuels extraction and overuse environmentally friendly amounts of minerals, while companies provide little information about their ecological footprint. It is also noteworthy to highlight such issues as a threat to private information and other data protection. The political problems concern human freedoms, the impact of the AI on people's behavior (up to the idea of using direct enforcement), the problem of global justice and fairness between generations as well as the problem of the "Anthropocene".

From an institutional point of view, there is a need for constant interaction between technological development, political and public debate. It is due to the fact that all people make a certain contribution to climate change and have to take responsibility for the future of the planet by changing their way of life. The integral system of legislative acts is required for the effective and safe use of the AI for environmental and other purposes. Such acts will regulate a single conceptual and categorical apparatus, fundamental principles and rules for the creation, testing, implementation, application and closure of such projects, the establishment of legal responsibility for possible negative consequences and the procedure for compensation for damage. The AI products and services are the subject to many areas of the law, including privacy, data security, product liability, intellectual property, and antitrust laws. In addition, these areas of the law are expected to be modified according to the new circumstances connected with AI. As AI is a principally new technical application and comprehensive legal risk assessment has not become the common place, the efforts to comply require non-standard approach and the drive to understand what society needs at the moment. As a sign of acceptance of the exceptional capabilities of AI, some leading businesses are demanding the adoption of the efficient regulatory framework.

The EU does not have a unified AI regulation system; however, a number of resolutions and the AI White Paper have already been adopted, which highlights the main problematic issues that require regulation and provides a roadmap that will be used for the future formation of the EU legislation. According to the pace of development in this area, it can be predicted that the EU will be one of the first creators of a legislative foundation, which will subsequently be implemented by other countries, including Ukraine. In turn, Ukraine has made first legal steps in this area. However, there is no AI use legislation. Moreover, little legal scientific research that would consider the issues of legal regulation of the AI in environmental protection and could become the foundation for the creation of relevant legislation has been made yet. Thus, it is a decisive action that may require long time towards ensuring human rights-based approach to the development, deployment and use of AI in Ukraine in order to meet environmental safety requirements and achieve sustainable development. Taking into account Ukrainian course towards European integration, it is obvious that the EU standards will be a foundation for this area and serve as initial point for the corresponding norms of Ukrainian legislation in the future. This will allow Ukraine to move forward in reducing its carbon footprint and combating climate change.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

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Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	Yes	Yes
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Detection of Land Use Land Cover Changes Using Remote Sensing and GIS Techniques in a Secondary City in Bangladesh

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Abstract

This study aims at classifying land use land cover (LULC) patterns and detect changes in a 'secondary city' (Savar Upazila) in Bangladesh for 30 years i.e., from 1990 to 2020. Two distinct sets of Landsat satellite imagery, such as Landsat Thematic Mapper (TM) 1990 and Landsat 7 ETM+ 2020, were collected from the United States Geological Survey (USGS) website. Using ArcMap 10.3, the maximum likelihood algorithm was used to perform a supervised classification methodology. The error matrix and Kappa Kat were done to measure the mapping accuracy. Both images were classified into six separate classes: Cropland, Barren land, Built-up area, Vegetation, Waterbody, and Wetlands. From 1990 to 2020, Cropland, Barren land, Waterbody, and Wetlands have been decreased by 30.63%, 11.26%, 23.54%, and 21.89%, respectively. At the same time, the Built-up area and Vegetation have been increased by 161.16% and 5.77%, respectively. The research revealed that unplanned urbanization had been practiced in the secondary city indicated by the decreases in Cropland, Barren land, Wetland, and Waterbody, which also showed direct threats to food security and freshwater scarcity. An increase in Vegetation (mostly homestead vegetation) indicates some environment awareness programs that encourage people to maintain homestead and artificial gardens. The study argues for the sustainable planning of a secondary city for a developing country's future development.

Keywords

LULC; Savar City; Urbanization; Spatial changes; ArcGIS

Introduction

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Land use land cover (LULC) is a distinct concept, but often, it is used interchangeably (Dimyati *et al.*, 1996; Fonji and Taff, 2014; Rawat and Kumar, 2015; Hu *et al.*, 2019; Spruce *et al.*, 2020). Land use is described what people do with the landscape environment for economic activities such as agriculture, commerce, settlement, and recreation; the land cover represents the physical landscapes of the ground surface, including crops, buildings, soil, water, grassland, and forest (Anderson *et al.*, 1976; Pilon, Howarth and Bullock., 1988; Rawat and Kumar, 2015; Rai *et al.*, 2017).

A secondary city in developing countries is an urban area where the population ranges from 100,000 to less than 750,000 (Davis, 1955; Rondinelli, 1983; Goodall, 1987; UN-HABITAT, 2008; World Bank, 2008). As reported by the World Bank, about 40% of the world's population resides in secondary cities. Secondary cities form a vital part of a growing global system that substantially impacts countries' economic development in the future (World Bank, 2009; Roberts and Hohmann, 2015). The secondary cities represent diverse population dynamics, infrastructure growth, and financial activities and struggle to manage urban development and environmental issues (Roberts and Hohmann, 2015; McEvoy *et al.*, 2014; Roberts, 2014; Marais, Nel and Donaldson, 2016). However, each county's city system has taken a significant role in neighboring cities of a primary city or metropolitan area (World Bank, 2008).

The land use pattern represents the socio-economic condition of a country. Two factors directly or indirectly affect the land use land cover (LULC) change: anthropogenic and natural activities. The anthropogenic activities, such as population growth, urbanization, economic, technologies, culture, and religion (Lambin *et al.*, 2001; Coppin *et al.*, 2004; Wang, Wu and Yang, 2014; Yesmin *et al.*, 2014), are the factors that alter the land use land cover (LULC). The knowledge of land use land cover (LULC) change is a new concern for making the best selection, planning, restoration, and maintenance of natural resources (Homer *et al.*, 2007; Ahmed and Ahmed, 2012; Jensen, 2014). So, the land use/cover change assessment is essential for environmental management to understand the landscape dynamics over time better.

Satellite results are now suited and helpful for land use land cover (LULC) transition assessment studies. Integrating the two technologies, i.e., remote sensing and GIS, help understand the environmental process and analyze a considerable extent of spatial data (Milla, Lorenzo, and Brown, 2005). This data has an unprecedented advantage over the ground survey method of remote sensing due to its wide-area coverage and effectiveness in map isolated or data-poor areas (Baban, 1999). Remote Sensing (RS) and Geographical Information System (GIS) techniques are more effective than conventional approaches because they offer high resolution, informative, precise, and up-to-date information to investigate landform shift in less time at a reduced cost and with greater precision (Jensen, 1983; Kachhwala, 1985; Jenson and Cowen, 1999; Belal and Moghanm, 2011).

In the context of Bangladesh, a large body of literature is available on land use land cover (LULC) changes, using RS and GIS techniques at national, regional, and local levels (Dewan, Yamaguchi and Rahman, 2012; Al Mamun, 2013; Islam *et al.*, 2014; Haque and Basak, 2017; Parvin *et al.*, 2017; Rai *et al.*, 2017; Bhuiyan *et al.*, 2019; Xu *et al.*, 2020). Several studies are found on land use land cover (LULC) change by using satellite images on Savar Upazila in the local context. These studies included the impact of ribbon development on land use along the Dhaka-Aricha highway in the context of the dynamics of the land price, land use transformation, and assessment of land-use change (Chowdhaury, 1990; Rashid, 2003; Sharif and Esa, 2013; Hasan, Hossain and Ahmad, 2017; Rahman, Rashid and Iqbal, 2021). Savar was a river-bound rural area in 1951, but it transformed into a modern road networked city by 2001 and has been rapidly growing as a secondary city in Bangladesh since 1949 (Rashid, 2003). Savar Upazila is the neighboring city of the northwest of the capital Dhaka city at about 24 kilometers. Besides the tannery and readymade garment industries, the country's Export Processing Zone (EPZ) exists here. The transformation of Savar Upazila from rural to suburban and urban was also revealed by the study on land use change and land value in the Savar municipality (Chowdhaury, 1990; Masud, 2008; Amin, 2009). Savar municipality has

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significant changes in the settlements that affect rural-urban migration and land price value (Rashid, 2003; Sharif and Esa, 2013; Rahman, Rashid and Iqbal, 2021). One of the recent studies was conducted by using CORONA 1953, SRDI Map 1992, and Landsat 8-OLI 2016 images and categorized the pictures into four classes, such as agricultural lands, homestead vegetation, settlement, and water bodies, where the increase of territory and homestead vegetation, and reduction of farmlands and water bodies were observed (Rahman, Rashid and Iqbal, 2021).

This study is different from the previous research conducted in this area between 1953 and 2015, classifying images only into four environmental elements. There is no assessment of the conversion matrix. This study's main objective is to derive land use land cover (LULC) changes category wise and to detect the conversion matrix taking the place of a secondary city (Savar Upazila) by using remote sensing and GIS techniques (with data representing for 30 years period, i.e., 1990 to 2020).

The following critical questions regarding land use land cover (LULC) change in Savar Upazila were addressed: (1) what are the major categories and status of land use land cover (LULC); (2) what are the net gains and losses; (3) what are the primary land use land cover (LULC) conversions from 1990 to 2020? To address these questions, the primary land use/cover categories were classified, and land use land cover (LULC) was quantified at the local scale using analysis of 30 m resolution Landsat imageries representing 30 years interval (1990–2020). Post-Classification Comparison (PCC) method was used to detect the land use land cover (LULC) conversion matrix. The findings accruing from data analysis of land use land cover (LULC) changes in Savar Upazila, Dhaka, Bangladesh, were evaluated.

Study Area

The secondary city, Savar, is an Upazila of Dhaka district, Bangladesh, located at 23.8583° N latitude and 90.2667° E longitude (Figure 1). According to the Bangladesh census, it had a population of 1,387,426 (BBS, 2014) in 2011. The study area is 28,593 hectares (ha) or about 285 square kilometers. Savar Upazila consists of 12 unions and one municipality. The elevation of the land increases from the east to the west. Different rivers surround this area.

The Dhalashwari River has a significant influence on the study area for agriculture and other socio-economic activities. The region has a subtropical monsoon climate. The mean annual precipitation is high, about 2,882 mm, mainly from June to September (Choudhury, 1999). The physiographic units are the terraces in the east and flood plains in the west. So, the river deposits of the flood plain soil are common in this area.

Material and Methods

Data acquisition and land use land cover (LULC) classification

The 30 m resolution Thematic Mapper (TM) 1990 and Enhanced Thematic Mapper Plus (ETM+) 2020 Landsat images were used in the research. They were gathered from the USGS Earth Explorer website (www.earthexplorer.usgs.gov). The photos were taken in February since it used to be the dry season when the sky was clear, and the images are selected based on the absence of cloud cover. The temporal shifts in water bodies are minimal during this period. Multiple atmospheric and topographical conditions may create data variances when multi-date imagery from various sources is used (Mondal *et al*., 2015). As a result, radiometric adjustments were used in this work, besides an atmospheric correction. Ground control points were obtained to rectify the 2020 image during fieldwork conducted in February 2021. Ten ground control points, mostly major road junctions, were created using Google Earth images from 2021 to improve georeferenced accuracy. In ArcMap 10.3, the 1990 image was co-registered with the 2020 image. Both images were projected using a 30 m resolution with a UTM coordinate system (UTM-WGS 1984 Zone 46).

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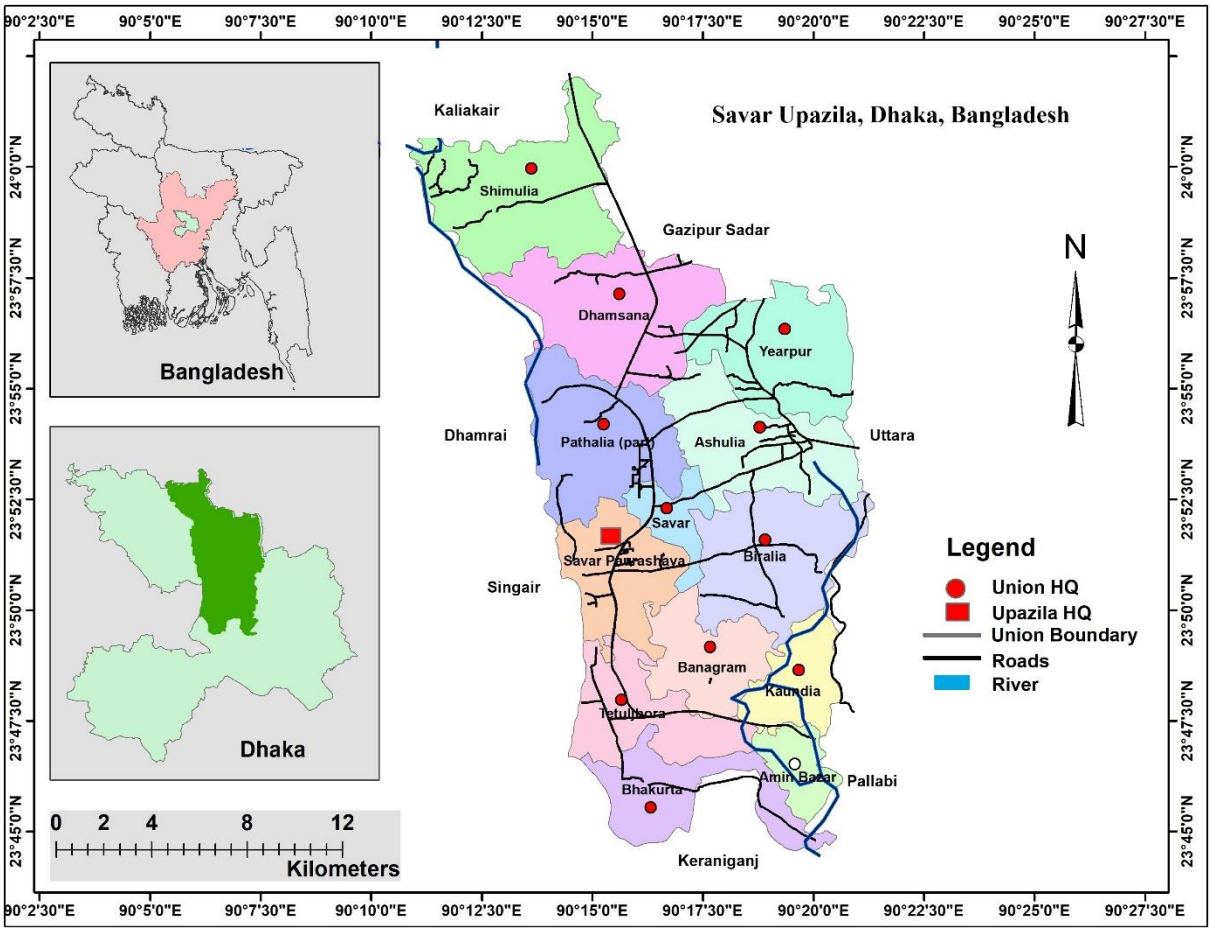

Figure 1: Location of the study area map of Savar Upazila, Dhaka, Bangladesh.

Table 1: Characteristics of Landsat satellite images data used for the study

Satellite name	*Sensor id*	*Row/ Path*	*Data acquisition date*	*Resolution*	*Source*
Landsat 5	TM	137, 44	24/02/1990	30 m	USGS
Landsat 7	ETM+	137, 44	28/02/2020	30 m	USGS

First and foremost, an appropriate categorization method for the study area is required to categorize satellite images. As a result, various types of LULC classes were identified using a modified classification method (FAO, 2011). The per-pixel supervised classifications were used, which categorize satellite imagery pixels with the same or comparable spectral reflectance characteristics. In the ArcMap version 10.3, the supervised classification method was used the maximum likelihood algorithm to determine the land use land cover (LULC) for the 1990 and 2020 Landsat imagery. The raster layer was added, then composited all bands and produced a False Color Composite (FCC). Some indices such as Normalized Difference Built-up Index (NDBI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) have been created for better classification of the images. Based on field observations, Google Maps and the different combinations of band images help distinguish the other land use land cover (LULC) in the pictures. Fifty pixels were captured for each training site and produced a signature file for each land use land cover (LULC). Then the image classification was carried out by applying the maximum likelihood classifier tool for each satellite image. The following steps were included in the approach to create LULC maps from satellite images in this study: data acquisition, classification scheme, classification of the satellite image, classified image, final LULC maps and accuracy assessment (Figure 2). In the study area,

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the following six land use land cover (LULC) classifications were identified: Cropland, Barren land, Built-up area, Vegetation, Waterbody, and Wetlands (See Table 2).

Table 2: Specific definitions of land use land cover (LULC) categories (FAO, 2011)

Land use/cover categories	*Definitions*
Cropland	Crops, paddy fields, and other vegetables.
Barren land	Unused agricultural land, loose and shifting sand, bare soil, and agriculturally unsuitable areas.
Built-up area	It includes a commercial, residential area, transportation, industrial infrastructures, and brickfields.
Vegetation	Sparsely vegetated areas with (2-10) % canopy cover, rural homestead, and rural vegetation.
Waterbody	Rivers, ponds, lakes, reservoirs, and other areas with flowing water (water persistence of 12 months/year).
Wetlands	Swamps, permanent and seasonally inundated areas (Water persistence > 4 months), and riverine areas.

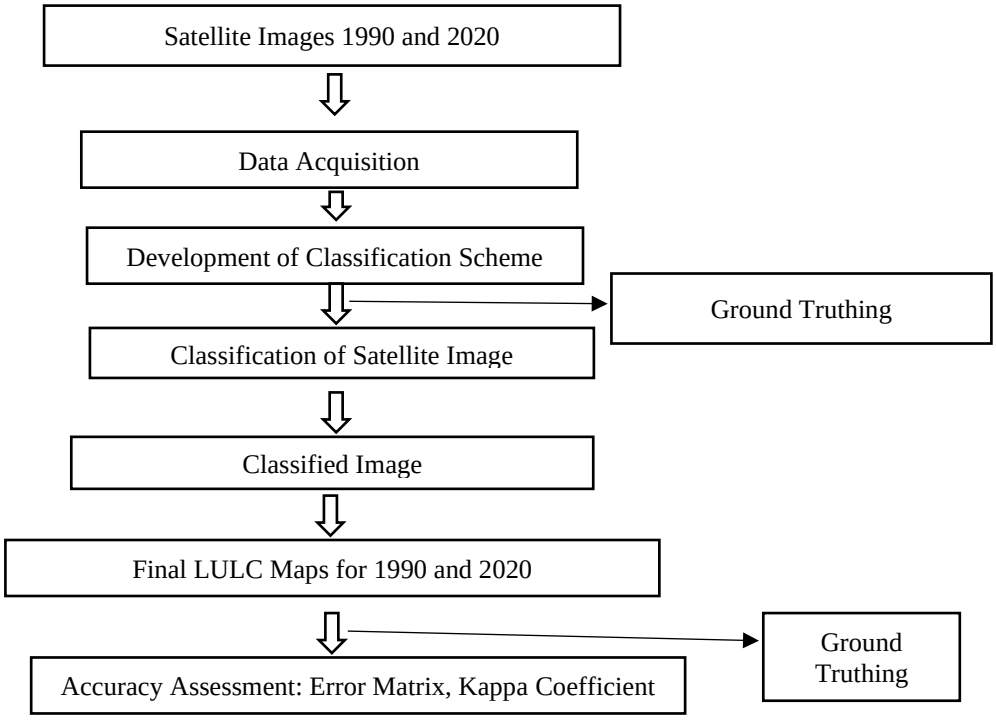

Figure 2: Flowchart of the land use land cover (LULC) mapping process.

Relative Changes of LULC (1990-2020)

The relative changes (LULC areas of 1990 — LULC areas of 2020) result from differing land use land cover (LULC) development patterns. Both periods had the same land use land cover categories.

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Detection of the conversion matrix

The land use land cover (LULC) conversion matrix was obtained by the Post-Classification Comparison (PCC) change detection method (Pontius, Shusas and McEachern, 2004; Dewan and Yamaguchi, 2009; Mondal *et al*., 2015). It is the most prevalent technique used to correlate maps of different roots despite some limitations. The method provides comprehensive and complete "from-to" land use land cover (LULC) change information (Coppin *et al*., 2004; Teferi *et al*., 2013; Rawat and Kumar, 2015; Hassan *et al*., 2016; Chowdhury, Hasan and Abdullah-Al-Mamun, 2020). Two classified Landsat satellite image maps from three different decade data matched using cross-tabulation matrix and overlay functions in ArcGIS to assess quantitative views of the changes from 1990 to 2020. Excel has been used in change matrix data analysis and calculating gross gains and losses for 1990-2020.

Accuracy assessment

For defining the confusion areas, ground verification was done. The accuracy assessment was driven by creating an error matrix and calculating overall accuracy, producer's accuracy, user's accuracy, and the Kappa statistic (Congalton, 1991). An overall accuracy of 83.3% for 1990 and 86.0% for 2020, on average around 85% (Table 3 & 4), were found. The Kappa Kat Co-efficient for 1990 and 2020 maps were 0.78 and 0.82, on average 0.8 (Table 3 & 4).

Table 3: Land use land cover (LULC) change map assessment accuracy in the year 1990.

Land cover categories	*Cropland*	*Barren land*	*Built-up area*	*Vegetation*	*Waterbody*	*Wetlands*	*Classification overall*	*User's accuracy*	*Overall accuracy*
Cropland	18	0	0	2	1	2	23	78.3%	83.2%
Barren land	1	18	2	0	0	1	22	81.8%	
Built-up area	2	5	85	2	3	4	101	84.2%	
Vegetation	1	0	1	22	2	2	28	78.6%	
Waterbody	1	1	0	2	39	2	45	86.7%	
Wetlands	2	0	2	2	3	26	31	83.9%	
Truth overall	25	24	90	30	48	37	250		
Producer's accuracy	72.0%	75.0%	94.4%	73.3%	81.3%	70.3%			

Table 4: Land use land cover (LULC) change map assessment accuracy in the year 2020.

Land cover categories	*Cropland*	*Barren land*	*Built-up area*	*Vegetation*	*Waterbody*	*Wetlands*	*Classification overall*	*User's accuracy*	*Overall accuracy*
Cropland	48	1	1	2	0	3	55	87.3%	86.0%
Barren land	1	26	2	0	0	1	31	83.9%	
Built-up area	0	3	70	0	0	2	75	93.3%	
Vegetation	1	0	0	19	0	0	20	95.0%	
Waterbody	2	1	0	0	17	4	24	70.8%	
Wetlands	5	1	2	0	2	35	45	77.8%	
Truth overall	57	32	75	21	19	45	250		
Producer's accuracy	84.2%	81.3%	93.3%	90.5%	89.5%	77.8%			

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Results and Discussion

Three land-use maps of 1990 and 2020 were brought from analyzing the Landsat images (Figure 3). These maps displayed land use land cover (LULC) classes and the changing land use pattern during 1990 and 2020 over 30 years. They also helped visualize the land use land cover (LULC) change perfectly. Every map is classified into six classes (i.e., Cropland, Barren land, Built-up area, Vegetation, Waterbody, and Wetlands).

