Study on the perspectives of application of eco-friendly laser biotechnology for environmental protection in Uzbekistan

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Abstract. Since few decades, the world is encountering unusual and daunting environmental challenges like global warming, climate change, pollution of the atmosphere and water, an emerging international crisis in water availability, long-term damage to ecosystems and substantial loss of biodiversity, waste production and disposal, damaged aquatic ecosystems, impacts of chemicals use and toxic substance disposal, as well as land degradation and deforestation. Accordingly, Uzbekistan has also been encountering some environmental issues, such as global Aral Sea crisis, soil erosion and desertification, wastewater, air pollution and a growing amount of municipal solid waste. Hence, this paper illustrates the major environmental challenges and risks in Uzbekistan, as well as, the possible application of environmentally friendly laser biotechnology for more efficient and rationale protection of ecosystems and wide-scale reclamation of deteriorated areas. Comprehensive use of laser irradiation can be effectively applied in environmental protection engineering and technologies for sustainable development in selected regions. Laser irradiation or photostimulation is a neoteric area and process of environmental biotechnology. In this process, coherent laser light is employed to optimize the natural processes involved in the bioremediation of xenobiotics or bioaccumulation of metals. Additionally, laser biotechnology could be broadly used for more efficient reclamation of contaminated soil, wastewater treatment, as well as for increasing the growth rate of irradiated plants and their resistance to various macro- and micro pollutants in the air, soil, and water.

1. Introduction

Uzbekistan is in the center of Central Asia, bordered on the south by Kyrgyzstan, Kazakhstan, Tajikistan, and Turkmenistan, and surrounded on the north by Kyrgyzstan, Kazakhstan, Tajikistan, and Turkmenistan. Uzbekistan's total area is around 477,400 km2, with scenery ranging from steppe and desert in the west to richer farming along the country's three major rivers as it heads east to the mountainous region. Uzbekistan boasts a diverse range of natural resources, including oil, natural gas, gold, and silver, and has Central Asia's largest population, with around 31 million people. The bulk of the population is ethnically Uzbek, but there are significant minorities in the country, including Russians, Tatars, Koreans, Kazakhs, Karakalpakians, Tadjiks, and Turkmens [1].

Notwithstanding Uzbekistan's diverse natural environment, decades of Soviet Union environmental neglect have combined with unbalanced economic policies in the Soviet south to make Uzbekistan one of the most serious of the Commonwealth of Independent States' (CIS) many environmental disasters. The widespread use of agrochemicals, the diversion of enormous amounts of irrigation water from the region's two rivers, and the chronic lack of water treatment plants are only a few of the factors that have resulted in widespread health and environmental problems [2]. Figure 1 highlights the overall ecosystem of the Republic of Uzbekistan.

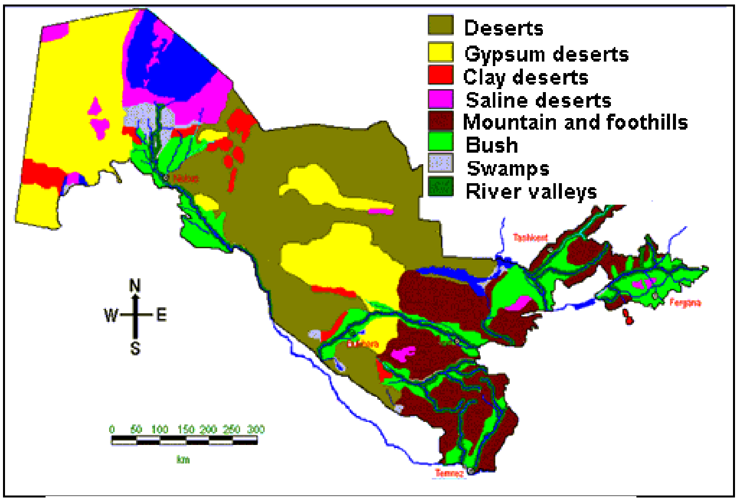

Figure 1. Map of the Ecosystems of Uzbekistan [2]

The Republic of Uzbekistan is directly confronted with two main hot zones in Central Asia: the Aral Sea and the Fergana Valley, both of which pose serious challenges to human growth and regional stability. As in the Fergana Valley, environmental stress causes economic and social deterioration and vice versa, resulting in social and political conflicts and even outright violent conflict. Water scarcity and quality, ethnic tensions, a lack of capacity, and delayed economic and structural reforms all contribute to increased security concerns [3].

Water, solid wastes, agriculture, and air pollution are the key environmental issues in Uzbekistan. Aside from the Aral Sea issue, the country faces contamination issues and water supply across the country and in the area [4-6]. Uzbekistan's second major challenge for human security is its agricultural heritage, which causes land deterioration and contamination. Furthermore, not only industrial, but also municipal solid wastes, as well as intensive fertilizer and pesticide use in agriculture, have all contributed to the severe contamination of Uzbekistan's rivers and lakes. Drinking water that has deteriorated is thought to be the cause of a variety of human health problems [4, 7, 8]. Agricultural wastes, as well as agricultural chemicals, have contaminated crop-growing areas' soil. NGOs have taken the lead in establishing environmental measures, such as conserving and protecting regional water resources, despite the government's founding of the State Committee for Environmental Protection in 1992.

The importance of ecological security research is to prevent the further degradation of the environment and the superfluous consumption of natural resources from easing the sustainable economic and ecological development. Hence, this study aims to highlight most critical environmental issues which Uzbekistan has been encountering since few decades and possibility of comprehensive application of ecologically-friendly laser biotechnology for environmental protection in Uzbekistan.

2. The Aral Sea Disaster and Environmental Health Crisis

The Aral Sea disaster can be traced back to Soviet Union choices in the 1960s, when every effort was made to boost cotton production, mostly by irrigation. The necessary water was sourced from the Aral Sea's rivers. The Soviet Union's water management had a series of disastrous environmental consequences that impacted the region, particularly the autonomous Republic of Karakalpakistan. Environmental repercussions include a drop in the Aral Sea's volume to less than half its original extent, full ecological degradation, and the virtual extinction of fish. Desertification of vast areas, including the Amu Darya and Syr Darya deltas, is “changing the climate in the region”, and has reduced the Sea's proximity to a lifeless desert [8, 9]. Environmental changes have a direct impact on the population. The lack of fish has virtually ruined the region's once-thriving fishing industry, leaving 60,000 people jobless.