Land use land cover (LULC) condition

Figure 3(a) represents land use land cover (LULC) patterns of the Savar Upazila for the year 1990, while figure 3(b) represents for the year 2020. These data show that in 1990, about 35.5% (10,105.6 ha) area was under Cropland, 8.4% (2,403.4 ha) under Barren land, 11.7% (3,337.7 ha) as Built-up area, 10.1% (2,900.8 ha) under Vegetation, 5.2% (1,499.1 ha) under Waterbodies, and 29.2% (8346.2 ha) under Wetlands. Figure 3(b) in 2020, 24.5% (7,009.9 ha) area was under Cropland, 7.5% (2,132.8 ha) under Barren land, 30.5% (8,716.6 ha) Built-up area, 10.7% (3068.3 ha) under Vegetation, 4.0% (1146.3 ha) under Waterbody, and 22.8% (6519.5 ha) under Wetlands (Figure 4 and Table 5).

Relative Changes of LULC (1990-2020)

Table 5 and Figure 6 show that the land use land cover (LULC) trend in the Savar Upazila has changed positively and negatively. Cropland area has declined from 1990 to 2020, accounting for approximately 10.8% of the estimated study area. The extent of Barren land has reduced by 0.9 % from 1990 to 2020. The Built-up area has risen by about 18.8%. Vegetation has grown from 1990 to 2020 and growth accounts for 0.6 %. The research area's Waterbody has decreased from 1990 to 2020, accounting for 1.2 %. The Wetlands field has narrowed from 8346.2 ha in 1990 to 6519.5 ha in 2020, a 6.4 % reduction.

Land use land cover (LULC) change assessment

The vital drivers for the land use land cover (LULC) changes consist of rapid settlement, industrialization, population growth, rural-to-urban migration. Savar Upazila is a fast-developing secondary-level city since 1949 (Rashid, 2003). The population density of the Upazila is the highest amount of any other Upazila in Bangladesh, about 4,951 per km^2 (Rahman, Rashid and Iqbal, 2021).

The study has estimated a total of 28,593 hectares of LULC changes from 1990 to 2020. Table 5 concluded that the dominant class of LULC changes were Cropland, Wetlands, Built-up area, Vegetation, Barren land, and Waterbody. The Cropland used for crops, paddy fields, and other vegetables vastly decreased from 10,105.6 ha (1990) to 7,009.9 ha (2020). A large amount of Cropland converted into the Built-up area, Vegetation and other activities. The agricultural land was 12471.6 ha (1953), 19000 ha (1992), and 7233.4 ha (2015) (Rahman, Rashid and Iqbal, 2021). Wetlands were the second dominant class and it included swamps, permanent and seasonally inundated areas (Water persistence > 4 months), and riverine areas. This LULC class also converted into mostly Cropland and Built-up area, others Vegetation, and Barren land from 8,346.2 ha (1990) to 6,519.5 ha (2020). Another study revealed that wetlands were 8,072 ha (1992) and 7,023.72 ha (2015) (Rahman, Rashid and Iqbal, 2021). It indicates that Savar Upazila's water bodies are no longer connected, potentially causing severe waterlogging. Because wetlands are now unable to hold a large amount of rainwater, this wetland shift may result in urban flooding.

In this study, dramatic changes are found in the Built-up area. It has increased by 8,716.6 ha (2020) from 3,337.3 ha (1990), where it was 3,347.6 ha (1992) and 7,9340.5 ha (2015) (Rahman, Rashid and Iqbal, 2021). The built-up area has included a commercial, residential area, transportation, industrial infrastructures, and brickfields except for the rural area. Rural to urban migration, ribbon development along highways, and good transportation facilities have worked as influential factors to trigger changes

(Chowdhaury, 1990; Hasan, Hossain and Ahmad, 2017). It helps many people to come to this Upazila for job-seeking and other purposes. So, the land value in this Upazila has also increased faster (Sharif and Esa, 2013). The study reveals that the built-up area has grown over the reduction of Cropland, Waterbody, and Wetland areas, indicating direct threats to food security and freshwater scarcity. Moreover, urbanization is expanded dramatically in the rapid and unplanned way, and unsustainably. Among the six LULC categories, a little significant change has been noticed in the Waterbody, including rivers, ponds, lakes, reservoirs, and other areas with flowing water (water persistence of 12 months/year) decreasing from 1,499.1 ha (1990) and 1,146.3 ha (2020). Moreover, it has been reduced due to riverine areas filling up with sand, river embankment, developed settlement, and infrastructure. It was also found from the literature that waterbodies are decreasing from 1203.2 ha (1992) and 1123 ha (2015) (Rahman, Rashid and Iqbal, 2021).

Land use land cover (LULC) conversion of different categories such as (a) change in Cropland, (b) change in the Built-up area, (c) change in a Waterbody, and (d) change in Wetlands in Savar Upazila, Dhaka during the last three decades from 1990 to 2020 is shown in figure 5. The maps have revealed the LULC categories gain from others or converted into other types of LULC categories. Barren land and Vegetation have not changed significantly. One of them has decreased, and another has increased its area below 1% due to afforestation and rural homestead gardening.

Various land categories to discover land reform over the last three decades, a conversion matrix was developed, which shows that (Table 6):

i. About 27.78% area of Cropland converted into the Built-up area and 14.2% area under Vegetation, 1.96% area under Waterbody, and 7.06% area under Wetlands;
ii. Approximately 25.99% of the Barren land area transferred to Cropland, 25.55% to the Built-up area, 6.31% to Wetlands, and 1.22% to Vegetation;
iii. About 23.18% of Vegetation area converted into Cropland and 18% under the Built-up area, 9.29% into Barren land and the rest of them slightly under Waterbody and Wetlands;
iv. About 15.15% Waterbody converted into Cropland and 1.16% into the Barren land, 9.5% area into the Built-up area, 30.85% into Wetlands; and
v. About 25.98% of Wetlands converted into Cropland and 2.67% under Barren land, 18.25% into the Built-up area, 9.05% in Vegetation, 5.95% of the area under Waterbody.

Table 5: From 1990 to 2020, the area and amount of transition in various land use land cover (LULC) categories in the Savar Upazila.

Land use land cover (LULC) categories	*1990*		*2020*		*Comparative Change (1990-2020)*	
	hectare (ha)	*%*	*hectare (ha)*	*%*	*hectare (ha)*	*%*
Cropland	10105.6	35.3	7009.9	24.5	-3095.7	-10.8
Barren land	2403.4	8.4	2132.8	7.5	-270.6	-0.9
Built-up area	3337.7	11.7	8716.6	30.5	5378.9	18.8
Vegetation	2900.8	10.1	3068.3	10.7	167.5	0.6
Waterbody	1499.1	5.2	1146.3	4.0	-352.8	-1.2
Wetlands	8346.2	29.2	6519.5	22.8	-1827.3	-6.4
Total	28593.4	100.0	28593.4	100.0	0.0	

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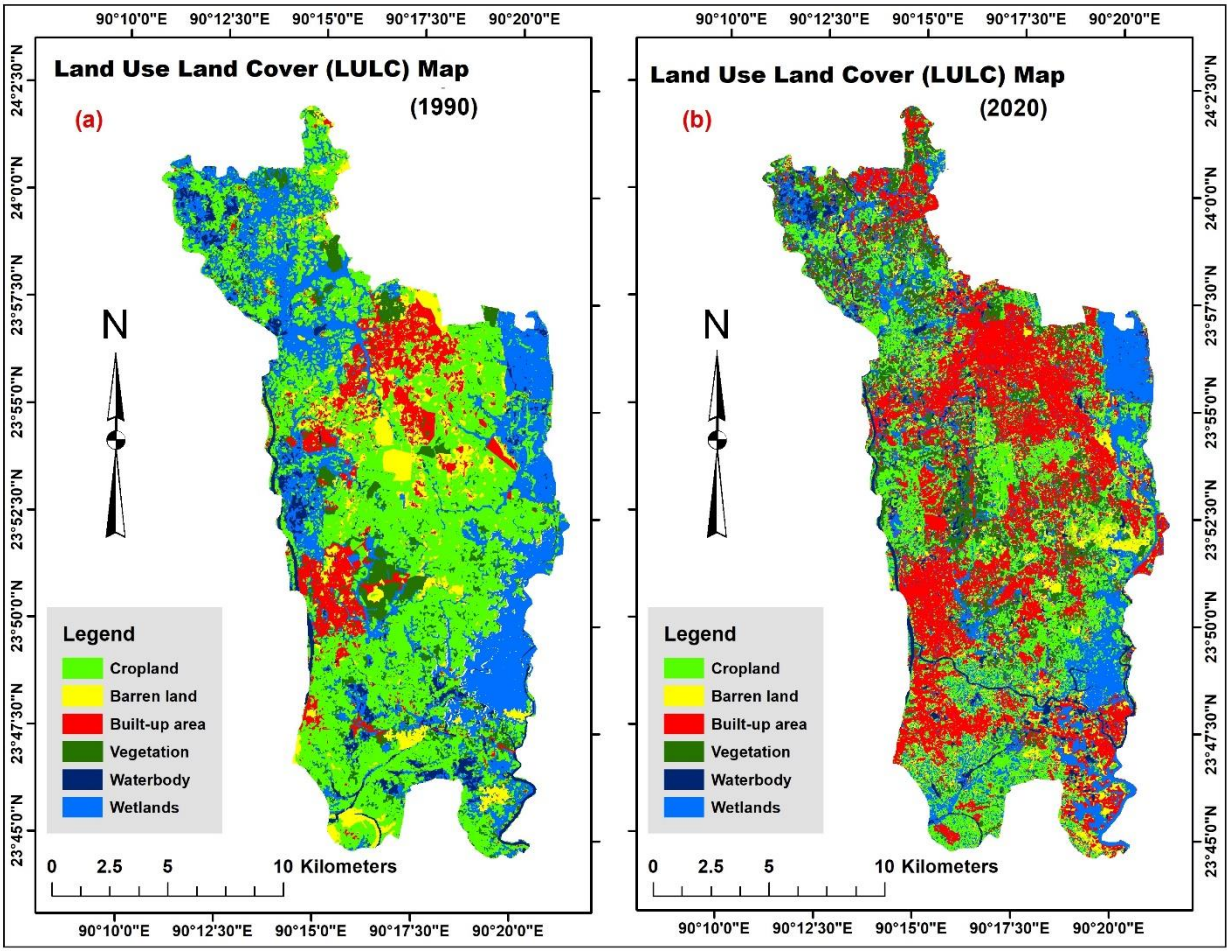

Figure 3: Land use land cover (LULC) classify maps of the Savar Upazila (a) in 1990 and b) in 2020 (Based on Landsat TM and ETM+ Satellite Imagery).

Table 6: Land use land cover (LULC) conversion matrix showing land enforcement (in %) of Savar Upazila.

Land use land cover (LULC) categories		*Year 1990*					
		Cropland	*Barren land*	*Built-up area*	*Vegetation*	*Waterbody*	*Wetlands*
Year 2020	Cropland	40.93	25.99	0	23.18	15.15	25.98
	Barren land	8.07	40.02	0	9.29	1.16	2.67
	Built-up area	27.78	25.55	100	18	9.5	18.25
	Vegetation	14.2	1.22	0	49.46	0	9.05
	Waterbody	1.96	0.91	0	0.06	43.34	5.95
	Wetlands	7.06	6.31	0	0.01	30.85	38.1
	Total	100	100	100	100	100	100

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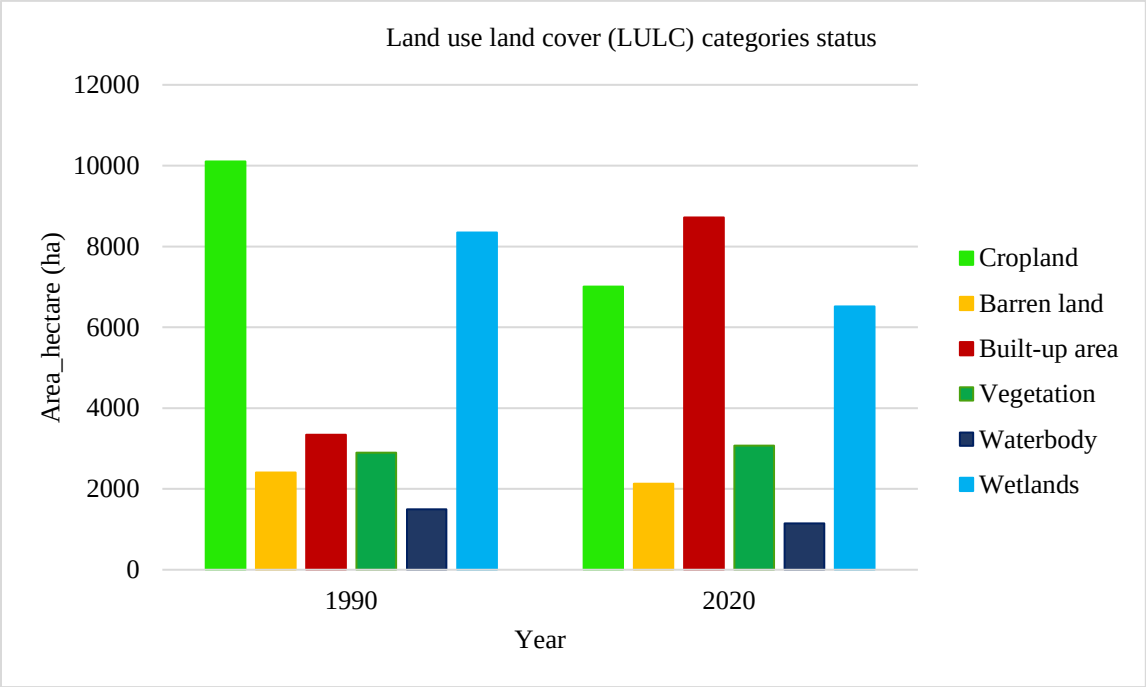

Figure 4: Land use land cover (LULC) categories status in the Savar Upazila from 1990 to 2020

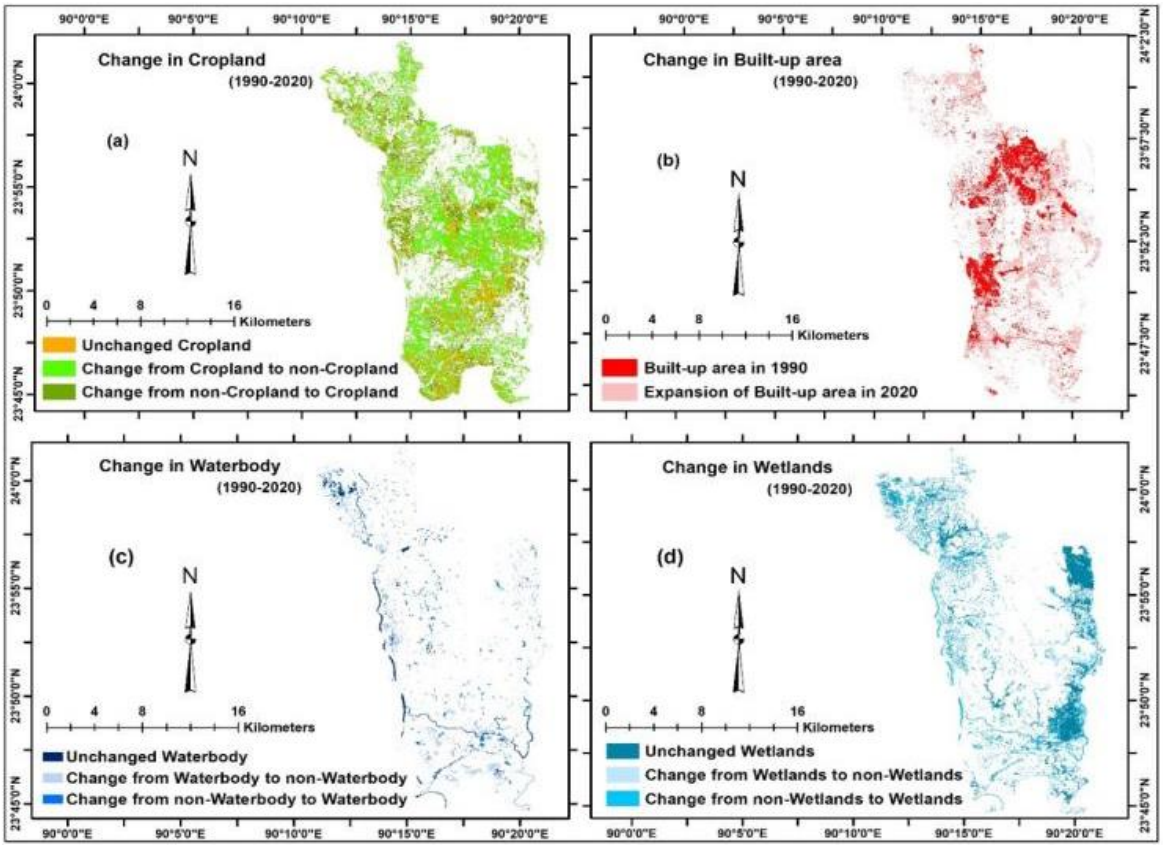

Figure 5: Land use land cover (LULC) conversion of different categories such as (a) change in Cropland, (b) change in the Built-up area, (c) change in a Waterbody, and (d) change in Wetlands in Savar Upazila, Dhaka during the last three decades (1990-2020).

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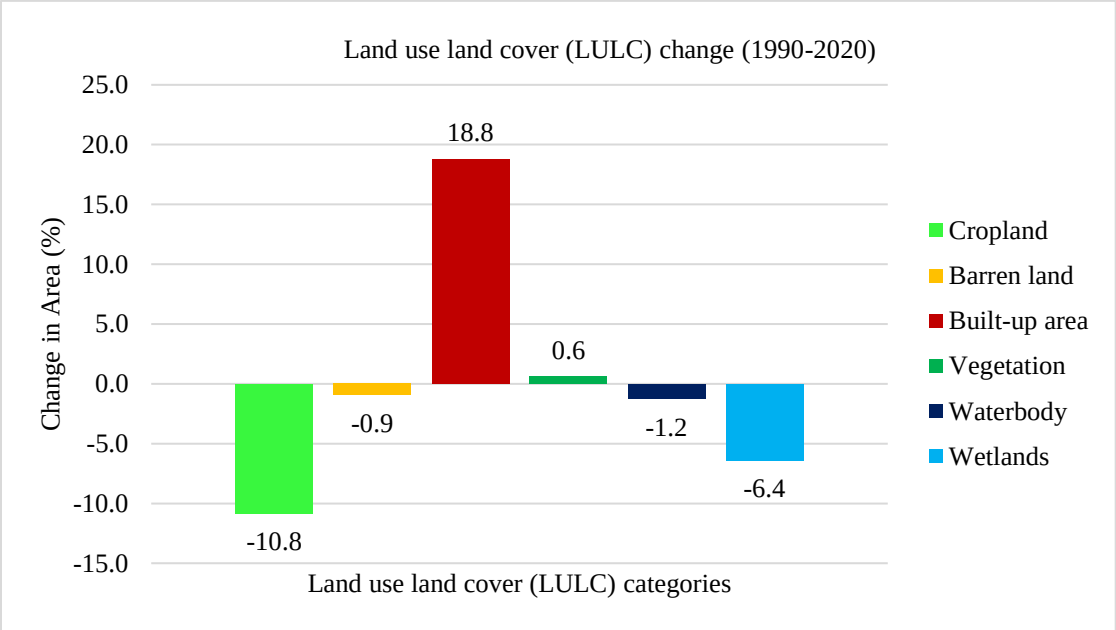

Figure 6: Land use land cover (LULC) change in the area (%) (1990-2020).

Conclusion

The growth of secondary city's built-up area is a growing concern to infrastructure development planned way. Furthermore, it has become a significant part of a country for economic activities and others production services. So, it will require sufficient well-designed data to make proper mapping and planning. Remote sensing and GIS techniques play an essential role in categorizing and quantifying landforms data of this secondary city which was not possible with traditional methods. The study shows that the dominant area is Cropland. The size under Cropland has decreased by 10.8% (3095.7 ha) due to developing infrastructures such as brickfields, artificial afforestation, and clear cropland to barren for development activities from 1990 to 2020. The second dominant class of land in the area is Wetlands, which decreased by 6.4% (1,827.3 ha) due to a built-up alteration area, Cropland, and Vegetation. It indicates that Savar Upazila's water bodies are no longer connected, potentially causing severe waterlogging. Because wetlands are now unable to hold a large amount of rainwater, this shift in wetlands may result in urban flooding. The third dominant class of land in the study area is the Built-up area which has increased more than 1.5 times than before 18.8% (5,378.9 ha) due to the expansion of the industrial infrastructure of the Savar Upazila during the last three decades.

Urbanization, Ribbon development along highways, and good transportation facilities have worked as influential factors for the observed changes. It helps rural to urban migrants who come to this Upazila for job-seeking and other purposes. So, the land value in this Upazila has also increased faster. The fourth land-use area is Vegetation rising by 0.6% (167.5 ha) due to afforestation and rural homestead gardening. The fifth category was Barren land which has decreased 0.9% (270.6 ha). The sixth class was Waterbody, which has reduced by 1.2% (352.8 ha) due to riverine areas filling up with sand, river embankment, developed settlement, and infrastructure.