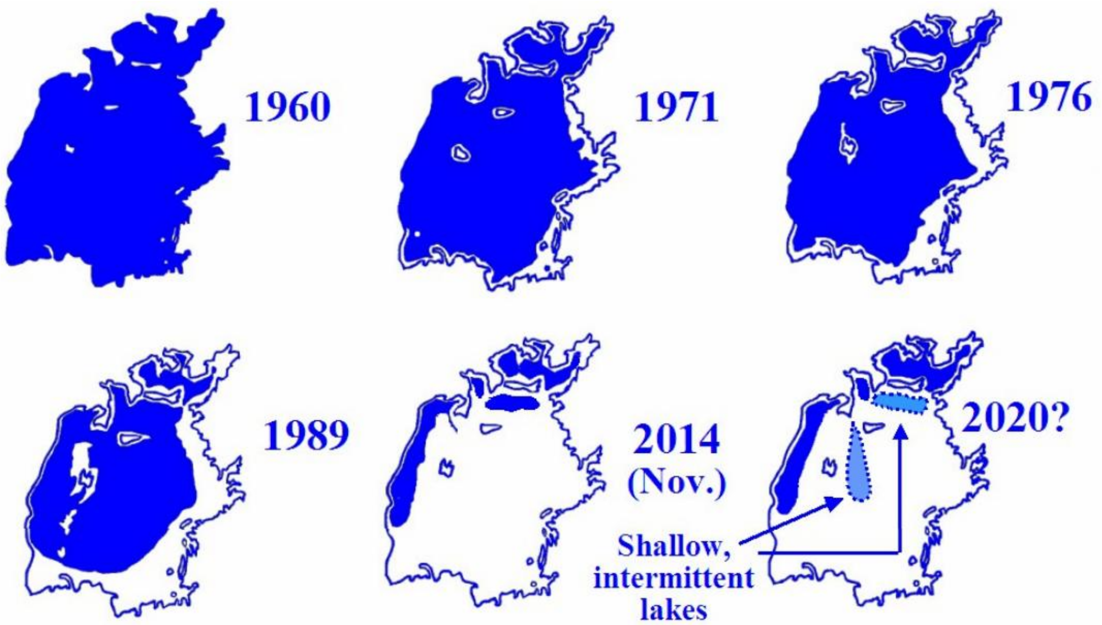

Figure 2. 20th and 21st Century desiccation of the Aral Sea: 1960 – 2020 [10]

The significant loss of inflowing water resulted in massive changes in water level, water chemistry (especially salinity), and the Aral's diversification into a few smaller water bodies (Figure 2). The Small Aral, the Eastern Large Aral, and the Western Large Aral have all emerged as a result of a persistent decline in water level.

Solonchaks and soils with takyric surface horizons are salt-affected soils in the southern Aral Sea basin. Surface crusts are present in both types of soils, which cover an area of more than 1,000,000 hectares. The surface crust of very saline Solonchak soils typically has a significant salt concentration. Takyric crusts, which are characterized as heavy-textured surface horizons of regularly flooded soils, have a reduced salinity, and their production is linked to the development of high sodicity when soluble salts are leached. Salt crusts covering areas of the lake bed that became exposed due to desiccation (about 4,000,000 ha total exposed area) are a third type of surface crust [11].

Environmental shifts in the Aral Sea have led in the extinction of fish stocks that historically provided nourishment and employment to nearby human communities, despite the fact that annual fish captures peaked at 44,000 tons in the 1960s. The current eastern and western Aral basins are hypersaline water bodies that have completely eliminated freshwater, brackish water, and marine fish and invertebrate species. Since the 1960s, changes in the Aral Sea's biotic composition have been closely studied and widely reported in Russian-language periodicals [12].
Environmental circumstances, not isolated toxins, undoubtedly have a significant impact on the health of the residents of the area. Pesticide pollution affects residents of the Syr Darya valley and, most likely, the Amu Darya valley far more than residents of the ancient Aral Sea coastline area. High levels of dibenzofurans and dioxins have been found in their bodies as a result of the use of specific pesticides. In Central Asia, water is a precious resource and possibly the most important economic component. The Aral Sea's problems will not be solved in the near future [13]. Nevertheless, with more water left over in the Amu Darya and the Syr Darya, the Aral Sea's area will grow, even if the Aral Sea will likely not restore its former extent in the next generation.

3. Soil Erosion and Desertification

Soil erosion and desertification are one of the major environmental and agricultural problems in the world. Although erosion and desertification have occurred throughout the history of agriculture, it has intensified in recent years [14]. Wind and water erosion take 75 billion metric tons of soil from the earth each year, the majority of which comes from agricultural land [15]. The loss of soil destroys arable land, rendering it unusable in the long run. Non-sustainable farming methods result in the destruction and abandonment of around 12×10^6 hectares of arable land per year, with only 1.5×10^9 ha of land being cultivated [16, 17]. Because to lost eroding land and the rise of the world population to about 6 billion people, per capita arable land shortages occur in Africa, Asia, and Europe [14, 18].
Soil erosion and desertification in Uzbekistan lead winds to carry salt and dust hundreds of miles, depositing it on cultivated land and in people's lungs. The history of Resurgence Island as a Soviet Defense Ministry test site poses an extra health risk. Lack of job and health-related concerns have prompted people to migrate from the Aral Sea region, uprooting people and increasing population density in other parts of the country, particularly in the capital city.