Overall, the study reveals that the built-up area has been increasing over the reduction of Cropland, Waterbody, and Wetland areas, indicating direct threats to food security and freshwater scarcity. Moreover, urbanization is expanded dramatically in the rapid and unplanned way, and unsustainably too. Hence, the government should take comprehensive research on geospatial analysis and science-based planning which is vital for planning to achieve the sustainable development goals of the country's secondary cities.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	No
Wrote the article/paper	Yes	No
Critical revision of the article/paper	No	Yes
Editing of the article/paper	No	Yes
Supervision	No	Yes
Project Administration	No	Yes
Funding Acquisition	No	Yes
Overall Contribution Proportion (%)	50	50

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Research involving human bodies (Helsinki Declaration)
Has this research used human subjects for experimentation? No

Research involving animals (ARRIVE Checklist)
Has this research involved animal subjects for experimentation? No

Research involving Plants
During the research, the authors followed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research on Indigenous Peoples and/or Traditional Knowledge
Has this research involved Indigenous Peoples as participants or respondents? No

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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Assessing Local Vulnerability to Climate Change by Using Livelihood Vulnerability Index: A Case Study of Dipang Watershed in Central Himalaya Region of Nepal

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Abstract

The current study uses the livelihood vulnerability index (LVI) and the Intergovernmental Panel on Climate Change livelihood vulnerability index (IPCC-LVI) approaches to assess household's livelihood vulnerability in the Dipang watershed located in the Central Himalayan region of Nepal. Primary data was collected through various participatory rural appraisal (PRA) tools such as direct observation, key informant interviews (KIIs), focus group discussions (FGDs) and household surveys. Similarly, data on climatic variables were collected from the nearby meteorological station over 30 years (1987-2018). The mean annual average temperature increased by 0.036°C while the average rainfall decreased by 2.30 mm. Respondents perceived a similar trend of rising temperatures, decreasing rainfall intensity, dryness in the atmosphere, and dwindling water sources. The overall LVI score (0.416) indicated that the households are vulnerable to climate change. Food (0.642) and natural disasters and climate variability (0.566) were the most vulnerable among all contributing factors. Similarly, the overall LVI-IPCC score (0.104) indicated that the households were moderately vulnerable due to high exposure (0.566), sensitivity (0.448), and low adaptive capacity (0.334). The study findings suggest an urgent need to reduce high exposure to climate risks, improved livelihood strategies, and boost agricultural productivity and health in the watershed area.

Keywords

Vulnerability assessment; Climatic variables; Exposure; Sensitivity; Adaptive capacity

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Introduction

Climate change is widely regarded as the most devastating threat to human well-being in recent history. The global average temperature has risen by 0.7°C over the last century and is expected to rise by another 1.1-6.4°C by the end of the twenty-first century (IPCC, 2013). Similarly, global average precipitation has increased by 2% over the same time and is expected to increase (IPCC, 2013). Climate change and its variability endangers various geophysical, biological, and socio-economic systems, impacting negatively the biodiversity (Chand *et al*., 2018; Sintayehu, 2018; Soni and Ansari, 2017), food security (Fanzo *et al*., 2017; FAO, 2018), water resources (Chhetri *et al*., 2018; Versini *et al*., 2016), economics (Hallegatte *et al*., 2018), health (Butler, 2018) and social equality (Denton *et al*., 2014).

Climate change is expected to have serious ecological, economic, and social consequences in South Asia, particularly in areas where livelihoods rely on the use of natural resources (Mishra *et al*., 2019). The Hindu Kush Himalayan region is extremely vulnerable to climate change due to its diverse geological and climatic conditions (Gertlitz *et al*., 2017; Gupta *et al*., 2019; Wester *et al*., 2019). Among them, Nepal is the fourth most vulnerable country in the world to climate change (Eckstein *et al*., 2018). Nepal is vulnerable to many natural disasters such as illnesses, floods, and landslides, with an average of 900 natural disasters claiming lives and endangering livelihoods each year (MoHA, 2009). As a result, over 1.9 million people are projected to be extremely vulnerable, with another 10 million facing the increased risks (MoEnv, 2010). Nepal, a developing country, is especially vulnerable to the consequences of climate change due to its exposure and sensitivity to climate extremes and its low adaptation capability (Kates, 2000).

Vulnerability assessment has proven to be a useful tool in assessing vulnerable systems to develop appropriate climate change policies (Schroth *et al*., 2016). Vulnerability assessment refers to a wide range of methods for systematically integrating and investigating the interactions between humans and their physical and social environments (Hahn *et al*., 2009). Vulnerability assessment is widely used in various research applications that include ecology, environmental health, sustainability, poverty alleviation, livelihood, development, and hazard and impact assessment for climate change (Füssel, 2007). The Livelihood Vulnerability Index (LVI) is useful for understanding climate change vulnerability. It provides a framework for analyzing the key components of livelihoods and the contextual factors that influence them (Adu *et al*., 2017). The LVI uses various indicators to assess exposure to natural disasters, climate variability, and household social and economic characteristics that influence their adaptive capacity and current health, food, and water resource characteristics that influence their sensitivity to climate change impacts. It has also been useful in factoring in biophysical and socio-economic components for better adaptation and mitigation measures and decision making (Panda and Amaratunga, 2016).

There is new and stronger evidence of climate change impacts on unique and vulnerable systems such as mountain communities and ecosystems, with increasing levels of negative impacts as temperature rise (Zemp *et al*., 2009). Dipang watershed is a part of the lake cluster of Phewa Lake, a designated Ramsar site. The watershed not only provides freshwater for agriculture and domestic use, but it also provides varieties of ecosystem services (Tognetti *et al*., 2017). These watershed services include provisioning services (irrigating water supply, fish supply, timber, fuel wood, food, medicine, and handicraft), regulatory services (climate regulation, disease regulation, and water purification) and cultural services (aesthetic and scenic beauty, recreational and tourism, educational resource service and festivals) (MoFE, 2018). However, the watershed is facing difficulties as a result of climatic and anthropogenic activities. Residents of the watershed rely on watershed services to support their livelihoods. Climate change is likely to influence these people's livelihoods. Moreover, limited studies exist regarding climate change vulnerability assessment at the watershed level in Nepal. Against this backdrop, the current study attempts to analyze the climatic variable trends and assess the livelihood vulnerability of the households using the LVI and LVI-IPCC approaches in the watershed. The study will provide government organizations and local policymakers with

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practical tools to understand demographics, social and other related factors contributing to framing better adaptation strategies.

Materials and methods

Study area

The study was conducted in the Dipang watershed of Kaski district situated in Central Himalayan region of Nepal. The watershed lies at latitude 28° 10′ 55.77″ N and longitude 84° 04′ 15.19″ E (Figure 1). The watershed includes Dipang Lake, one of the lake clusters in the Pokhara Valley, a designated Ramsar site. The lake cluster is home to 263 plant species (203 terrestrial and 60 aquatic plant species), 168 bird species, 28 fish species, 11 frog species, 28 reptile species, and 36 animal species (Tamrakar, 2008). The main draw for tourists is the spiny babbler *(Turdoides nepalensis*), wren babbler (*Pnoepyga immaculate*), comb duck (*Sarkidiornis melanotos*), Baer's pochard (*Aythya baeri*), and ferruginous duck (*Aythya nyroca*). The lake also contains common otter (*Lutra lutra*), which is listed as Appendix I (CITES)[1] and nearly extinct (IUCN)[2] (Tamrakar, 2008). Dipang lake is the fourth largest lake in the cluster, covering a total catchment area of 2.39 km^2 and a water body area of 0.14 km^2 (MoFE, 2018). Dipang watershed is the representation of the middle mountain forest ecosystem inhabited by 182 households. It is covered mostly by swampland and water bodies. The Khatre and Kusunde rivers are its major watersheds, with the Kahur, Kaure and Deurali rivers as other tributary streams (MoFE, 2018). The watershed is rich in biological diversity and is a great spot for recreational activities outside Pokhara city. The watershed's main draws are white lotus and swans. It is also the habitat of a rare aromatic local rice variety i.e., Samunderphinj. The watershed is under threat due to the expansion of invasive species such as water hyacinth (*Eichhornia crassipes*), gajar ghans (*Parthenium hysterophorus*), morning glory (*Ipomoea purpurea*) and ban mara (*Lantana camara*) (MoFE, 2018).

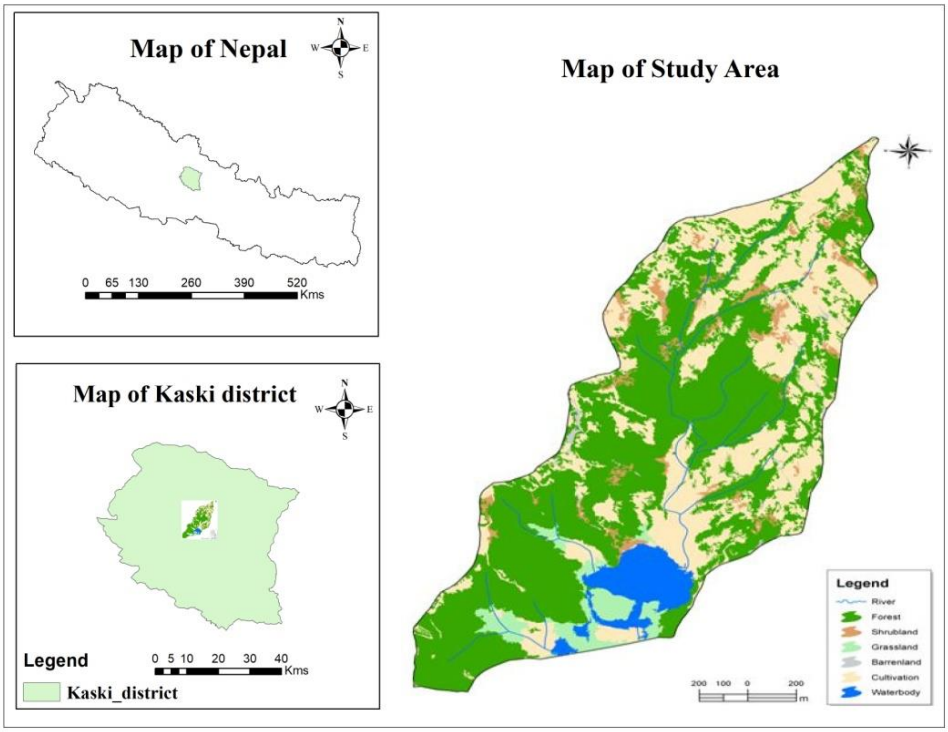

Figure 1: Map showing the study area (Dipang watershed)

[1] The Convention on International Trade in Endangered Species of Wild Fauna and Flora
[2] International Union for Conservation of Nature

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Data collection

The study employed both primary and secondary data. Primary data was collected during 2018-19 to identify the livelihood vulnerability related to climate change at the watershed level. Several PRA tools were used for this purpose, such as direct observation, KIIs (Key Informant Interviews), FGDs (Focus Group Discussions) and household surveys. A total of 10 key informants representing the local community in terms of their social status, economic well-being, knowledge and ecological regions were interviewed. FGDs were conducted in the study area to gather information related to the social-economic dimensions of the watershed. Similarly, household data were collected using a pre-tested, semi-structured questionnaire. A total of 10 households were initially surveyed to test the questionnaire. With the help of the supervisor and climate change experts, the questionnaire was then finalized based on pre-test surveys. The finalized questionnaire consisted of 2 sections, namely: socio-economic profile and livelihood vulnerability. The socio-economic profile included the respondent's basic social and economic profile, whereas the livelihood vulnerability section included seven livelihood components and their sub-components (Table 1). Due to the homogeneity of the population under investigation, a simple random sampling approach was used to gather household data. As the total number of households is relatively low, 30% of them were surveyed. Furthermore, secondary data, i.e., data related to climatic variables for a period of 30 years (1989-2018), were collected from the nearby Meteorological Station of Pokhara, Kaski district to study climatic variations of the watershed.

Table 1: List of major components and sub-components of LVI used in the study

S.No.	*Major Components*	*Sub-components*
1.	Natural disasters and climate variability	Average number of flood, drought and landslides etc. events in the past 10 years
		Percentage of households that did not receive a warning about recent natural disasters
		Percentage of households with an injury or death as a result of natural disasters
		Mean standard deviation of the monthly average of average maximum daily temperature (1989-2018)
		Mean standard deviation of the monthly average of average minimum daily temperature (1989-2018)
		Mean standard deviation of average monthly precipitation (1989-2018)
2.	Social Networks	Percentage household had to receive help through social networks
		Percentage household borrowed money through social networks
		Percentage of households that have not gone to their local government for assistance for the past 12 months
3.	Livelihood strategies	Percentage of households with family members working in a different community
		Percentage of households dependent solely on agriculture as an income source
		Average Agricultural Livelihood Diversification Index
4.	Sociodemographic profile	Dependency ratio
		Percentage of female-headed households
		Percentage of households where the head of household has not attended school
		Percentage of households with orphans

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S.No.	*Major Components*	*Sub-components*
5.	Water	Percentage of households reported having water availability problem
		Percentage of households that utilize a natural water source
6.	Food	Percentage of households dependent solely on the family farm for food
		Percentage of household struggle to find food support for whole year
		Average Crop Diversity Index
		Percentage of households that do not save crops
		Percentage of households that do not save seeds
7.	Health	Average time to the health facility
		Percentage of households with a family member with chronic illness
		Percentage of household with members missed school/work in past two weeks

Climatic variability trend analysis

To find a linear trend in the data, simple linear regression was used. Equation 1 depicts the linear trend between time-series data (y) and time (t).

$Y = a + bt$ ……1

where, y= temperature or rainfall, t= time (year), 'a' and 'b' are constants estimated by the principle of least squares.

Vulnerability analysis

LVI approach

The livelihood vulnerability index developed by Hahn *et al.* (2009) was adopted to assess the risk derived from climate variability. This approach consists of seven major components, i.e., natural disaster and climate variability, social networks, livelihood strategies, socio-demographic profile, water, food and health. Each major component has several sub-components, and each sub-component contributes equally to the overall index. The sub-components were developed based on a review of the relevant literature and consultation with experts, as shown in Table 1. A balanced weighted approach was followed for the LVI calculation (Sullivan, 2002; Pandey and Jha, 2012). To standardize each sub-component, equation 2 was used:

$$Index_{Sb} = \frac{S_C - S_{min}}{S_{max} - S_{min}} \quad \ldots\ldots 2$$

where, Sb = original sub-component or indicator value for the watershed

S_{max} and S_{min} = the maximum and minimum sub-component values determined using all the sub-component values from the communities.

After standardization, the value of each major component was calculated using equation 3.

$$M_b = \frac{\sum_{i=1}^{0} - Index_{Sb^i}}{n} \quad \ldots\ldots 3$$

where, M_b = one of the seven major components for the watershed

$Index_{Sb^i}$ = the sub-component value of indicator belonging to major component for the watershed.

n = the number of sub-components in each major component

The watershed level LVI was calculated as the weighted average of the seven major components as in equation 4, i.e.,

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$LVI_b = \frac{\sum_{i=1}^{7} -W_{Mi}M_{bi}}{\sum_{i=1}^{7} -W_{Mi}}$ ……..…...4

where, LVI_b = the Livelihood Vulnerability Index for the watershed.
W_{Mi} = the weight of major component i, decided by the number of sub-components in the major component.
M_{bi} = the value of the ith major component in the watershed

The LVI was scaled from 0 (least vulnerable) to 1 (most vulnerable). The index below 0.5 was interpreted as not vulnerable, while above 0.5 was interpreted as vulnerable (Hahn *et al*., 2009).

LVI-IPCC approach
LVI-IPCC approach incorporates the IPCC vulnerability definition. The IPCC definition characterizes vulnerability (to climate change) as a function of a system's exposure and sensitivity to climatic stimuli and its capacity to adapt to their (adverse) effects, which corresponds to outcome (or endpoint) vulnerability. In this approach, seven major components were classified into three categories, i.e., exposure, sensitivity and adaptive capacity. The exposure index contained natural disasters and climate variability, the sensitivity index contained food, water and health, and the adaptive capacity index contained socio-demographic profile, livelihood strategies and social networks. Each of these three categories of IPCC factors was calculated based on the equation:

$CF_b = \frac{\sum_{i=0}^{n} WMiMbi}{\sum_{i=1}^{n} WMi}$ ……5

Where, CF_b is an IPCC-defined contributing factor (exposure, sensitivity, adaptive capacity) for watershed b, Mbiis the major component for Watershed indexed by i, WMi is the weight of each major component, and n is the number of major components in each contributing factor.

Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using the following equation:

$LVI - IPCC_b = (e_b - a_b) * S_b$ ……6

where, $LVI–IPCC_b$ is the LVI for watershed 'b' expressed using the IPCC vulnerability framework, 'e' is the calculated exposure score, 'a' is the calculated adaptive capacity score and 's' is the calculated sensitivity score for the watershed. The LVI – IPCC was scaled from -1 (least vulnerable) to +1 (most vulnerable) as follows:

Table 1: Categories for LVI-IPCC Scale

S.N.	*Vulnerability class*	*LVI*
1	Very high	0.61-1
2	High	0.21-0.60
3	Moderate	0.20-(-0.19)
4	Less	(-0.20)-(-.60)
5	Very less	(-0.61)-(-1)

Source: IPCC (2001)

Results and Discussion

Socio-demographic characteristics of the respondents

Most of the respondents were males (84.21%), and a few were females (15.79%). The respondents belonged to three categories of castes, namely upper caste Brahmin/Chettri (45.61%), scheduled castes (35.09%) and scheduled tribes (19.30%). Most of the respondents were older than 50 years (56.14%), while only 12.28% of the respondents were less than 30 years. Agriculture (85.96%) was the major occupation of the

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respondents, followed by services (7.02%) and business (3.51%). In terms of educational attainment, the majority of respondents (50.88%) had completed 10th grade, followed by illiterates (30.33%), intermediate level (7.02%), and graduates and above (1.75%). Only 3.51% of all households had enough food from agriculture for the whole year, while the majority had adequate food for 3-6 months (49.12%), followed by 9-12 months (28.07%), and 6-9 months (19.03%). Table 3 shows the respondent's socio-demographic characteristics.

Table 3: Socio-demographic characteristics of the respondents

S.N.	*Characteristics of the respondents*		*Frequency*	*Percentage (%)*
1	Gender	Male	48	84.21
		Female	9	15.79
2	Caste	Schedule caste	20	35.09
		Scheduled Tribe	11	19.30
		Brahmin/Chettri	26	45.61
3	Major Occupation	Agriculture	49	85.96
		Services	4	7.02
		Business	2	3.52
		Others	2	3.51
4	Age	<30 years	7	12.28
		31-50 years	18	31.58
		>50 years	32	56.14
5	Education	Illiterate	19	33.33
		Up to 10th grade	29	50.88
		Intermediate level	4	7.02
		Graduation and more	1	1.75
6	Food sufficiency from agriculture	3-6 month	28	49.12
		6-9 month	11	19.30
		9-12 month	16	28.07
		> 12 month	2	3.51

Climatic data trend

Temperature

The analysis revealed that the mean annual maximum temperature, minimum temperature and average temperature have increased by 0.04, 0.03 and 0.04ºC per year, respectively (Figure 2). The mean annual maximum temperature was recorded highest in 2009 and the mean annual minimum temperature in 2006. The trend of the maximum temperature of the watershed is less than that of the overall Gandaki province (0.078ºC per year) and Nepal (0.054ºC per year) (Upadhayaya and Baral, 2020). The result of the trend analysis is similar to the findings of Karki *et al*. (2020) who recorded the mean annual temperature, minimum temperature and average temperature and accounted an increase in temperature by 0.04, 0.02 and 0.03ºC per year, respectively. This might be due to the topo-climatic environment of the watershed, which is in between the Terai[3] and Himalayan regions of the country.

[3] Lands lying at the foot of a watershed/Himalayas

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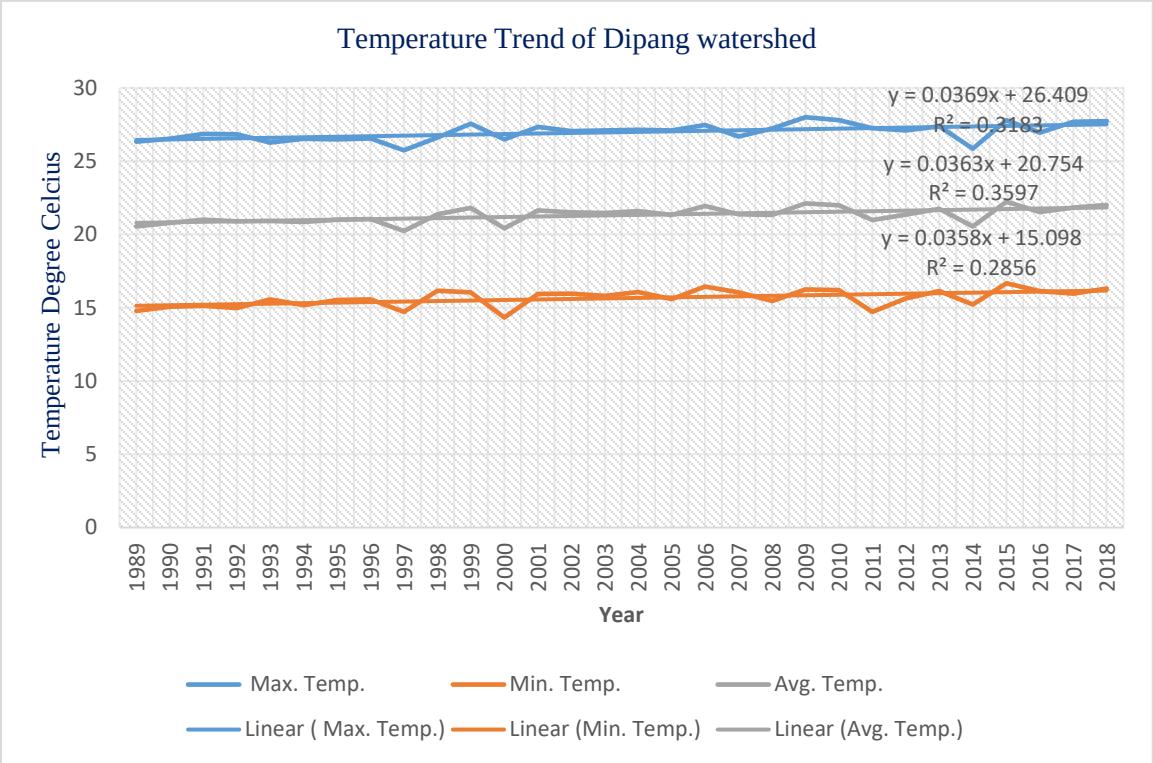

Figure 2: Temperature trend of the Dipang watershed

Precipitation

The average annual rainfall from 1989 to 2018 was estimated to be 3,907.85 mm. The average annual rainfall was found maximum in 1998 (4,879) and minimum in 2009 (2,716.8 mm). The average annual rainfall was found to be decreasing at the rate of 2.30 mm per year. The data showed large inter-annual rainfall variability, as shown in Figure 3. The decreasing rainfall trend in the country is quite evident in many studies (DHM, 2017). The decreasing rainfall trend can adversely impact agricultural productivity and food security (Lamichhane *et al*., 2020), eventually impacting the well-being of agriculture dependent communities.

Perception on changes in climatic variables and its perceived impacts

There has been a shift in climatic circumstances, according to the majority of the respondents. Based on their observations and personal experiences, the individuals perceived that the climate patterns had altered. 82.4% of respondents perceived an increase in temperature; none stated it was cooler than before, while 7% indicated there had been no change in the temperature, and 10.6 percent had no idea about the temperature rise/fall. Similarly, 66.7% of respondents reported a decrease in rainfall, 17% reported an increase in rainfall, and the rest reported that rainfall had remained constant. Figure 4 depicts the impression of a shift in climatic variables.