4. Water Quality: Causes of Contaminated Water

Water supply and quality are major concerns in Uzbekistan. Indeed, the vast majority of the country's streams are moderately or seriously contaminated, posing a serious threat to human health and deteriorating irrigated land. Industry, agriculture, and human settlements are the main sources of pollution. The distribution of critical water supplies has periodically sparked disputes between Uzbekistan and its downstream neighbors as well as upstream states, causing Uzbekistan to drastically reduce commerce and close its borders on occasion [19].
Monoculture of cotton along Uzbekistan's riverbeds, along with intensive irrigation and pesticide use, has resulted in widespread salinity and impurity throughout the country, as well as a significant reduction in biodiversity. Furthermore, large-scale chemical use for cotton production, inadequate drainage, and ineffective irrigation systems are examples of situations that resulted in a high filtering of salinized and contaminated water back into the soil [4-6]. Chemical fertilizers and insecticides were applied at a rate of twenty to twenty-five kilograms per hectare on average in the Central Asian republics in the early 1990s, compared to three kilograms per hectare for the entire Soviet Union. As a result, the fresh water supply has been contaminated further [7, 8]. Uzbekistan's water has also been harmed by industrial pollution [19]. Concentrations of oil and phenol compounds in the Amu Darya have been found to be significantly over acceptable health levels. Uzbekistan has made significant attempts to increase agricultural diversity and change irrigation practices since independence. However, the economic importance of agriculture, along

with a rise in arable land, means that environmental pressure on the ecosystem and the people who live within it will continue.

Pollution of the air has also been caused by poor water management and the widespread use of agricultural pesticides. Salt and dust storms, as well as pesticide and defoliant spraying for the cotton crop, have wreaked havoc on rural air quality.

5. Air Pollution from Industry

Factory and automobile emissions are posing an increasing danger to air quality in metropolitan areas. In Uzbekistan, only around half of industry smokestacks have filtering equipment, and none of them can filter gaseous pollutants. Furthermore, a large number of existing filters are damaged or inoperable. Tashkent, Fergana Valey, and Olmaliq all have air pollution levels that are higher than the permissible amounts of nitrogen dioxide and particulates [20]. Heavy metals like nickel, lead, zinc, copper, mercury, and manganese have been identified at high concentrations in Uzbekistan's atmosphere, owing to the combustion of fossil fuels, garbage, and ferrous and nonferrous industries. Heavy metal concentrations were found in particularly high proportions in Toshkent Province and the southern region of Uzbekistan near the Olmaliq Metallurgy Combine.

6. Municipal Solid Waste Management

Currently, the global growth of municipal solid waste (MSW) has become the biggest problem in developed and developing countries [21-25]. Uzbekistan is considered as the country with the highest population among other Central Asian countries. According to the State Statistics Committee of the Republic of Uzbekistan, the population of Uzbekistan amounted to 33,724,500 people by October 2019. For these reasons, the amount of solid waste generated is much higher compared to other countries in Central Asia.