61.4% of the respondents perceived that dryness in weather has increased, while 26.32% responded that dryness has decreased and 5.26% responded that there has been no change in dryness over the 30 years (1989-2018). Similarly, 78.9 % of the respondents expressed their views that the intensity of rainfall has decreased, 14% perceived it has increased, and 7.1% had no idea about the intensity of rainfall. Regarding water sources, 42.10%, 35%, and 17.5% of the respondents perceived a decrease, an increase, and no change, respectively. Figure 5 depicts respondent's perception of changes in climate trends.

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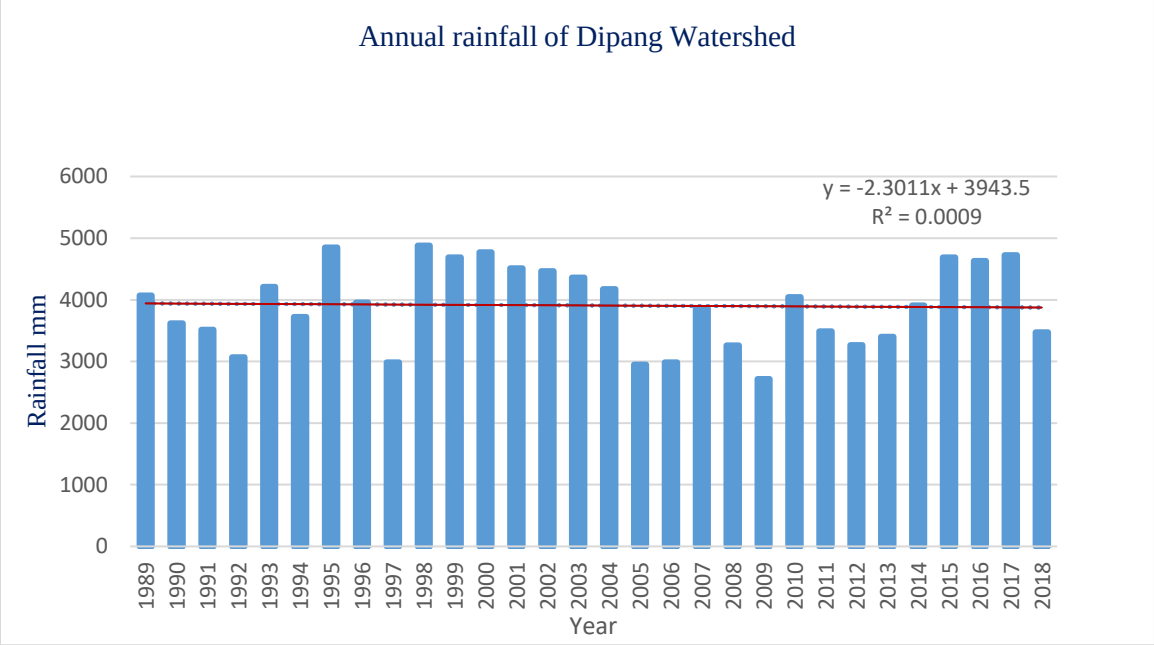

Figure 3: Rainfall trend of the Dipang watershed

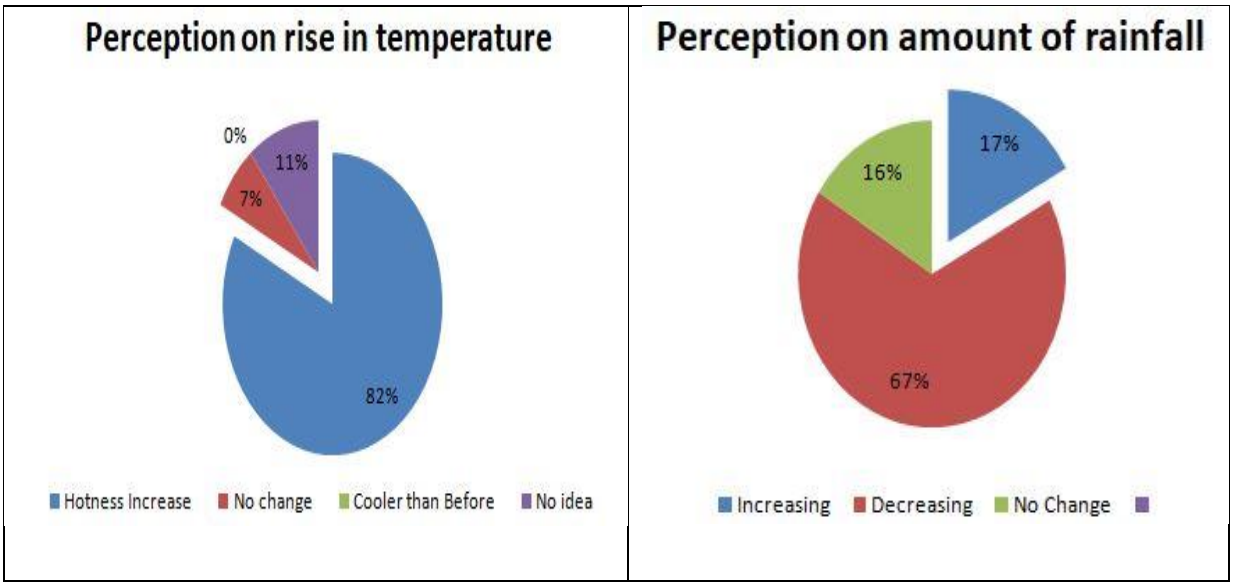

Figure 4: Perception on change in climatic variables

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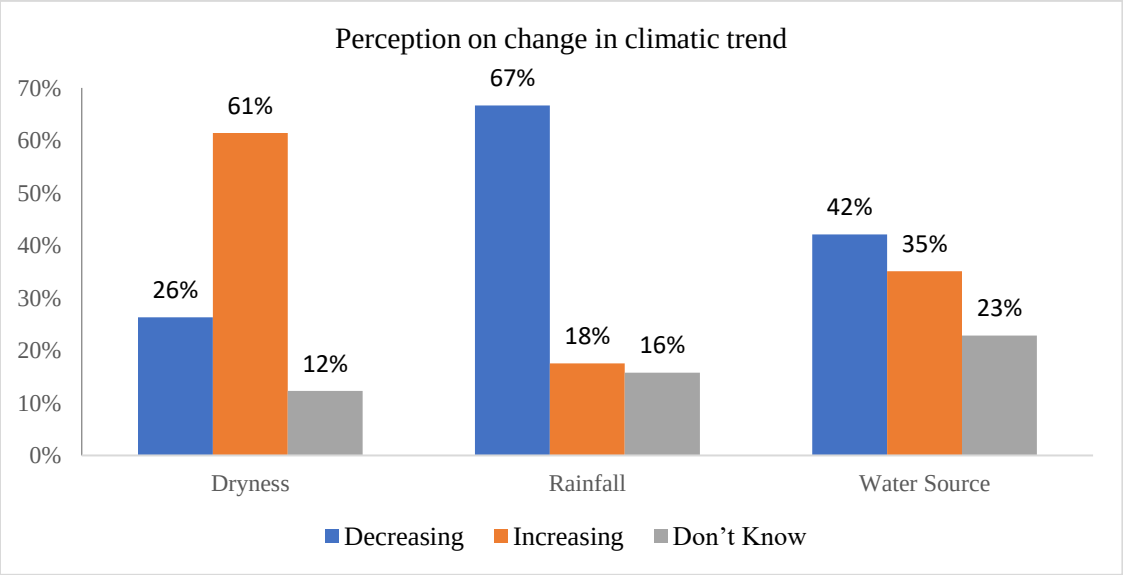

Figure 5: People perception of change in climatic trend

Livelihood vulnerability index analysis

The values of the main components and sub-components contributing to LVI of the watershed are presented in table 3, along with its composite values. A higher index value score signifies higher vulnerability and vice-versa. The overall result showed low household livelihood vulnerability (0.416) in the study area. Out of the seven major components undertaken for the study, households were highly vulnerable to food (0.642) and natural disasters and climate variability (0.566) components. All other components, i.e., water (0.241), socio-demographic profile (0.276), livelihood strategies (0.306), social networking (0.420) and health (0.460), showed low household vulnerability.

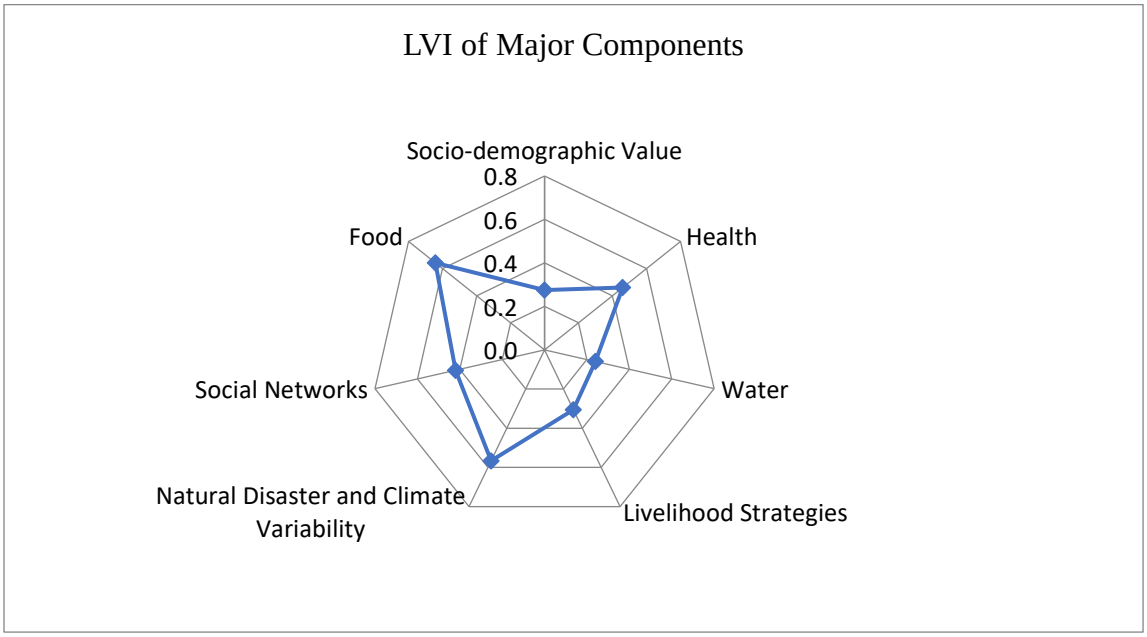

Figure 6: LVI scores of the major components

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Table 3: Values of main components and sub-components contributing to LVI

Major component	*Subcomponents*	*Units*	*Actual value*	*Standardized value*
Sociodemographic	Dependency ratio	Ratio	0.27	0.09
	% of female-headed households	%	15.79	0.16
	Avg. age of female-headed households	1/years	0.02	0.40
	% household heads did not complete school	%	33.33	0.33
	The average age of household head	1/years	0.02	0.40
Livelihood Strategies	% of households with a family member working in a different community	%	36.20	0.36
	% of households solely dependent on agriculture as an income source	%	44.45	0.44
	Average livelihood diversification index	1/(no. of livelihoods+1)	0.20	0.11
Social Networks	% household had to receive help through social networks	%	66.67	0.67
	% household borrowed money through social network	%	36.84	0.37
	% household that has not gone to their local government for assistance	%	22.40	0.22
Health	Average time to the health facility	min	77.40	0.59
	% households who reported diseases	%	33.33	0.33
	% households where a family member missed school/work in the past 2 weeks due to illness	%	8.50	0.09
	% households that did not treat water	%	82.45	0.83
Food	% of households dependent solely on the family farm for food	%	42.00	0.42
	% of households struggle to find food in a year	%	78.94	0.79
	Average crop diversity Index	1/(no.of crops+1)	0.25	0.25
	% of households that do not save crops	%	96.49	0.96
	%of households that do not save seeds	%	78.94	0.79
Water	% of households reported having water availability problem	%	32.50	0.33
	% of households that utilize a lake water source	%	15.60	0.16
Natural disasters and climate variability	The average number of flood, drought and landslides, pest and diseases events in the past 20 years	count	2.00	1.00
	% of households that did not receive a warning about recent natural disasters	%	100.00	1.00
	% of households with an injury or death as a result of natural disasters	%	1.70	0.02
	Mean Standard deviation of average monthly Temperature (1989 - 2018)	degree C	0.585	0.10
	Mean Standard deviation of average monthly precipitation (1989 - 2018)	mm	53.89	0.12

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	% of households reporting the change in temperature in the last 20 years	%	87	0.87
	% of households reporting the change in precipitation in the last 20 years: 85 percent	%	85	0.85

The food component (0.642) contributed to the highest household vulnerability. Food produced from agriculture has only been sufficient for a few months of sustenance, and only a few households have been able to store food and seeds from agricultural operations. Natural disasters and climate variability consisted of high household livelihood vulnerability (0.566). A similar study conducted in the Moma and Mabote districts of Mozambique (Hahn *et al*., 2009) reflected the lower index values of natural disasters and climate variability compared to this study. The higher values are the results of the perception of change in climatic parameters, incidences of frequent natural disasters such as floods, droughts and landslides and lack of early warning system.

The lowest value for LVI was found for the water component, as most households have access to water round the year. The availability of water from the lake has not been affected by climate change, which indicates the increase in the water area in the lake during the last decade (MoFE, 2018). The lower values of the socio-demographic profile of the study area were consistent with the findings of the study carried out in Lete and Kunjo village of Mustang, Nepal (Urthody and Larsen, 2010), Melamchi River Valley, Sindhupalchowk, Nepal (Sujakhu *et al*., 2019) and Ghana (Baffoe and Matsuda, 2017). As people have job opportunities in other communities and nearby city, and are diversifying income sources, the study found alternate livelihood strategies have been adopted in the area because the livelihood strategies index is low, which is similar to the findings obtained in Moma and Mabote districts of Mozambique (Hahn *et al*., 2009). The social networks component value (0.420) is similar to the study conducted by Urothody and Larsen (2010), which can be attributed to different cooperatives and sub-village development committees and better linkage with the local government. The value of the health index of the study (0.46) is the same as the health index of Nariva wetland (0.46), but higher than Caroni wetland (0.36) (Shah *et al*., 2013). No water is treated for drinking purposes in the study area. This situation can outrage water-borne diseases in the upcoming years as the lake water has been adequately unnoticed for management by government agencies. The results revealed that the vulnerability indices of the major components ranged from 0.241 (water) to 0.642 (food). The graphical presentation of livelihood vulnerability indices is shown in figure 6.

LVI-IPCC

The LVI-IPCC was computed by grouping the seven major components into three categories: exposure, sensitivity, and adaptive capacity. Exposure was made up of only one major component score, while sensitivity and adaptive capacity comprised the aggregated scores of three major components each. According to the LVI-IPCC vulnerability scale, the overall household LVI was moderately vulnerable (0.104). This was similar to the findings from Langtang Valley, Nepal (Nepal *et al*., 2019) and Lower Niumi and Kombo South district, Gambia (Amuzu, 2018), where households were moderately vulnerable with the values of 0.098, 0.023 and 0.02, respectively. The average values of factors contributing to the IPCC-LVI were 0.334, 0.448 and 0.566 for adaptive capacity, sensitivity and exposure, respectively. This indicates that the study area is more exposed to climate change and has a lower adaptive capacity. The graphical representation of the different contributing components to LVI-IPCC is given in figure 7.

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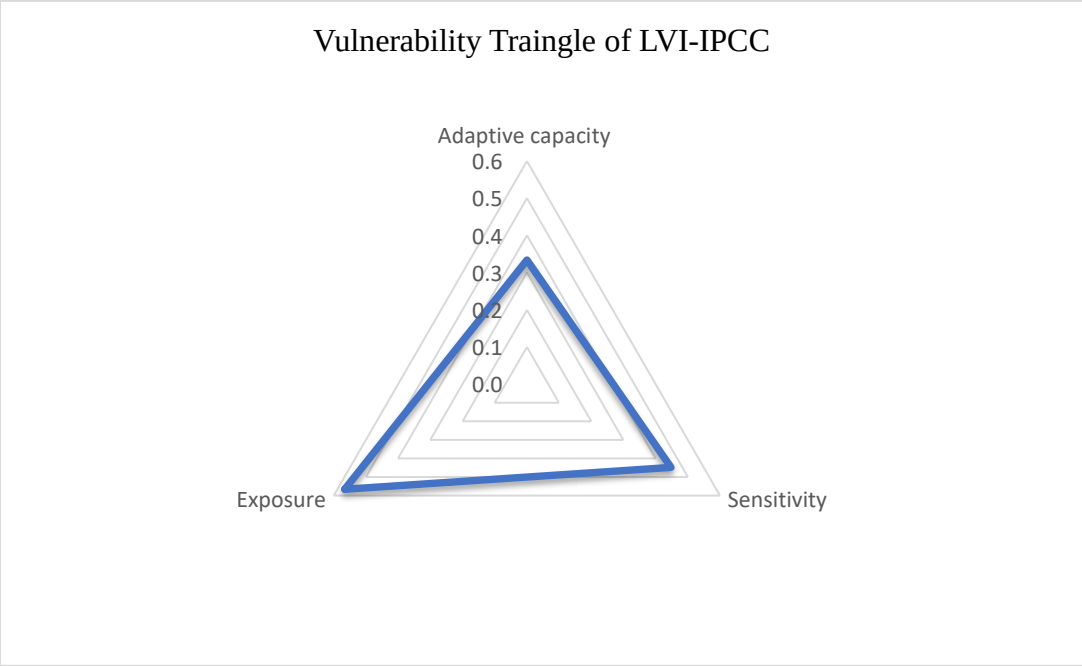

Figure 7: Values of different components contributing to LVI-IPCC

Conclusion and Policy Implication

This study examined the current understanding of climate change impacts on local people's livelihoods in the Dipang watershed by analyzing trends in climatic variables and employing a livelihood vulnerability index. The watershed has witnessed a rise in average annual temperature and decreased rainfall over the 30 years (1989-2018).The LVI (0.416) and LVI-IPCC (0.104) scores indicated that the watershed is low and moderately vulnerable to climate change, respectively. Among all the major components of LVI, food and natural disasters and climate variability contributed significantly to the watershed's vulnerability. The water (0.241) and socio-demographic profile (0.276) were two major components that contributed the lowest for LVI. According to the LVI-IPCC contributing factors, the watershed has high exposure (0.566) and sensitivity (0.448), but low adaptive capacity (0.334).

Climate variability is expected to increase over time, implying an urgent need to reduce the watershed's high exposure to climate risks, improve livelihood strategies, and boost agricultural productivity and health. Agriculture being the main occupation of the people, policy and decision makers should design and implement strategies that reflect the needs of farmers by providing climate resilient seeds, bio-fertilizers, adoption of new farming technologies, integration of diversified agricultural systems and suitable market for agro-based products to make a living. Furthermore, government organizations and policymakers should also, focus on diversifying local people's income sources beyond agriculture. These findings will be critical in developing appropriate adaptation strategies, thereby safeguarding the livelihoods of the watershed's vulnerable population.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

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Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	No	No	No	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Supervision	Yes	Yes	Yes	Yes	Yes	No
Project Administration	Yes	No	No	No	No	No
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M – 00250 | Research Article

Assessment of Temporal Variation of Water Quality Parameters and the Trophic State Index in a Subtropical Water Reservoir of Bangladesh

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Abstract

This study was conducted to determine the suitability of water quality for fisheries management in Kaptai Lake from February 2019 to January 2020. Results showed that the temperature, transparency, TDS, pH, DO, EC, alkalinity and hardness were 20.9 to 31.8°C, 17 to 303 cm, 40 to 105 mg/L, 6.82 to 7.96, 6.1 to 7.65 mg/L, 75.33 to 172.33 µS/cm, 37 to 83 mg/L and 35 to 190 mg/L, respectively. However, nutrients as NH_3, NO_3^-, NO_2^-, PO_4^{3-} and SO_4^{2-} were 0.01 to 0.05, 0.03 to 2.21, 36 to 96, 0.01 to 0.04 and 0.3 to 1.9 mg/L, respectively. Chlorophyll *a* and trophic state index (TSI) were 0.70 to 2.12 µg/L and 27.43 to 37.79, respectively. Study revealed that SO_4^{2-}, DO and TDS were higher than the standard of ECR. On the other hand, NH_3, NO_3^-, NO_2^-, PO_4^{3-}, temperature, transparency, pH, EC, total hardness, total alkalinity, Chlorophyll *a* and TSI were within the standard levels. Concentrations of NO_3^-, NO_2^-, PO_4^{3-}, Chlorophyll *a* and TSI (CHL) showed no significant variation with seasons. Conversely, TDS, transparency, EC, alkalinity, hardness, and SO_4^{2-} were lower in monsoon compared to pre-monsoon and post-monsoon seasons. Besides, temperature, NH_3, DO and TSI (SD) were higher in monsoon season. Results concluded that the Kaptai Lake is in mesotrophic condition with TSI (CHL) less than 40, and prominently there was a positive relationship between Chlorophyll *a* and Trophic State Index (TSI). In this regard, major nutrients and Chlorophyll *a* concentration in the Kaptai Lake may have an impact on the aquatic environment.

Keywords

Seasonal variation; Water quality; Dissolved nutrient; Chlorophyll *a*; Kaptai Lake; Bangladesh

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Introduction

Bangladesh is enriched with extensive water resources distributed all over the country (Rahman *et al.*, 2014). The Kaptai reservoir was created with the construction of an earthen dam across the Karnaphuli River at Kaptai, about 70 km upstream from the estuary of Chittagong, for the production of hydroelectricity, which came into operation in January 1962 (Bashar *et al*., 2015). At present, Kaptai reservoir supports small-scale fisheries, which is rich in fish species diversity and contributing approximately 63,000 ton freshwater fish annually (Ahmed *et al.*, 2001). As fishery is the secondary enterprise in this lake, the Bangladesh Fisheries Development Corporation has no control over the water level fluctuations (Bashar *et al*., 2014). Over the years, 8 species of fish disappeared, 7 species dwindled (Haldar *et al*., 1992). Quality of surface water is important for long term uses, which affects community health, hampers aquaculture practices and also creates aesthetic problem in the locality. Every water use requires a certain minimum water quality ensuring no harm to the user (Kabir *et al*., 2020). At present land use changes, urban human habitation, inland navigation activity as well as major development scheme in terms of road, bridge and other construction works are greatly affecting this freshwater resource (Rubel *et al*., 2019; Kabir and Naser, 2011).

Water quality generally means the component of water that must be present for optimum growth of aquatic organisms (Ahatun *et al*., 2020). The determinant of good growth in water body includes dissolved oxygen (DO), hardness, turbidity, alkalinity, nutrients, temperature, etc. in most of the water bodies. This concentration level increases due to human activities and lack of environmental regulation (Ehiagbonare and Ogunrinde, 2010). Assessment of water resource quality of any region is an important aspect of developmental activities, because rivers, lakes and manmade reservoirs are used for water supply to domestic, industrial, agricultural and fish culture (Pal *et al*., 2015). For maintaining the productive as well as balanced aquatic environment, nutrients are the prime crucial elements (Ahatun *et al*., 2020). All aquatic organisms including fish depend directly on nutrients for their survival, growth and reproduction. Some nutrient levels are related to the chlorophyll availability on water body, which means the availability of phytoplankton in the water (Shukla *et al*., 2013). Thus, nutrient availability is directly related to the productivity of the water body (Rahaman *et al*., 2013). A shortage of nutrients causes the water body to be unproductive. An excess of nutrients causes eutrophication by algal bloom and makes the water toxic. Algae play an important role in all aquatic ecosystems by providing all living organisms of water bodies with preliminary nutrients and energy required. However, abnormal and excessive algal growth, called as algal bloom, would be detrimental as much (Ghorbani *et al*., 2014; Stauffer *et al*., 2019). So, nutrient concentration must be within an acceptable limit for a good aquatic environment and for better production of aquatic organisms including fish (Senthilkumar *et al*., 2008).

The algal flora of the Kaptai Lake is very poorly known; but the available information suggests that the Kaptai Lake has a low diverse algal flora comprised of both benthic and planktonic forms in the freshwater environments. Since algal flora play very important role in ecological context: the study of Chlorophyll *a* concentration is utmost important. Chlorophyll *a* is the pigment that allows plants and algae to photosynthesize, in which plants use the sun's energy to convert carbon-dioxide and water into oxygen and cellular material. It also absorbs energy from wavelengths of violet-blue and orange-red light, while reflecting green-yellow light (Suzuki *et al*., 1997; Islam *et al*., 2019). Chlorophyll *a* concentration may change the surrounding environment physically, chemically, and biologically in the ways that favor or not favor their continued persistence. The study of Chlorophyll *a* concentration is considered useful for interpreting hydro-chemical variations in freshwater reservoir. So, the temporal and spatial Chlorophyll *a* concentration may act as an indicator of the water quality fluctuation in response to changing environment (Rahaman *et al*., 2013; Senthilkumar *et al*., 2008). All aquatic organisms depend directly on nutrients for their survival, growth and reproduction. Some nutrient levels are related to the Chlorophyll *a* availability in the water body, which means the availability of phytoplankton in the water. Thus, nutrient availability is directly related to the productivity of the water body. A shortage of nutrients causes the water body to be unproductive, and an excess of nutrients causes eutrophication by algal bloom and makes the water toxic

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(Islam *et al*., 2017; Islam *et al*., 2019). Thus, the nutrient concentration must be within suitable limit for a good aquatic environment and for better production of aquatic organisms (Rahaman *et al*., 2015). In the past decades, limnologists have developed many methods to assess the trophic status, including the character method (Rao, 1956), parameter method, the biotic indices method (Alba-Tercedor, 1996), the phosphorus budget model method (Dillon and Rigler, 1974) and the trophic state index method (Carlson, 1977). Among these developed methods, Carlson's trophic state index (TSI) is one of the most widely accepted methods in evaluating the trophic status because that Carlson's TSI is a continuous number in assessing the trophic status, which can provide a more precise assessment of the trophic status than other conventional methods (e.g., parameter method), which only provides a rough typological trophic information (Wang *et al*., 2011). In addition, Carlson's TSI is easy to be implemented with the easy analysis of the limiting factors of the trophic status (Nion *et al.*, 2020). The phytoplankton is microscopic single-celled plant that plays an important role in the ecosystem as a major primary producer through photosynthesis (Johan *et al*., 2018). The most influential factors on Chlorophyll *a* may be dependent on the different water quality patterns in lakes (Li *et al*., 2017).

Previous research on Kaptai Lake included physical and chemical limnology by Khan and Chowdhury (1994), macro-benthic invertebrate fauna by Khan *et al*. (1996), population biology and environment of two carps by Azadi *et al*. (1997), and environmental impact assessment by Alam *et al*. (2006). Although there are a few publications on the physical and chemical limnology of Kaptai Lake, a full study on the seasonal change of water quality (physical, chemical, biological, and anionic) parameters as well as the trophic status index (TSI) in Kaptai Lake is sorely lacking. Therefore, the goal of this proposed study is to collect data on changes in water quality indicators and TSI in Kaptai Lake over the course of a year in order to offer baseline data to aid in lake ecosystem management decisions. Thus, the current study attempted to evaluate seasonal variations in physicochemical parameters and nutrients in the lake water column, as well as to assess seasonal variations in Chlorophyll *a* concentration and the trophic status index (TSI) in the lake water column at Bangladesh's Kaptai Lake.

Materials and Methods

Study area: The study was conducted in Kaptai Lake water reservoir of Bangladesh. The Kaptai Lake (Latitude 22°09'N and Longitude 92°17'E) has drowned almost the whole of the middle-Karnafuli valley and the lower reaches of the Chengi, Kasalong and Rinkhyong Rivers (Figure 1). The shoreline and the Basin of Kaptai Lake are very irregular. Its important morphometric and hydrographic features are as follows: surface elevation 31.1 m, surface area 58,300 ha, volume 524,700 m^3, total annual discharge 1,707,000 m^3, storage ratio 0.31, mean depth 9 m, maximum depth 32 m, outlet depth 15.5 m, mean annual water level fluctuation 8.14 m, growing season 365 days, total dissolved solids 76 ppm and specific conductance 144 mhos at 25°C (Banglapedia, 2016).

Sample collection: For seasonal monitoring of water quality (physicochemical and anionic) such as temperature, transparency, total dissolved solids (TDS), pH, dissolved oxygen (DO), electrical conductivity (EC), total alkalinity, total hardness; major dissolved nutrients such as ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^-), sulphate (SO_4^-) and Chlorophyll *a* concentrations, surface water samples were collected from 4 fixed sampling stations of the Kaptai Lake aquatic ecosystems during the study period from February 2019 to January 2020, whereas the period were divided as pre-monsoon (February to May), monsoon (June to September) and post-monsoon (October to January) seasons, respectively. The four sampling stations namely St-1 (Rangamati Sadar), St-2 (Kaptai), St-3 (Langadhu), and St-4 (Mohalchari) were selected taking following aspects into consideration: i) the streams and drainage arms, ii) catchment area and iii) water level of the lake. To analyze the physicochemical quality, major nutrients and Chlorophyll *a* concentration, 1,000 ml water was collected in plastic bottles with double stoppers from each sampling station. Before sampling, the bottle was cleaned and washed with detergent solution and treated with 5% nitric acid (HNO_3) over night. The bottles finally rinsed with deionized water and dried. At each sampling

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station, the sampling bottles were rinsed at least three times before sampling was done. Pre-prepared sampling bottles were immersed about 10 cm below the surface water. After sampling, the bottles were screwed carefully and marked with the respective identification number. Then the samples were kept frozen (-20°C) until analysis (within 48 hrs.) to avoid further contamination (Senthilkumar *et al*., 2008; Rahaman *et al*., 2013).

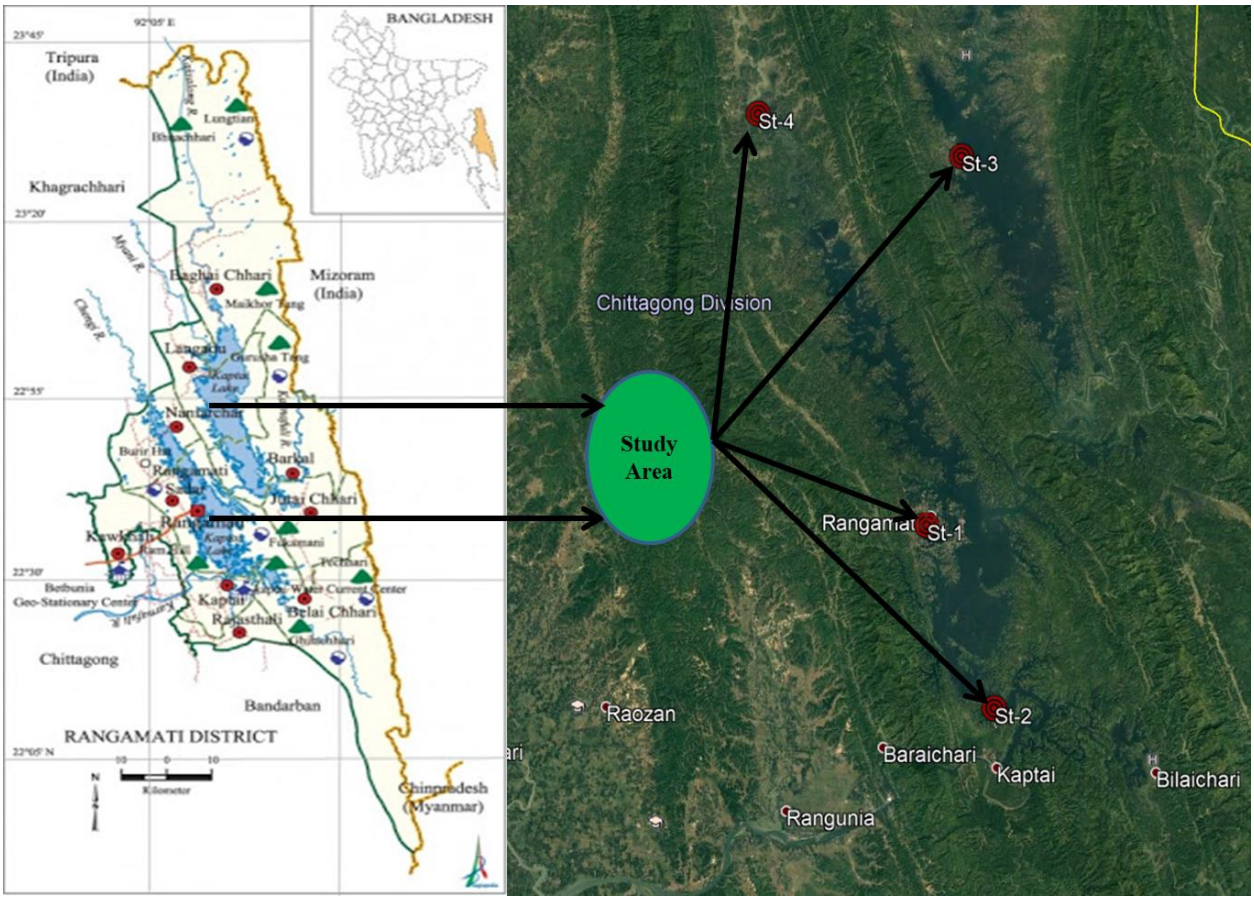

Figure 1: Map showing the study area at Kaptai Lake in Bangladesh (Banglapedia, 2016).

Sample analysis: The physicochemical parameters were analyzed in the laboratory of the Department of Environmental Science and Resource Management of the Mawlana Bhashani Science and Technology University. Temperature and pH were determined by the thermometer and digital pH meter, respectively. Buffer solution containing pH 7.0 was used to calibrate the digital pH meter. The Secchi disc was used to determine the transparency of water. The DO was determined by digital DO meter where sodium thiosulphate (0.025N) was used as a reagent. The EC and TDS were determined by EC and TDS meter, respectively. Total alkalinity (TA) and total hardness (TH) were determined by using titration technique. For the determination of dissolved nutrient concentrations, the water samples were prepared for ionic test followed by APHA (2005) using chromatographic (Shimadzu Ion Chromatograph, HIC-10-A, Japan) analysis in the Laboratory of the Bangladesh Fisheries Research Institute (BFRI), Mymensingh. After instrumental measurements, the values of ions including ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), phosphate (PO_4-P) and sulphate (SO_4) were calculated using computer aided tools. The Chlorophyll *a* of water samples was analyzed by 90% acetone method in the Biochemistry and Molecular Biology Laboratory of the Mawlana Bhashani Science and Technology University.

Statistical analysis: The data were assembled and set out in appropriate form and were subjected to statistical analysis. The Statistical Package for Social Sciences (SPSS version 16.0) was used to present and interpret the collected data. Pearson's correlation matrix was used to examine specific relationships among the parameters studied.

Results and Discussion

Physiochemical water quality

Temperature: Water temperature is critical since it is an important environmental quality metric that must be measured. By doing so, we can see the characteristics of the water such as the chemical, biological, and physical properties of the water. Water temperature is an important factor in determining whether a body of water is acceptable for aquatic ecosystem (Kabir *et al*., 2020). During the monsoon, the highest temperature (31.8°C) was recorded at St-3, while the lowest temperature (20.9°C) was recorded at St-1 during the post-monsoon (Figure 2). The highest mean temperature 31.1°C was found in monsoon and the lowest 21.12°C was found in post-monsoon (Table 1). Bashar *et al*. (2015) discovered that the average water temperature in Kaptai Lake ranged from 21.04 to 31.52°C, with a maximum of 31.5°C in September and a minimum of 21.04°C in January. According to Meghla *et al*. (2013) the temperature of Turag River water was 30.95, 32.36 and 17.75°C during the pre-monsoon, monsoon, and post-monsoon seasons, respectively. This may be attributed to different collection timings and seasonal influences (Srivastava and Kanungo, 2013).

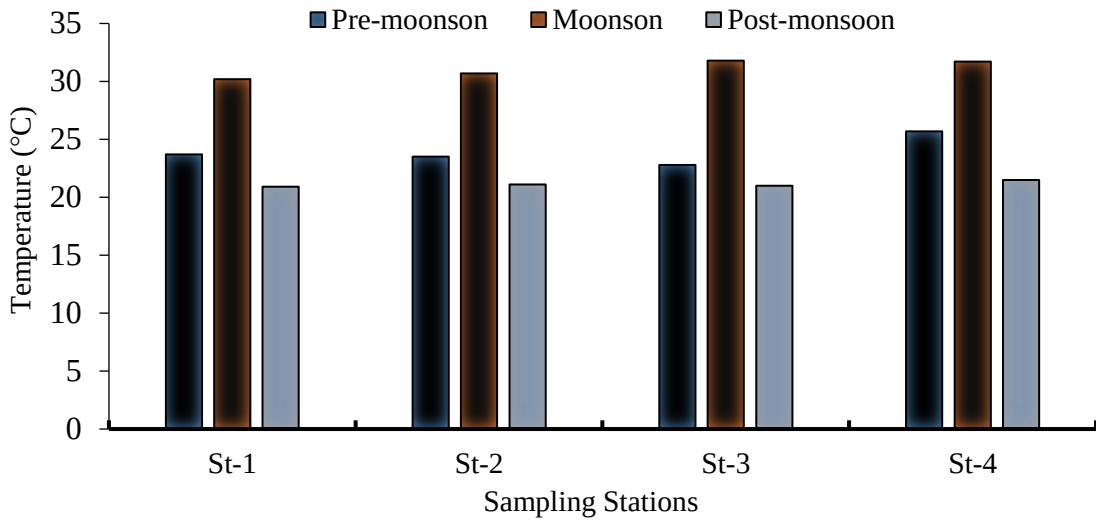

Figure 2: The temperature at various sampling stations during different seasons

Transparency: Water transparency changes can affect essential features of aquatic ecosystems, influencing the use of critical habitats or resources and resulting in phenotypic divergence. Changes in the availability of vital resources as a result of habitat productivity changes could have an impact on resource utilization and, as a consequence, population divergence (Islam *et al*., 2015a). The water transparency of the four stations was within the range of 17 to 303 cm. The highest transparency 303 cm was found at St-2 during post-monsoon and the lowest transparency 17 cm was found at St-4 during monsoon (Figure 3). On an average the highest transparency 303 cm was found in post-monsoon and the lowest transparency 17 cm was found in monsoon season (Table 1). The limit of Secchi disc visibility in Kaptai Lake was found to vary throughout the year, with high visibility in the winter and low visibility during the dry season. The inflow of suspended matter and silt from hill streams triggers a rapid increase in turbidity. During the monsoon

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season, Chowdhury and Mazumder (1981) and Haldar *et al*. (1992) recorded high turbidity in the same lake. Water bodies that are productive should have a transparency of no more than 40 cm (Rahman, 1992).

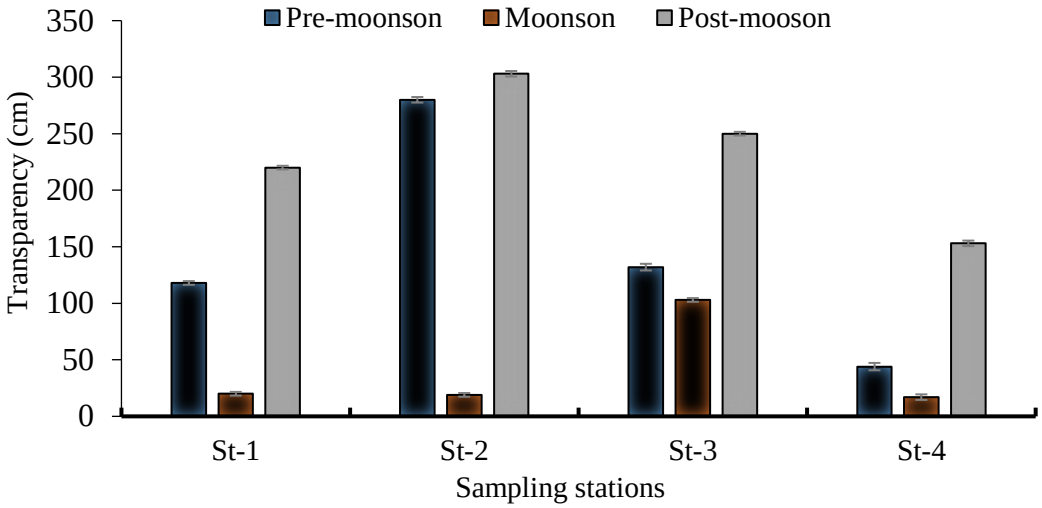

Figure 3: Water transparency at various sampling stations during several seasons

Total Dissolved Solid (TDS): In bodies of water, like rivers, higher levels of TDS often harm aquatic species. TDS changes the mineral content of the water, which is important to survival of many animals. Also, dissolved salt can dehydrate the skin of aquatic animals, which can be fatal. It can increase the temperature of the water, which many animals cannot survive in (Islam *et al*., 2012). The lowest TDS content 40 mg/L was found at St-3 during monsoon and the highest TDS 105 mg/L was found at St-2 during post-monsoon season (Figure 4). The average TDS in different season during the study period ranged from 44.5 to 80.5 mg/L. The mean highest TDS 80.5 mg/L was found in post-monsoon and the lowest TDS 44.5 mg/L was observed in monsoon season (Table 1). As a result, TDS concentrations in some stations are beyond the range, while others are within the range established by ECR (1997). TDS concentrations in Kaptai Lake were 52 to 54 mg/L, compared to 39 to 42 mg/L in Bogakain, a natural high altitude lake in Bangladesh (Barua *et al*., 2016; Khondker *et al*., 2010). The TDS levels in the Brahmaputra River ranged from 183 to 185 mg/l and 157 to 198 mg/l (Islam *et al*., 2015a,b), while TDS levels in the Buriganga River ranged from 378.75 to 616.75 mg/L and 205 to 240.5 mg/L during the dry and wet seasons, respectively, exceeding the normal level in both seasons (Islam *et al*., 2012).

pH: If the pH of water is too high or too low, the aquatic organisms living within it will die. The pH can also affect the solubility and toxicity of chemicals in the water (Islam *et al*., 2015a,b). The pH of the water at the four stations ranged from 6.82 to 7.96. During the pre-monsoon season, the highest pH 7.96 was found at St-2, while the lowest pH 6.82 was found at St-4 during the post-monsoon season (Figure 5). The highest pH 7.62 was found in pre-monsoon and the lowest pH 6.77 was found in post-monsoon season (Table 1). The pH in freshwater should be in the range of 6.5 to 9 according to EPA water quality guidelines (EPA, 2017). Kaptai Lake's water pH is between 7.46 and 7.75, which is within the appropriate range (Barua *et al*., 2016). The pH of the water in the Kaptai Lake was often found to be alkaline in nature, ranging from 6.9 in July to 7.6 in May. According to the results of the report, the pH level is within the appropriate range for fisheries production and is nearly identical to the previous record. The pH levels in Ashulia beel were 7.1 to 7.8 in the wet season and 7.1 to 8.4 in the dry season, confirming the slightly alkaline quality of the beels water (Islam *et al*., 2010). In a study conducted at Ramna, Crescent, and Hatirjheel Lakes in Dhaka City, the pH was found to be in the range of 7.67 to 7.85 (Islam *et al*., 2015c).

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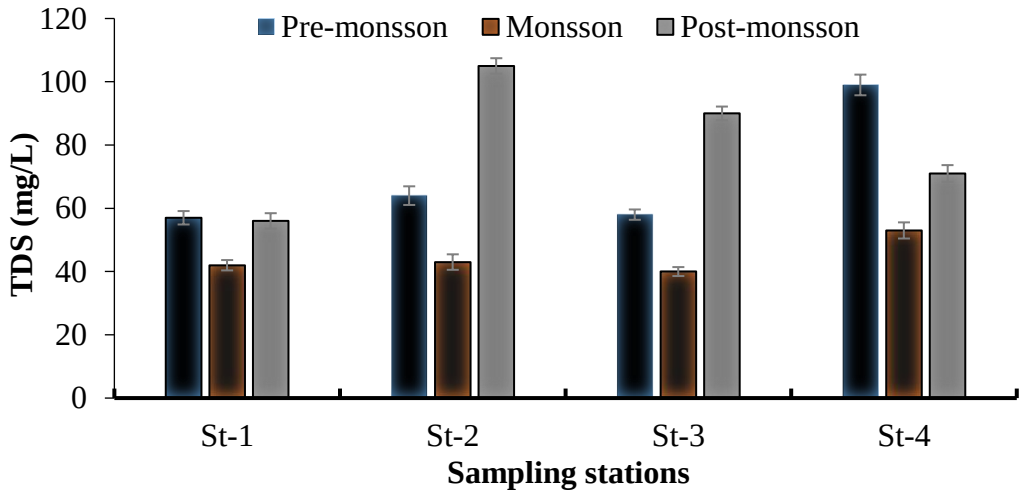

Figure 4: The TDS concentrations at various sampling stations during different seasons

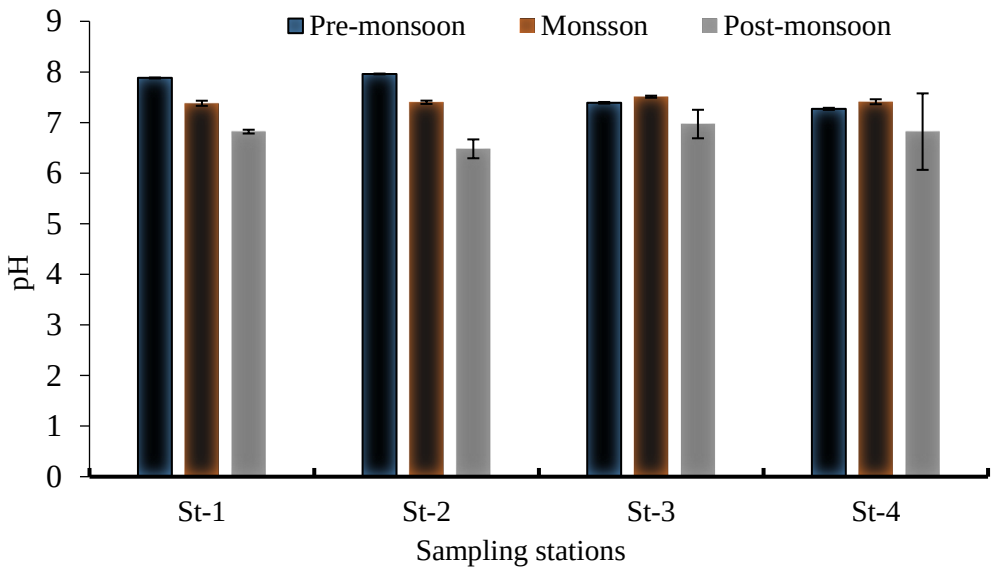

Figure 5: The pH at various sampling stations during different seasons

Dissolved Oxygen (DO): DO is one of the most important indicators of water quality. It is essential for the survival of fish and other aquatic organisms. Oxygen dissolves in surface water due to the aerating action of winds. Oxygen is also introduced into the water as a byproduct of aquatic plant photosynthesis. When dissolved oxygen becomes too low, fish and other aquatic organisms cannot survive (Islam *et al*., 2017). The DO of the water at the four stations ranged from 6.1 to 7.65 mg/L. During the pre-monsoon season, St-1 had the lowest DO content of 6.1 mg/L, while during the monsoon season; St-3 had the highest DO content of 7.60 mg/L (Figure 6). During the study period, the average DO of the different stations ranged from 6.35 to 7.21 mg/L. Adequate DO is needed to maintain good water quality, aquatic organism endurance, and microorganism putrefaction of waste (Islam *et al*., 2010; Rahman *et al*., 2012). For fisheries, the optimal DO concentrations ranged from 4 to 6 mg/L (Boyd, 1998), below which most aquatic species will perish.

During the wet season, the measured DO amount of Ashulia beel was 1.1 to 2.1 mg/L, and during the dry season, it was 0.5 to 2.0 mg/L (Islam *et al*., 2010). In Dhaleswari River, the lowest value of DO was observed 4.9 mg/L in monsoon and 4.1 mg/L in post-monsoon season, suggesting that the concentration of DO was higher in monsoon than in post-monsoon and pre-monsoon seasons (Islam *et al*., 2012). However, the present investigation disclosed that the obtained results of DO were within the permissible limit (5.0 mg/L) for aquatic environment established by ECR (1997).

Table 1: Water quality parameters along with Trophic State Index (TSI) in Kaptai Lake

Parameters	*Seasons (Mean ± SD)*			*Average*
	Pre-monsoon	*Monsoon*	*Post-monsoon*	
Temp. (ºC)	23.9±1.07	31.1±0.67	21.1±0.23	25.37±5.16
Transp. (cm)	68.25±85.60	31.63±36.63	45.00±54.19	48.29±18.53
TDS (mg/L)	69.5±17.24	44.5±5.82	80.5±18.58	64.83±18.45
pH	7.63±0.30	7.43±0.05	6.77±0.18	7.28±0.45
DO (mg/L)	6.36±0.15	7.21±0.36	7.02±0.23	6.86±0.45
EC (µS/cm)	125.83±16.5	82.50±8.15	141.25±24.29	116.53±30.46
Alkalinity (mg/L)	97.5±23.04	67.00±21.9	137.5±31.12	100.67±35.36
Hardness (mg/L)	71.25±7.15	43.00±6.36	66.25±8.89	60.17±15.08
NH_3 (mg/L)	.0018±.0008	0.0325±.015	0.03±0.00707	0.02±0.02
NO_3 (mg/L)	1.25±0.34	1.33±0.61	1.605±0.204	1.40±0.19
NO_2 (mg/L)	0.02±0.007	0.025±0.015	0.02±0.00707	0.02±0.003
PO_4 (mg/L)	1.17±0.698	1.81±0.291	1.13±0.703	1.37±0.38
SO_4 (mg/L)	63.5±10.92	57±22.022	69.00±8.227	63.17±6.01
Chlorophyll *a* (µg/L)	1.51±0.076	1.60±6.476	0.978±0.160	1.36±0.34
TSI (SD)	57.73±9.49	77.49±10.35	48.33±3.59	61.18±14.88
TSI (CHL)	34.57±0.527	33.82±3.73	29.71±1.807	32.70±2.62

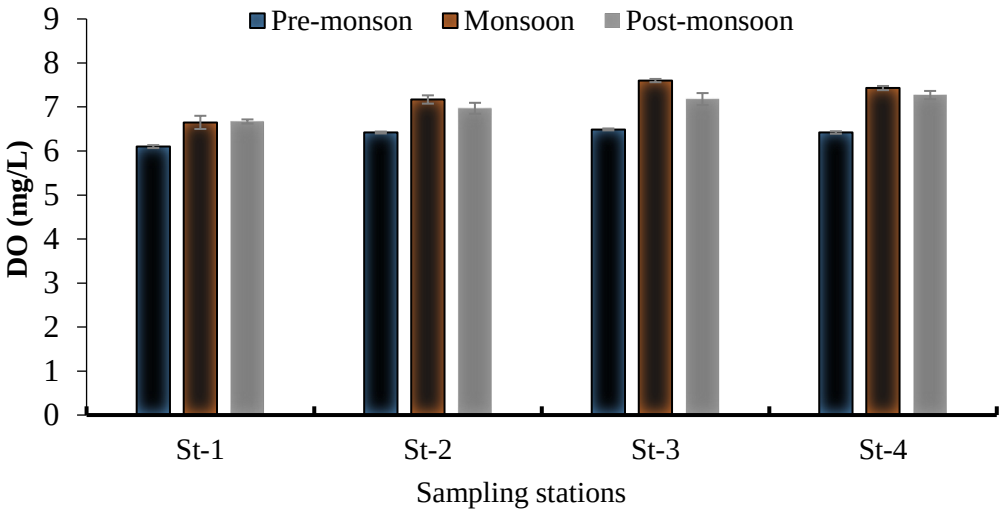

Figure 6: The DO contents in different season at different sampling station

Electrical Conductivity (EC): Significant changes (usually increases) in EC may indicate that a discharge or some other source of disturbance has decreased the relative condition or health of the water body and its associated biota (Islam *et al*., 2019). The lowest EC 75.33 µS/cm was found at St-3 during monsoon and the highest EC 172.33 µS/cm was found at St-3 during post-monsoon season (Figure 7). The average EC in

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different season during the study period ranged from 82.50 to 141.24 µS/cm. Usually, the highest EC 141.24 µS/cm was found in post-monsoon and the lowest EC 82.50 µS/cm was observed in monsoon season (Table 1). Ahmed *et al*. (2001) discovered that conductivity in Kaptai Lake was between 91.9 and 106.4 µS/cm, which were monitored from October to May. Patra and Azadi (1985) reported a similar phenomenon in Chittagong's Halda River. In the dry season, the EC surpassed the normal amount of 700 µS/cm (EQS, 1997), which has a negative impact on aquatic life (Yasmeen *et al*., 2012).

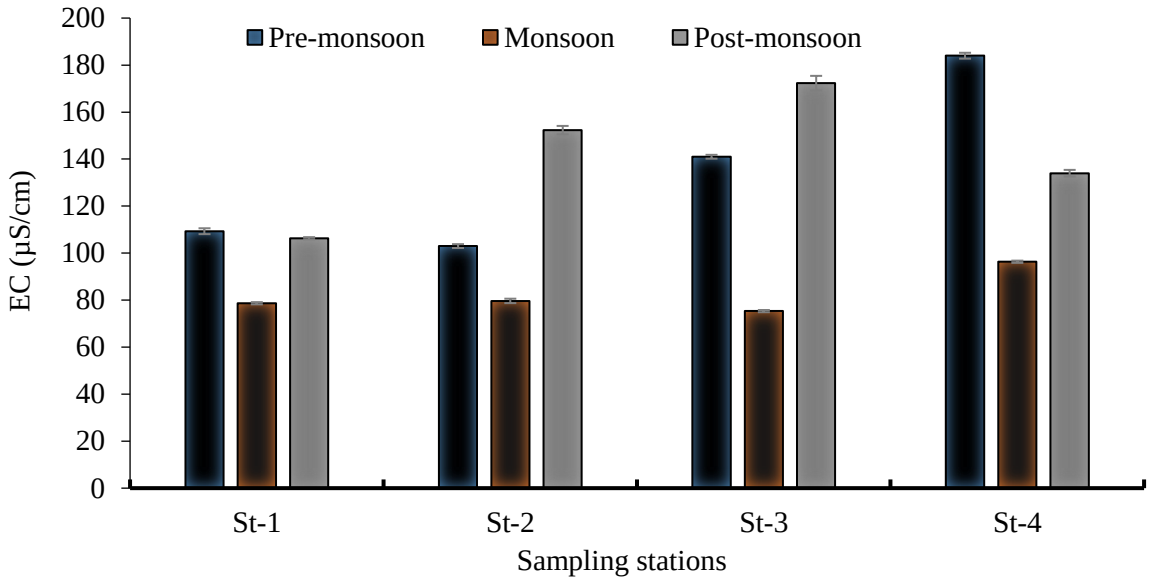

Figure 7: The EC values at various stations during various seasons

Total Alkalinity: Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes. Living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0. Higher alkalinity levels in surface waters will buffer acid rain and other acid wastes and prevent pH changes that are harmful to aquatic life (Kabir *et al*., 2020). The alkalinities of sample water for the four stations were within the range of 35 to 190 mg/L. The lowest alkalinity 35 mg/L was found at St-3 during post-monsoon and highest alkalinity 71.90 mg/L was found at St-1 during post-monsoon season (Figure 8). On an average, the highest alkalinity 137.5 mg/L was found in post-monsoon and the lowest alkalinity 62.5 mg/L was observed in monsoon season (Table 1). According to Bashar *et al*. (2015), the highest total alkalinity (90.68 mg/L) in Kaptai Lake occurred in December of 2013 and the lowest (51.9 mg/L) occurred in December of 2012. A total alkalinity value of more than 80 mg/L suggests a nutrient-rich, hard-water lake, and such lakes are often the best fish producers (Bashar *et al*., 2015). According to the results of this study, total alkalinity indicates that Kaptai Lake could be considered medium to highly productive in terms of fish production. In monsoon, post-monsoon, and pre-monsoon seasons, the concentration of alkalinity in Dhaleshwari River was found to vary from 126 to 200, 150 to 595, and 450 to 640 mg/L, respectively (Islam *et al*. 2012). The alkalinity of the Turag River was found to be 404 mg/L in the post monsoon, 581 mg/L in the pre-monsoon and 150 mg/L in the monsoon season (Meghla *et al*., 2013).

Total Hardness: The most important impact of hardness on fish and other aquatic life appears to be the effect the presence of these ions has on the other more toxic metals such as lead, cadmium, chromium and zinc. Generally, harder the water, lower the toxicity of other metals to aquatic life (Islam *et al*., 2015a,b). The hardness of water sample for the four stations was within the range of 37 to 83 mg/L. The lowest hardness 37 mg/L was found at St-4 during monsoon and highest hardness 83 mg/L was found at St-1 during pre-monsoon (Figure 9). The average highest hardness 71.25 mg/L was found in pre-monsoon and the

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lowest hardness 43 mg/L was found in monsoon season (Table 1). Hardness of water is due to the presence of chloride, sulfate, carbonate and bicarbonate (Rahman *et al*., 2012). According to Brown *et al*. (1970) a soft water body contains 0 to 60 mg/L calcium carbonate. Accordingly, the water of the Kaptai Lake may be regarded as slightly hard (Ahmed *et al*., 2001). The concentration of total hardness of Turag River was found varying from 116 to 156 mg/L in post-monsoon, from 130 to 176 mg/L in pre-monsoon and from 42 to 70 mg/L in monsoon season (Meghla *et al*., 2013). The concentration of total hardness of Pungli River was found varying from 28 to 72 mg/L in post-monsoon, from 40 to 60 mg/L in pre-monsoon and from 20 to 56 mg/L in monsoon season (Suravi *et al*., 2013).

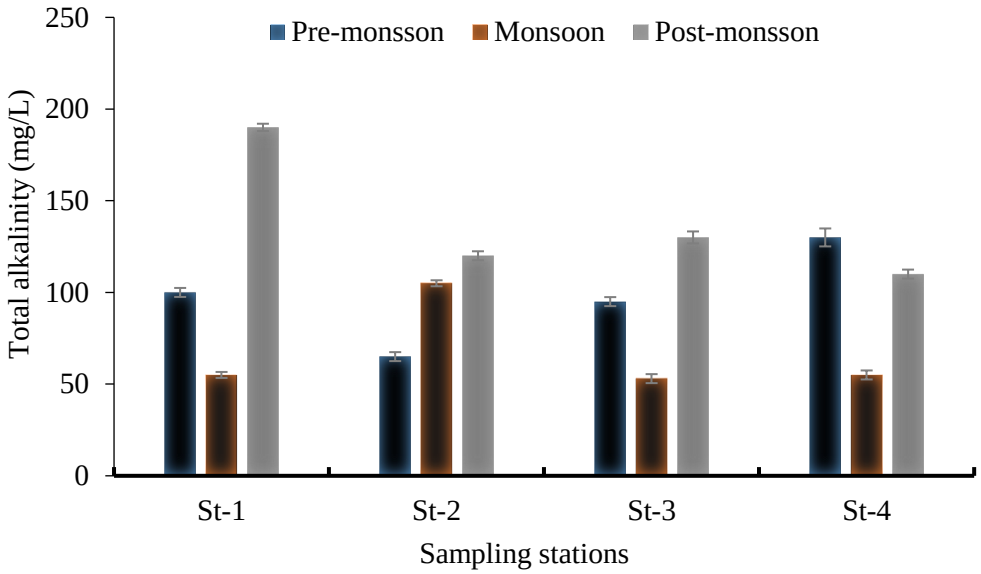

Figure 8: The total alkalinity contents in different season at different station

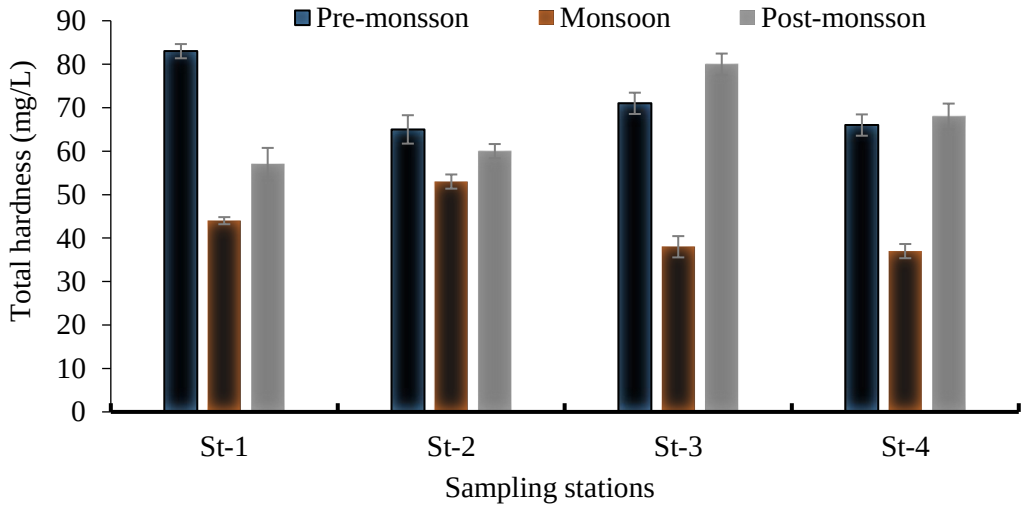

Figure 9: Total hardness contents in different season at different station

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Dissolved nutrients

Ammonia (NH_3-N): When excessive quantities of ammonia are present in water, aquatic species find it difficult to expel the toxicant, resulting in toxic accumulation in internal tissues and blood, and possibly death (Nion *et al*., 2020). The lowest concentration (0.01 mg/L) of NH_3-N was found at St-1 along with St-4 during pre-monsoon and highest concentration (0.5 mg/L) was found at St-4 during monsoon season (Table 2). On the other hand, the highest concentration of NH_3-N 0.0325 mg/L was recorded during monsoon while the lowest concentration 0.0018 mg/L was found during pre-monsoon season (Table 1). Ahmed *et al*. (2001) found NH_3-N content 0.4 mg/L in Kaptai Lake which is comparatively higher than the present findings. In Sundarbans, the NH_3-N concentrations were 0.035, 0.037 and 0.07 mg/L during high tide in pre-monsoon, monsoon and post-monsoon, respectively; and the NH_3-N concentrations were 0.078, 0.034 and 0.052 mg/L during low tide in pre-monsoon, monsoon and post-monsoon season, respectively (Nion *et al*., 2020).

Nitrate (NO_3-N): Nitrates are necessary nutrients, but excessive levels can cause serious water quality issues. Excess nitrates, when combined with phosphorus, can hasten eutrophication, resulting in substantial increases in aquatic plant growth and changes in the types of plants and animals that dwell in streams. Thus, excess nitrates can produce hypoxia and be hazardous to warm-blooded animals (Kabir *et al*., 2020). The lowest NO_3-N concentration (0.3 mg/L) was found at St-1 and St-3 during monsoon, and highest concentration (1.9 mg/L) was found at St-4 during monsoon season (Table 2). The mean highest concentration of NO_3-N (1.625 mg/L) was recorded during post-monsoon while the lowest concentration (1.25 mg/L) was found during pre-monsoon season (Table 1). Rahman *et al*. (2017) reported that the nitrate value varied from 0.79 to 1.11 mg/L in Kaptai Lake water. The maximum concentration of NO_3-N was found in monsoon (1.11 mg/L) and the minimum was found in the early monsoon (0.79 mg/L), which is almost similar to the present investigations. The NO_3-N concentrations ranged from 3.5 to 12.3, 8.4 to 27.2 and 5 to 50 mg/L during high tide, and 6.1 to 12.2, 4.2 to 28.2 and 10 to 47 mg/L during low tide at pre-monsoon, monsoon and post-monsoon seasons, respectively, in the Sundarbans (Nion *et al*., 2020).

Nitrite (NO_2-N): Excessive nitrite may accumulate in the blood of some fish species and, among other things, cause the oxidation of iron in hemoglobin producing methemoglobin, which is not capable of transporting oxygen (Islam *et al*., 2017). The concentrations of NO_2-N at four stations were within the range of 0.01 (at St-2 along the study period) to 0.04 mg/L (at St-1 along with St-4 during monsoon) (Table 2). However, the mean highest concentration of NO_2-N (0.025 mg/L) was recorded during monsoon while the lowest concentration of NO_2-N (0.02 mg/L) was found during pre-monsoon and post-monsoon season (Table 1). Haque *et al*. (2018) found that the NO_2-N concentration varied from 0.0992 to 0.119 mg/L with a mean concentration of 0.109 mg/L in Kaptai Lake water.

Phosphate (PO_4-P): Algae, which are aquatic plants that include many single-celled, free-floating plants, grow rapidly when more phosphates are added to the water. Excessive algal cloud lowers the quantity of sunlight available to other plants, killing them in some cases. When algae die, the microorganisms that break them down deplete dissolved oxygen in the water, depriving and sometimes smothering other aquatic organisms (Nion *et al*., 2020). During pre-monsoon and post-monsoon, the lowest concentration of PO_4-P 0.09 mg/L was found at St-3 whilst the highest concentration 2.21 mg/L was found at St-3 during monsoon season (Table 2). Moreover, the highest concentration of PO_4-P (1.81 mg/L) was recorded during monsoon while the lowest concentration (1.13 mg/L) was found during post-monsoon season (Table 1). The PO_4-P in the Kaptai Lake study area varied from 0.32 to 0.41 mg/L with a mean value of 0.367 mg/L, whereas lowest value observed in pre-monsoon and highest value observed in post-monsoon season (Haque *et al*., 2018). Khan *et al*. (1996) also found a prominent increase of PO_4-P in dry season compared to rainy season in this lake water.

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Table 2: Dissolved nutrient concentrations in water of Kaptai Lake

Parameter (mg/L)	*Pre-monsoon*				*Monsoon*				*Post-monsoon*			
	St-1	*St-2*	*St-3*	*St-4*	*St-1*	*St-2*	*St-3*	*St-4*	*St-1*	*St-2*	*St-3*	*St-4*
NH_3	0.002	0.001	0.003	0.001	0.01	0.03	0.05	0.01	0.002	0.001	0.003	0.001
NO_3	1.1	1.2	1.8	0.9	0.3	1.5	1.9	0.3	1.1	1.2	1.8	0.9
NO_2	0.02	0.01	0.03	0.02	0.01	0.01	0.04	0.01	0.02	0.01	0.03	0.02
PO_4	1.10	1.50	0.09	1.99	1.39	1.87	2.21	1.39	1.10	1.50	0.09	1.99
SO_4	80	50	65	59	48	50	36	48	80	50	65	59

Sulphate (SO_4): Reduced sulfur concentrations have a negative impact on algae development in aquatic species. Sulfate is the most frequent type of sulfur in well-oxygenated waters. Algal growth is impossible when sulfate levels are less than 0.5 mg/L. Sulfate salts, on the other hand, can be major pollutants in natural waters (Kabir *et al*., 2020). The lowest concentration of SO_4 (36 mg/L) was found at St-4 during monsoon and highest concentration (94 mg/L) was found at St-1 during monsoon season (Table 2). On average the highest concentration of SO_4 (69.75 mg/L) was recorded during post-monsoon while the lowest concentration of SO_4 (57 mg/L) was found during monsoon season (Table 1). The safe limits for SO_4 concentration for aquaculture ranged from 5 to 100 mg/L (Boyd, 1998) and values in both the seasons were much below this range, except at Subolong in dry season (Karmakar *et al*., 2011). The SO_4 concentrations ranged from 119 to 272, 30 to 90, 32 to 130 mg/L with mean concentrations 187.8, 53.19 and 76.87 mg/L found during high tide in pre-monsoon, monsoon and post-monsoon, respectively, in Sundarbans (Nion *et al.*, 2020). However, the current analysis found lower SO_4 concentrations at all sampling sites across the three seasons of Kaptai lake water than the ECR anticipated (1997).

Biological water quality

Chlorophyll a*:* The chlorophyll molecule allows algae to absorb energy from light; a process known as photosynthesis. Thus, chlorophyll can be used as a measure of algal content in lake. Chlorophyll *a* is a type of chlorophyll molecule which is common in algae. Whilst measurement of the Chlorophyll *a* content of lake water will not measure all of the algae in a lake, it can be a good overall indicator of general patterns in phytoplankton growth and die-back and is widely used by freshwater and marine scientists. The highest Chlorophyll *a* (2.21 µg/L) was found at St-2 during monsoon and the lowest Chlorophyll *a* (0.70 µg/L) was found at St-1 during post-monsoon season (Figure 10). The mean highest Chlorophyll *a* (1.60 µg/L) was found in monsoon and the lowest Chlorophyll *a* (0.98 µg/L) was found in post-monsoon season (Table 1). Chlorophyll *a* is a good indicator of the total quantity of algae in a lake. Algae are a natural part of any lake system, but large amounts of algae decrease water clarity, make the water look green, can form surface scums, reduce dissolved oxygen levels, can alter pH levels, and can produce unpleasant tastes and smells (Pavluk and Bij De Vaate, 2017). Phytoplankton biomass as Chlorophyll *a* correlated positively with phytoplankton density and water depth. The concentrations of Chlorophyll *a* ranged from 0.611 to 0.840, 0.217 to 1.168 and 0.180 to 1.75 mg/L during high tide, and 0.638 to 0.883, 0.218 to 1.189 and 0.69 to 1.88 mg/L during low tide over pre-monsoon, monsoon and post-monsoon season, respectively (Nion *et al.*, 2020).

Estimation of Trophic State Index (TSI)

Chlorophyll a *TSI:* The Chlorophyll *a* TSI status for the four sampling stations was within the range of 27.43 to 37.79. The highest Chlorophyll *a* TSI (37.79) was found at St-2 during monsoon and the lowest Chlorophyll *a* TSI **(**27.43) was found at St-1 during post-monsoon (Figure 11). However, the highest Chlorophyll *a* TSI (34.56) was found in pre-monsoon and the lowest Chlorophyll *a* TSI (29.71) was found in post-monsoon season (Table 1). Chlorophyll *a* TSI values range from 11.31 to 13.77 in the pre-monsoon,

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from 19.11 to 20.84 in the monsoon, and from 14.81 to 17.38 in the post-monsoon. Khondker *et al.* (2010) recorded Chlorophyll *a* TSI 41.24 in Bogakain Lake of Bandarban, Bangladesh. Results of the study revealed that Kaptai Lake tends to be more or less oligo-mesotrophic condition. According to Yang *et al.* (2012), on the basis of Chlorophyll *a* TSI the lake is oligo-mesotrophic (30<TSI≤40).

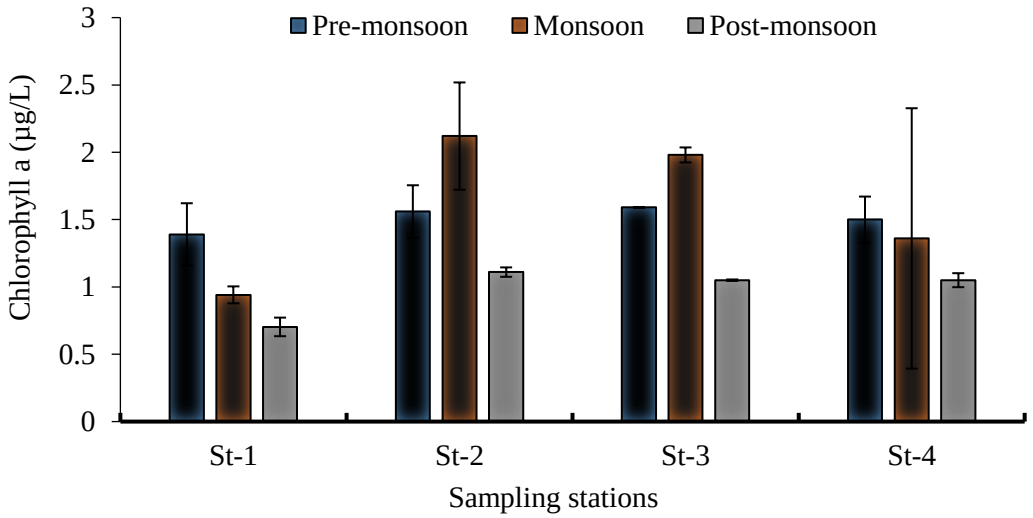

Figure 10: The context of Chlorophyll *a* (±SD) in different season at different station

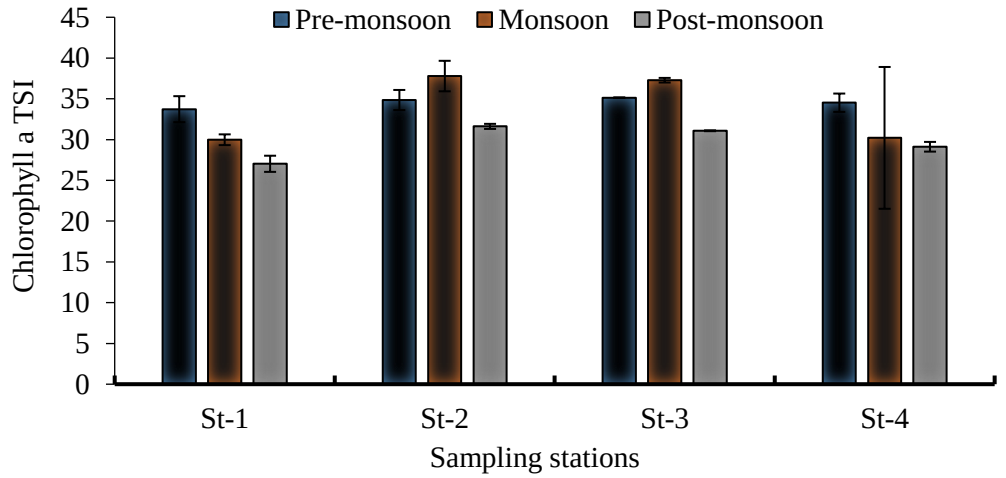

Figure 11: The status of Chlorophyll *a* TSI in different season at different sampling station

Secchi Disc TSI: The Secchi disc TSI status of water samples collected from the four sampling stations were within the range of 44.02 to 83.23. The highest Secchi disc TSI (83.23) was found at St-1 during monsoon and the lowest Secchi disc TSI **(**44**.**02) was found at St-2 during post-monsoon season (Figure 12). The highest Secchi disc TSI (77.49) was found in monsoon and the lowest Secchi disc TSI (48.33) was found in post-monsoon season (Table 1). The average TSI (SD) was found 89.80, 107.83 and 100.73 in pre-monsoon, monsoon and post-monsoon season, respectively. The Secchi disc TSI of Kaptai Lake recorded 48.19 in pre-

monsoon and 53.00 in post-monsoon season (Rahman *et al.*, 2014). Results of the study found that according to Yang *et al*. (2012) on basis of Secchi disc TSI the lake has middle eutrophic (60<TSI ≤70) condition.

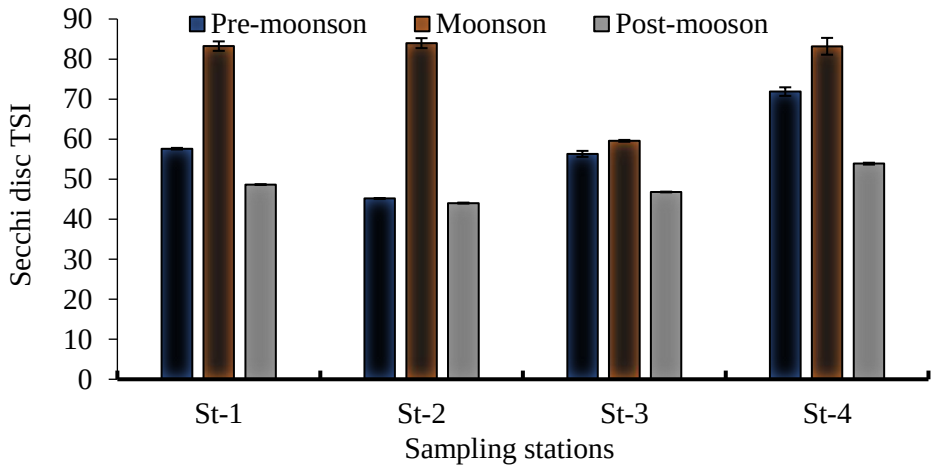

Figure 12: The status of Secchi disc TSI in different season at different sampling station

Source identification of water quality parameters and Chlorophyll *a*

Statistical analyses were performed to elucidate the associations among physicochemical parameters and nutrients quality and to identify the important factors involved in controlling the transport and distribution of physicochemical parameters. Pearson's correlation (PC) matrix for analyzed physiochemical parameters and nutrient quality parameters were calculated to see the parameters interrelations with each other and the results are presented in Table 3. pH-NO_2 and hardness-SO_4 show significant positive correlations with each other in pre-monsoon seasons, which means that one parameter can predict the significance of the other. Reversely, transparency-alkalinity and NO_3-PO_4 show significant negative correlation with each other in pre-monsoon season. Besides, transparency-pH, EC-TDS, NH_3-NO_3 show significant positive correlations with each other and temperature-TDS, temperature-EC show significant negative correlation with each other in monsoon seasons, respectively. However, pH-NO_2, DO-EC, hardness-SO_4 and transparency-alkalinity, PO_4-NH_3 show significant positive and negative correlation with each other in post-monsoon season, respectively.

Table 3: Pearson correlation coefficients (r) among physicochemical parameters and dissolved nutrients in Kaptai Lake water

Pre-monsoon	*Temp.*	*Transp.*	*TDS*	*pH*	*DO*	*EC*	*Alkalin*	*Hardn*	*NH_3*	*NO_3*	*NO_2*	*PO_4*	*SO_4*	*Chloro-phyll **a***
Temp.	1													
Transp.	-0.627	1												
TDS	0.009	0.734	1											
pH	-0.063	-0.553	-0.517	1										
DO	0.714	-0.448	0.226	0.41	1									
EC	0.592	-0.589	-0.021	0.664	**.952***	1								
Alkalin	0.607	**-.991****	-0.695	0.645	0.529	0.681	1							
Hardn	-0.679	-0.113	-0.74	0.406	-0.658	-0.398	0.095	1						
NH_3	-0.629	0.142	-0.089	0.743	0.047	0.252	-0.033	0.474	1					
NO_3	-0.54	0.492	0.441	0.413	0.188	0.243	-0.372	0.026	0.854	1				
NO_2	-0.155	-0.346	-0.285	**.964***	0.456	0.678	0.46	0.296	0.853	0.632	1			

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Pre-monsoon	*Temp.*	*Transp.*	*TDS*	*pH*	*DO*	*EC*	*Alkalin*	*Hardn*	*NH_3*	*NO_3*	*NO_2*	*PO_4*	*SO_4*	*Chloro-phyll **a***
PO_4	0.707	-0.396	-0.159	-0.546	0.011	-0.131	0.286	-0.346	**-.962***	-0.946	-0.714	1		
SO_4	-0.528	-0.327	-0.835	0.614	-0.441	-0.148	0.328	**.965***	0.538	0.041	0.486	-0.358	1	
Chlorophyll ***a***	0.172	0.435	0.883	-0.091	0.609	0.433	-0.347	-0.772	0.158	0.614	0.139	-0.326	-0.745	1

Monsoon	*Temp.*	*Transp.*	*TDS*	*pH*	*DO*	*EC*	*Alkalin*	*Hardn*	*NH_3*	*NO_3*	*NO_2*	*PO_4*	*SO_4*	*Chloro-phyll **a***
Temp.	1													
Transp.	.400	1												
TDS	**-.982***	-.500	1											
pH	.217	.970*	-.303	1										
DO	-.308	.601	.288	.777	1									
EC	**-.987***	-.532	**.995****	-.350	.214	1								
Alkalin	.146	-.609	.042	-.568	-.266	.002	1							
Hardn	.521	-.438	-.357	-.493	-.463	-.382	.911	1						
NH_3	-.686	-.110	.548	-.084	-.020	.612	-.703	-.823	1					
NO_3	-.538	.155	.371	.159	.093	.430	-.868	-.921	**.963***	1				
NO_2	-.604	-.582	.532	-.597	-.480	.614	-.290	-.393	.845	.697	1			
PO_4	-.778	.098	.646	.194	.359	.677	-.734	-.933	.925	.926	.616	1		
SO_4	.523	-.158	-.578	-.389	-.876	-.497	-.136	.193	.100	.114	.363	-.253	1	
Chlorophyll ***a***	.320	.456	-.226	.549	.649	-.322	.373	.337	-.774	-.677	-.945	-.477	-.636	1

Post-monsoon	*Temp.*	*Transp.*	*TDS*	*pH*	*DO*	*EC*	*Alkalin*	*Hardn*	*NH_3*	*NO_3*	*NO_2*	*PO_4*	*SO_4*	*Chloro-phyll **a***
Temp.	1													
Transp.	-.627	1												
TDS	.009	.734	1											
pH	-.063	-.553	-.517	1										
DO	.714	-.448	.226	.410	1									
EC	.592	-.589	-.021	.664	**.952***	1								
Alkalin	.607	**-.991****	-.695	.645	.529	.681	1							
Hardn	-.679	-.113	-.740	.406	-.658	-.398	.095	1						
NH_3	-.629	.142	-.089	.743	.047	.252	-.033	.474	1					
NO_3	-.540	.492	.441	.413	.188	.243	-.372	.026	.854	1				
NO_2	-.155	-.346	-.285	**.964***	.456	.678	.460	.296	.853	.632	1			
PO_4	.707	-.396	-.159	-.546	.011	-.131	.286	-.346	**-.962***	-.946	-.714	1		
SO_4	-.528	-.327	-.835	.614	-.441	-.148	.328	**.965***	.538	.041	.486	-.358	1	
Chlorophyll ***a***	.523	.238	.834	-.295	.686	.445	-.190	-.968*	-.247	.227	-.132	.098	-.931	1

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed)

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Conclusion

The current study is a baseline investigation of the seasonal change of physicochemical characteristics in the Kaptai Lake, which will provide useful information for lake ecosystem management and conservation. Despite receiving wastes from many anthropogenic chemical sources, the water quality of Kaptai Lake is still good. The physiochemical parameters of Kaptai Lake such as pH, DO, EC, NH_3, NO_3^-, NO_2^- and PO_4^{2-} concentrations were in favor of aquaculture. Total alkalinity, total hardness and concentration of SO_4^{2-} were higher than the standard. The presence of a large amount of total dissolved solids in the reservoir is quite concerning. Furthermore, urban pollution has put the water supply and domestic use in Rangamati town in jeopardy. In this case, it is vital to take control measures to prevent contamination in order to preserve the lake's life.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5	Author 6	Author 7
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	Yes	Yes	No	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes	No	No
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes	Yes	Yes
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M – 00251 | Review Article

Comprehensive Overview of REDD+ in India: Status, Opportunities and Challenges

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Abstract

Climate change is a worldwide issue with detrimental effects on ecosystems and human well-being. Reducing Emissions from Deforestation and Forest Degradation (REDD) is a worldwide policy tool for combating climate change by reducing emissions from the forestry sector and has received widespread attention. Since the program's inception, India has been a strong advocate for REDD+ and its activities. The goal of this research is to evaluate India's current REDD+ readiness. India is the fourth largest CO_2 emitter in the world, accounting for 7% of global CO_2 emissions. India's emission trajectory shows the country's ever-increasing CO_2 emission trend, with an annual average increase rate of 5-6 percent. India has a large geographical area and forest cover, and it holds 7,124.6 million tons of carbon stock. Forests are traditionally managed through a participatory approach, which is similar to REDD+ activities. India has made significant progress toward REDD+ implementation by developing a national REDD+ strategy, enacting consistent laws and regulations, and demonstrating accountability and monitoring of national forest carbon. However, several issues, including forest dependency, community rights, capacity building, policies, and finance, should be carefully addressed to overcome hurdles in REDD+ implementation.

Keywords

Carbon stock; Participatory approach; Forest dependency; Community rights

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Introduction

Climate change is a worldwide phenomenon with negative consequences for ecosystems and human well-being. It is defined as "a change in the condition of the climate that may be recognized by changes in the mean and/or variability of its attributes over time, generally decades or more" (IPCC, 2007). Both natural and human processes cause climate change. Forest fires, earthquakes, volcanoes, and permafrost are examples of natural processes (Yue and Gao, 2018), whereas human processes include activities linked to energy generation, industrial activities, and land use, land-use change, and forestry (LULUCF) (Edenhofer *et al*., 2014). The rise in greenhouse gas (GHG) concentrations in the atmosphere as a consequence of human activity is the major cause of climate change. Carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O), and Chlorofluorocarbons (CFCs) are the main GHGs (UNFCCC, 2008). These GHGs have a major role in global warming (IPCC, 1996), with CO_2 accounting for nearly 60% of total global warming (Chand *et al*., 2018; Sahu *et al*., 2015). Between 1984 and 2019, CO_2 and CH_4 rose by 19% and 13%, respectively (Cail and Criqui, 2021). The continuous increases in these GHGs due to human activities will hasten global warming and speedup disasters like erratic rainfall, flood, changing rainfall patterns, drought, and drying water sources (IPCC, 2014). Anthropogenic activities have already caused global warming of 1.0°C over pre-industrial levels. If the current emission rate persists, global warming is projected to surpass 1.5°C by 2050 (IPCC, 2018).

The UNFCCC (United Nations Framework Convention on Climate Change) achieved an agreement at the COP3 (Conference of Parties) to minimize the potential effects of climate change, known as the Kyoto Protocol. Under Kyoto Protocol, forests are regarded essential for their carbon sinks' role because they can capture and store CO_2 from the atmosphere (Bohara *et al*., 2018). The Kyoto Protocol is a pact aiming to decrease GHGs. It was signed in 1997 and ratified on 16th February 2005. The Protocol's goals are to keep GHG levels in the atmosphere constant at a level that avoids detrimental human impact on the climate system (UNFCCC, 2005). During the first commitment period of the Kyoto Protocol (2008-2012), the Parties pledged to reduce their GHG emissions by an average of 5% compared to 1990 levels. An amendment to the Kyoto Protocol was accepted at the Doha climate change conference in 2012 to bridge the gap between the end of the first Kyoto phase in 2012 and the start of the new global agreement (the Paris Agreement) in 2020. In this amendment, participating countries agreed to cut their GHG emissions by at least 18% below 1990 levels during the second commitment period (2013-2020). The Kyoto Protocol has proposed three different flexibility options for nations to meet the emission reduction goal: Joint Implementation (JI), Clean Development Mechanism (CDM), and Emission Trading (ET). Under CDM, the carbon services of the forests were enlisted, and records on emissions from LULUCF activities were maintained (Sud *et al*., 2012). Since COP3, the term "avoided deforestation" has been used to refer to decreasing emissions from deforestation in underdeveloped nations. During the International Conference in Marrakesh in 2001, the concept of avoided deforestation was dropped, leaving afforestation and reforestation as permissible CDM project activities. It was due to fear of undercutting Annex-I nation's[1] efforts to reduce fossil fuel emissions and flooding the market with large carbon credits from the forestry sector. However, during COP11 in Montreal in 2005, the Coalition of Rainforest Nations, headed by Costa Rica and Papua New Guinea, established RED (Reducing Emission from Deforestation) to limit deforestation (UNFCCC, 2005). RED occurred when the Kyoto Protocol was signed, which aimed to reduce emissions from technological projects. REDD (Reducing Emissions from Deforestation and Forest Degradation) emerged at COP13 in Bali, Indonesia, in 2007, when deforestation and forest degradation were seen as equal threats to the Protocol's emission reduction promise. Following that, at COP14 in Poland in 2008, the addition of "+" to REDD was agreed. The evolution of REDD+ is shown in figure 1.

[1] https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states?field_national_communications_target_id%5B515%5D=515

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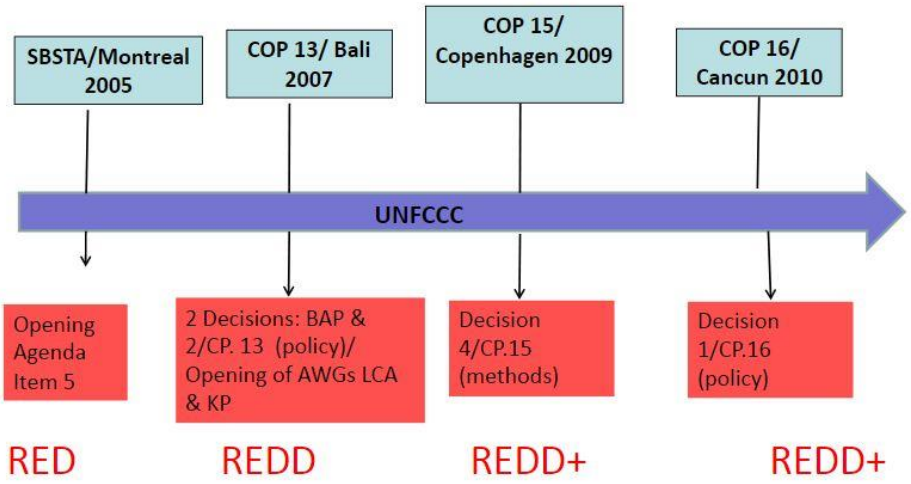

Figure 1: Evolution of REDD+

Since its debut, REDD+ has received much attention in international forums (Seymour and Busch, 2016). REDD+ is a global policy tool created by the UNFCCC to address climate change by decreasing emissions from the forestry sector. The forestry sector accounts for approximately 9-11 percent of the total GHG emissions, or about 5.8 Gt CO_2 equivalents per year, mostly in poor and tropical countries (IPCC, 2014). However, REDD+ includes biodiversity conservation and improved rural livelihoods in addition to stopping deforestation and forest degradation (Caplow *et al*., 2011; Turnhout *et al*., 2016). The official definition of REDD+ by the UNFCCC is "*reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries*" (Olander, 2012; UNFCCC, 2011). REDD+ is probably the most potent means to tackle climate change globally (Stern, 2007). It has the highest potential to reduce emissions from AFOLU (Agriculture, Forestry, and Other Land Use) (IPCC, 2014).

India's proposal to incorporate compensation for forest protection in forest-based mitigation measures was accepted at COP12 in Nairobi, Kenya. India has been a strong proponent of REDD+ and actively participates in high-level climate change discussions. India ranks 10th amongst the most forested nations of the world (FAO, 2020). The total forest cover in India is 712249 sq km (21.67% of the total geographical area), and 95,027 sq km of tree cover or tree outside the forest (2.89% of total geographical area) (IFSR, 2019). However, the National Forest Policy of 1988 envisages achieving 33 percent of forest and tree cover. An additional land area of 29.58 million hectares needs to be brought under the tree-cover through various programs like National Afforestation Programme, Green India Mission, National Agroforestry Policy, National Green Highway Mission etc. to achieve the targets mentioned in National Forest Policy. Also, more than 40 percent of forest is degraded or understocked (Aggarwal *et al*., 2009) and needs restoration efforts. With the available technical and institutional capabilities for Forest Management, India is well-positioned to benefit from REDD+ activities. In this context, the current research explores India's current REDD+ readiness.

Global GHG Emitters

China (28%) is the world's biggest GHG emitter, followed by the United States (15%), the European Union (9%), and India (7%). They account for nearly 60 percent of the global GHG emissions (Cail and Criqui, 2021). Between 1990 and 2019, China and India increased their global emission share, while the United States and the European Union decreased. Figure 2 depicts the four jurisdictions' share of global emissions from 1990 to 2019. China and India increased their global emission share from 11 to 28 percent and 3 to 7 percent, respectively. This has largely been attributed to increased global coal consumption (Olivier *et al*.,

2020). On a per capita basis, India's emissions are 70% below the world average (Bhattacharya and Mehra, 2021). Forests neutralize 11% of India's GHG emissions. The emission shares of the United States and the European Union have decreased over the same period, falling from 23 to 15 percent and 20 to 9 percent, respectively (Cail and Criqui, 2021).

India is the fourth-largest CO_2 emitter in the world. India contributed roughly 7 percent of total global greenhouse gas emissions. Cail and Criqui (2021) opined that with the current trends and Indian economy, reliance on coal for energy will further increase CO_2 footprint of India. The Government of India in its Climate Action Plan for post 2020 as per National Determined Contribution to the UNFCCC, has pledged to reduce the emissions intensity of its gross domestic product by 33 to 35 percent by 2030 from 2005 level. Also, India aims to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost international finance including from Green Climate fund, thus addressing the issue of emission from industry and energy sector.

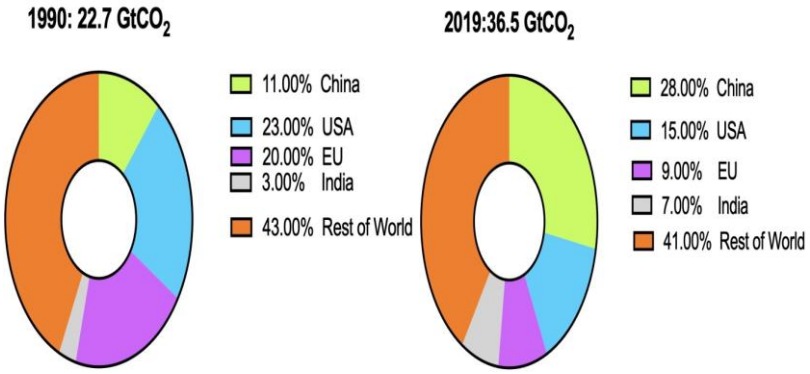

Figure 2: Global emission share by different jurisdictions in 1990 and 2019

Forest and Carbon stock status of India

India is one of the world's 17 mega biodiversity nations. India's forests cover 21.54 percent of its land area (FSI, 2019), accounting for 1.8 percent of the world's forest area (FAO, 2020). Similarly, it also harbors 8 percent of the total world's flora in 5 major and 16 sub-major forest types as classified by Champion and Seth (1968). Of these forest types, tropical forests alone share 83 percent (Suganthi *et al.,* 2017) and are the major reservoir of carbon in the country.

From 1995 to 2019, carbon stocks in India's forests are estimated to have increased from 6245 million tons to 7124.6 million tons (FSI, 2019). The soil organic pool was the biggest, accounting for about 56 percent of the total, followed by the aboveground carbon pool(31%)(FSI, 2019). By 2030, India has committed to increase the carbon stock by 2.5- 3.0 billion tons via increasing forest and tree cover under the Intended Nationally Determined Contribution (INDC). In 2010, India submitted a national report to the UNFCCC, illustrating the change in carbon stocks from 1994-95 to 2004-05. The carbon stock change in Indian forests revealed a progressive, positive change in the following period (1995-2019) as shown in figure 3.

Deforestation and Forest Degradation

Deforestation and forest degradation have been major contributors to global GHG emissions (Le Quéré *et al*., 2018). They are responsible for up to 25 percent of the total annual GHG emissions (IPCC, 2014; Le Quéré *et al*., 2015; Pendrill *et al.*, 2019). Anthropogenic activities result in the addition of 42 billion tons of CO_2 every year (IPCC, 2018) and have already added about 600 giga tons of carbon to the atmosphere since 1870 (Federici *et al*., 2018).

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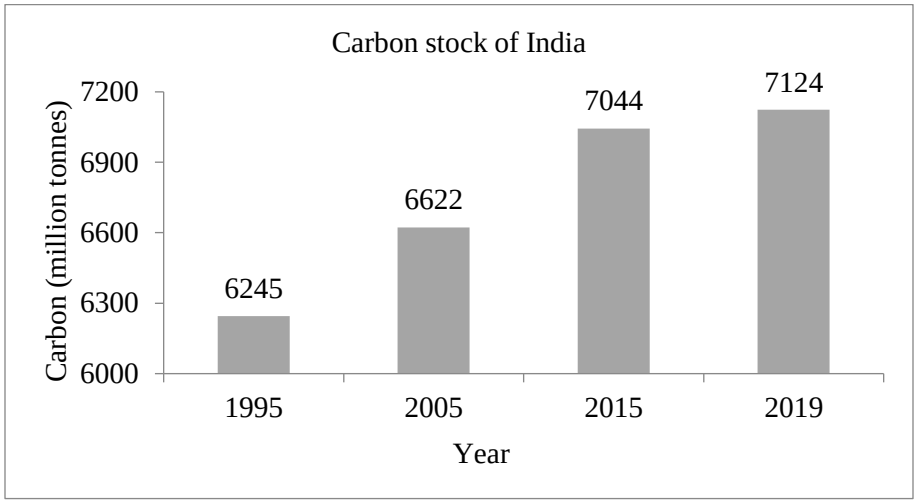

Figure 3: Carbon stock of India (1995-2019)

Agriculture, Forestry, and Other Land Use (AFOLU) activities have contributed nearly 23 percent of total net anthropogenic emissions from 2007-16 (IPCC, 2019). Since the Rio Summit of 1992, 250 million hectares of tropical forests have been diverted for agriculture (Neupane, 2015). Deforestation decreased from 12 million hectares to 10 million hectares between 2010 and 2015 (FAO, 2020). However, emissions from forest degradation rose by one-third during the same period (FAO, 2015). In India, deforestation is not much problem (Singh *et al*., 2015). According to research, forest degradation shares about 2.1 billion tons of CO_2 emissions every year in 74 developing nations (Pearson *et al*., 2017). It is estimated that anthropogenic activities at this rate will increase temperature by 1°C (0.8°C to 1.2°C) (Allen *et al*., 2018; IPCC, 2018), causing severe climate problems.

To develop an effective REDD+ intervention, it is essential to address the causes of deforestation and forest degradation (Hosonuma *et al*., 2012; Kissinger *et al*., 2012; Minang *et al*., 2014; Moonen *et al*., 2016). Understanding and linking direct and indirect drivers to policy development and implementation is critical (Goetz *et al*., 2014; Tegegne *et al*., 2016; Yoshikura *et al*., 2016) to modify recent trends in forestry leading towards better climate future.

Figure 4: Elements of REDD+ (*Source*: UN-REDD, 2016)

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Elements of REDD+

For eligibility of countries to receive finance under REDD+ programme, a developing country must have accepted documents of 4 key elements of REDD+ as given in figure 4.

REDD+ Strategy of India

One of the four major elements of REDD+ is developing a National REDD+ strategy. India has prepared its National REDD+ strategy in 2018 and submitted to UNFCCC with technical inputs from the Indian Council of Forestry Research and Education (ICFRE). This is required to be eligible for getting result-based financial incentives. India's National REDD+ Strategy lays out the conducive and enabling environment for REDD+ implementation to support multiple REDD+ accords of UNFCCC. The main goal of the REDD+ Strategy is to make it easier for the country to implement the REDD+ programme following relevant UNFCCC decisions made at the Cancun, Warsaw, and Paris COPs.

REDD+ covers trees inside forest areas as well as trees outside forests, regardless of their legal status. FSI defined forest as "all lands, more than one hectare in area, with a tree canopy density of more than 10 percent irrespective of ownership, land use and legal status. These lands may or may not be part of a designated forest area. Orchards, bamboo, and palm trees are also included." In India's REDD+ context, this definition of the forest will be used to create a national greenhouse gas inventory. The land classifications for REDD+ operations were developed based on a thorough understanding of its various components and their significance. According to the Cancun Agreements, REDD+ actions are specified and executed in three stages.

- Development of National REDD+ Strategies;
- Implementation of national policies/strategies that can strengthen and support REDD+ activities; and
- Transformation into results-oriented activities that are thoroughly assessed, reported, and validated.

REDD+ may be applied at the sub-national level to seek financial assistance for REDD+ deployment in physiographic zones that span multiple states. However, participating States would need to create sub-national Forest Reference Levels (FRL) with Forest Monitoring Systems with the technical assistance of government institutions such as the Forest Survey of India (FSI) to seek REDD+ funding.

National Forest Reference Emission Level (NFREL)

REDD+ urges developing nations to establish "National Forest Reference Emission Level (NFREL) and/or National Forest Reference Level (NFRL) or, if appropriate, as an interim measure, sub-national REL and/or RL, following the national circumstances". FREL/FRL serves as the standard for evaluating country's performance in the implementation of REDD+ activities.

India has laid significant emphasis to establishing a carbon stock reference level in forests. With the technical help of the Forest Survey of India (FSI), India submitted the NFREL to the UNFCCC in 2018, which has been technically reviewed by assessment team of the UNFCCC. The selected activity is sustainable forest management, and all five CO_2 pools were considered to formulate the country's forest reference level. India proposed FRL of 49.70 million tons of CO_2 equivalent per year, the historical average from 2000 to 2008 (MoEFCC, 2018). This reference level will be used as a baseline for carbon stock, and its increment will be monitored forward.

National Forest Monitoring System (NFMS)

The NFMS is one of the components for implementing REDD+ initiatives in developing countries (as provided in paragraph 71 of UNFCCC Decision 1/CP.16). NFMS should be versatile and expand on current systems. It should represent the phased strategy of the REDD+ implementation and enable the country's assessment of various forest types. NFMS should provide transparent, time-consistent, and appropriate information for measurement, reporting, and verification accounting for national capabilities (MoEFCC, 2018). The systems must also combine remote sensing with ground-based forest carbon measurement to estimate human greenhouse gas emissions from forests.

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Forest Survey of India (FSI) is in charge of developing the NFMS in India. FSI started assessing forest cover using LANDSAT-MSS satellite data in 1987 with an 80 meter spatial resolution. Mapping of forest cover is being done at a scale of 1:50000 with recent advancements in remote sensing methodologies. Since 1987, India has had a robust forest monitoring system that uses satellite-based remote sensing technology to detect forest and tree cover changes on a two-year cycle. FSI is using a combination of remote sensing and ground-based data to estimate carbon in India's forests using the IPCC's tier 2 and 3 approach. LISS-III data has been used with a spatial resolution of 23.5m and 1 hectare as the minimum mappable unit. India has been consistent in its assessment of forest resources. It has shown complete responsibility and monitoring of national forest carbon, which is a pre-requisite for result-based financial incentive for REDD+.

Safeguard Information System

Seven safeguards for REDD+ operations were agreed upon by COP16 (UNFCCC, 2010). The safeguards are often known as Cancun safeguards and are listed below as in COP decision 1/CP.16 of UNFCCC:

Figure 5: Seven Cancun safeguards (Source: UNFCCC, 2010)

REDD+ programmes are likely to ensure social and ecological benefits in a long-term manner, and also ensure adressal of potential risks to human and nature. UNFCCC urges the country to address and respect safeguards and develop a mechanism of Safeguard Information System (SIS) to address the potential threats to the community, environment and biodiversity. Safeguards are being addressed through a combination of forest governing structures, existing legal and institutional frameworks, and sources of information. SIS is being developed to meet its objectives as per Cancun agreement.

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Issues and Challenges for REDD+

REDD+ may enhance forest governance by spurring changes in favour of the mechanism. (Mulyani and Jepson, 2013). However, several issues and challenges have already been uttered (Angelsen, 2008; Fletcher *et al*., 2016; Phelps *et al*., 2010). Some of them, with relation to India, are as follows:

Dependence on forests

India bears a large population living around forests i.e., 173,000 forest fringe villages inhibit more than 300 million people (MoEFCC, 2018). These people are wholly/partly dependent on the forest for their livelihood. Furthermore, 27.5 percent of the overall population lives in poverty and relies on forest goods and services for a living, either directly or indirectly. The heavy reliance on the forests leads to forest degradation. REDD+ aims to reduce forest degradation, and high forest dependence may be a hurdle for the same. There is need to address forest dependence by creating alternate sources of income, value-addition of the forest produce, increasing awareness, to decrease pressure on the forest resources. Similarly, demand and supply imbalances in the market for forest products, which emerge from exploitation of forests beyond their carrying capacity (Aggarwal *et al.*, 2009) must be adequately addressed.

Community rights

REDD+ debates across the globe have been dominated by concerns about the infringement of human and community rights of forest-dependent people. Fears regarding land grabbing and invasion by elite groups can be stimulated (Larson *et al*., 2013). Inconsistency in land rights and carbon tenure resulting in inequitable benefit-sharing (Vergara-Asenjo *et al*., 217) and exclusion of overall community rights of tribals in decision-making have been major hurdles for REDD+ potential beneficiaries globally (Chhatre *et al*., 2012; Hiraldo and Tanner, 2011; Luttrell *et al*., 2013; Lyster, 2011; Sikor *et al*., 2010).

REDD+ implementation requires the absolute participation of all relevant stakeholders. Individual and community rights over forest areas are not new issues in India. The Forest Right Act, 2006[2] clearly defines the rights of individuals and communities over the forest and forest resources. The forest policy of India recognizes the rights of people and advocates participatory management of the forest. The concept of JFMC (Joint Forest Management Committee) in India was initiated in 1990s to improve the quality of the forest and the economic status of the local communities that are dependent on the forests. 22 million hectares of forests are being managed by more than 118000 JFMC's involving about 20 million people in JFM programme. JFMC provides a framework for benefit-sharing of REDD+ incentives and community inclusion in REDD+ implementation while respecting the community's rights over forest resources.

Capacity building and awareness

REDD+ success, no doubt is highly dependent upon the active participation of all relevant stakeholders. Capacity building of stakeholders towards REDD+ related issues is one of the challenges for REDD+ implementation (Rawat *et al*., 2020). Participatory forest management in India has been successful and well known all over the world. However, the REDD+ approach and its process are not well known to several stakeholders, especially forest-dependent users. Inadequate understanding of the REDD+ strategy needs a large-scale sensitization and capacity-building effort. Similarly, the capacity building of grassroots institutions and their engagement in REDD+ implementation must be adequately addressed. Along with awareness and capacity building initiatives, the strong benefit-sharing mechanism needs to be expressly specified. Along with awareness and capacity building initiatives, the robust benefit-sharing mechanism needs to be expressly specified. Regular training and capacity building programmes are organized for

[2] https://tribal.nic.in/FRA/data/FRARulesBook.pdf

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officers and frontline forest staffs on REDD+ MRV, a programme for capacity building of State Forest Departments for Developing State REDD+ Action Plan has also been initiated by ICFRE.

Acts and Policies

India is one of the few countries that have increased its forest and tree cover (24.56%), gradually aiming toward fulfilling the goal of national forest policies. According to the latest Indian State of Forest Report (IFSR) of 2019, the forest and tree cover at the national level increased by 5,188 square kilometers (0.56%) compared to the ISFR report of 2017. However, attaining the forest cover to 33 percent of the country's land area, according to National Forest Policy (1988)[3], is a long run.

REDD+ has been extensively debated in India since the commencement of global climate change negotiations. India supports the success of REDD+ implementation through JFM programmes and other participatory approaches. The participatory approach has been very effective in engaging people in forest management, and it could be a significant factor for REDD+ success in the country (MoEFCC, 2018). However, there is speculation on tenurial security, institutional and financial viability, gender equality, benefit-sharing, and ownership of forest products such as NTFPs in designated areas have been raised (TERI, 2004). The National REDD+ strategy and Safeguard Information System addresses these concerns based on existing Policies, Laws, Regulations, and Act's as per the potential policy approach based on socio-environmental and technological perspectives and requirements of the country.

Several acts and legislations are formulated in the country, keeping the country's commitment at national and international conferences regarding forest conservation. Policies and acts of India that supports and uplifts REDD+ activities are Indian Forest Act (1927)[4], Wildlife Protection Act (1972)[5], Water (Prevention and Control of Pollution) Act (1974)[6], Forest Conservation Act (1980)[7], Air (Prevention and Control of Pollution) Act (1981)[8], Environment (Protection) Act (1986)[9], National Forest Policy (1988)[3], Panchayat (Extension to Scheduled Areas) Act (1996)[10], Biological Diversity Act (2002)[11], National Environment Policy (2006)[12], The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act (2006)[2], National Tribunal Act (2010)[13], National Agroforestry Policy (2014)[14], National Working Plan Code (2014)[15] and National Action Plan on Climate Change (2008)[16]. The proposed National Forest Policy (2018)[17] acknowledges the need to combine climate change mitigation and adaptation measures to mitigate the hazardous effects of climate change. The draft is no such exemption that emphasizes sustainable forest management through the mechanism of REDD+. Although India has progressive policies and legislation to handle REDD+ concerns, certain modifications may be necessary in the future to meet the changing paradigm of forest management.

[3] http://asbb.gov.in/Downloads/National%20Forest%20Policy.pdf
[4] http://nbaindia.org/uploaded/Biodiversityindia/Legal/3.%20Indian%20forest%20act.pdf
[5] https://legislative.gov.in/sites/default/files/A1972-53_0.pdf
[6] https://tnpcb.gov.in/pdf_2019/WaterAct17519.pdf
[7] http://nbaindia.org/uploaded/Biodiversityindia/Legal/22.%20Forest%20(Conservation)%20Act,%201980.pdf
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[16] http://www.nicra-icar.in/nicrarevised/images/Mission%20Documents/National-Action-Plan-on-Climate-Change.pdf
[17] http://www.indiaenvironmentportal.org.in/files/file/Draft%20National%20Forest%20Policy,%202018.pdf

Finance

Multilateral organizations have assisted nations with high deforestation rates via readiness programmes such as the Forest Carbon Partnership Facility (FCPF) and the UN-REDD initiative. REDD+ financing can be done through public, private, national or international support. Over $10 billion funding has been committed for REDD+ already, almost half of it being result-oriented (Norman and Nakhooda, 2015).

The World Bank's FCPF and the bio-carbon fund have proved to be difficult for nations to participate and, while having a variety of funding sources, obtaining funds has been difficult (Streck, 2016). The main reason can be the inclusion of REDD+ credit for funding in markets. If REDD+ credits are utilized as an offset, market financing may be contentious. It has been argued ideologically that paying others to enable one to pollute is unethical. Market flooding has also been a worry, with cheap REDD+ credits could potentially reduce the market price of carbon driving out mitigation in the energy sector (Angelsen *et al*., 2012). Also, the absence of a long-term plan for meeting the monetary requirements of REDD+ nations exist. Although short-term financing is accessible, the disbursement process is often slow and cumbersome. Also, finance from private investors frequently went unnoticed due to modest carbon prices (Hamrick and Gallant, 2018). Most importantly, there is no complete uniformity in the criteria that nations must meet to get financing (Pesti *et al*., 2017). In India, lack of national and international finance are identified as the challenges for implementation of REDD+ activities (Rawat *et al*., 2020).

REDD+ funding will be raised domestically via the Green India Mission, Namami Gange Programme, Green Highway Policy, and other initiatives in India (Bhattacharya and Mehra, 2021). Budget shortfall will be communicated for support from UNFCCC and Green Climate Fund. The question remains the same as other countries have and will be facing in performing REDD+ activities in the country, i.e. availability of funds (when and where?).

Conclusion

India is the tenth most forested country on the planet. India's total forest and tree cover is estimated to be 24.56 percent of its total land area. Due to protection of forests, carbon stocks in Indian forests have been steadily increasing since 1994. Since its inception, India has been a leader in expanding the scope of REDD+ and advocating for the conservation of different ecological services. The activities of REDD+ are similar to the traditional management and conservation of forests through a participatory approach. REDD+ has gained the utmost attention from policy and decision makers. This forest-based mitigation strategy to tackle climate change issues offers a unique chance to strengthen forest conservation and sustainable management.

India has made significant progress toward REDD+ implementation by developing a national REDD+ strategy, enacting uniform laws and regulations, and demonstrating complete accountability and monitoring of national forest carbon, all of which are required for REDD+ finance. Despite having several challenges in REDD+ implementation, India is ready for the implementation of REDD+. Also, India already acknowledges the significant contribution of REDD+ processes in bringing different stakeholders of the Indian forestry sector together to protect the forests and safeguarding community rights. Overall, the government sees REDD+ as a proper tool to fetch reward for the earlier efforts of forest conservation through the provision of forest carbon services to the international community and an opportunity for a better future climate.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5	Author 6
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	Yes	No	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes	Yes
Supervision	Yes	Yes	Yes	Yes	Yes	No
Project Administration	Yes	Yes	No	No	No	No
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Research involving Plants
During the research, the authors followed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Yes

Research on Indigenous Peoples and/or Traditional Knowledge
Has this research involved Indigenous Peoples as participants or respondents? No

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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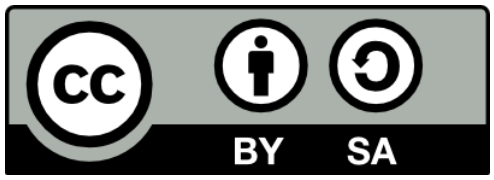

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