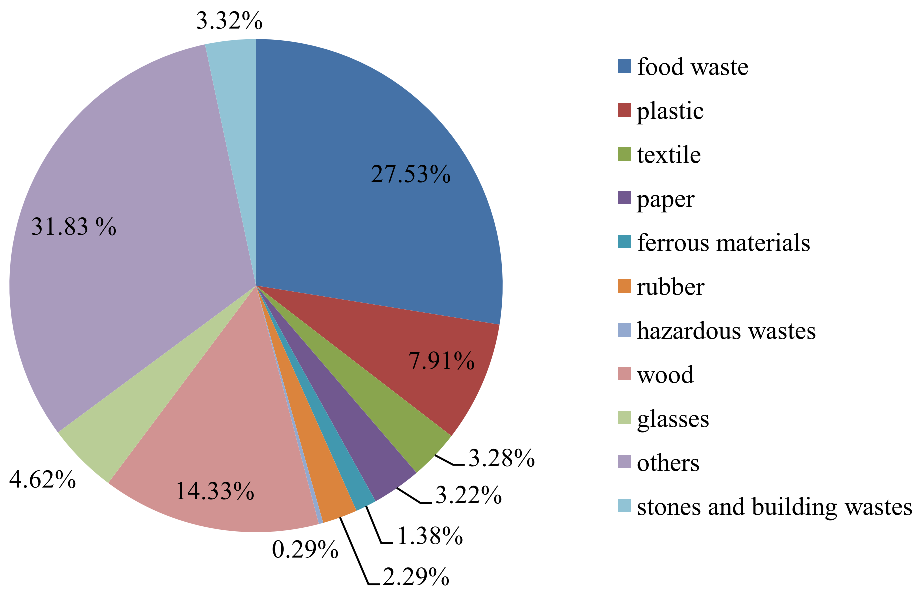

Figure 3. MSW composition in Uzbekistan (2017-2018) [26, 27]

Annually, 35 million cubic meters of household waste and 100 million tons of industrial waste are generated in the republic. Today, 2 billion tons of MSW have accumulated at the landfills [26, 27]. Based

on the results of studies in 2017-2018, Figure 3 shows main composition of MSW in the Republic of Uzbekistan.
According to the State Environmental Protection Committee of the Republic of Uzbekistan, modern clusters were launched in 2017 for a full recycling of solid waste: from garbage collection to its processing. In May 2018, the President of Uzbekistan adopted a resolution "Measures to further improve the system of household waste management" [23, 25]. This document is aimed at improving the sanitary and environmental situation in the republic. To date, 183 enterprises are operating for processing the recyclables extracted from MSW. The total processing capacity of enterprises is 894 thousand tons of recyclables per year, of which: 72 polymer processing enterprises, 65 waste paper processing enterprises, 17 rubber and tire processing plants, 6 cullet processing enterprises, 2 oil and textile processing enterprises, 10 metal processing plants, and 11 processing plants for other recyclables.
Apparently, MSW has a negative impact on the environment and human health, as well as pose a threat to environmental safety and public health. Therefore, as in the whole world, Uzbekistan is facing acute issues of safe disposal of solid waste [23, 25]. The issues of safe disposal of solid waste can be resolved by using appropriate advanced and environmentally friendly methods and technologies, such as energy efficient thermolysis, pyrolysis, and gasification [24, 28-35] in integration with green chemistry, nanotechnology and renewable energy, which can reduce the volume of waste efficiently [36, 37].

7. Application of Laser Bio-Technology for Environmental Protection

According to sustainable development principles, laser biotechnology could be applied in environmental engineering technologies [38]. Laser Stimulation can also be utilized to improve the efficiency of wastewater treatment, soil reclamation, bioremediation capabilities, and the growth of energy and food crops.
Dobrowolski pioneered the use of laser stimulation of various plant species, soil bacteria, and fungi in environmental biotechnology in the late twentieth century for the optimization of bioremediation processes, such as the removal of pollutants from sewage and soil reclamation, as well as the increase of biomass production by plants cultivated in polluted soils. Furthermore, laser stimulation allows for the optimization of natural biological processes through better phenotypic expression and adaptation to various contaminants in the natural environment, including more efficient bioremediation of particular elements [38-40].
Bioremediation of extremely hazardous metals using empirically selected wavelength, energy density, and time of irradiation of coherent light is far more efficient than any other approach of contaminated soil remediation. Even when using similar laser biostimulation algorithms, there are significant variances in the bioremediation of Pb, Cd, and Ni, depending on the genotype irradiated and the photonic structure [41].
Not just for diverse industrial zones, but also for areas with high salt levels in the soil or soils degraded by petrochemical toxins, Laser Biotechnology offers a new perspective on reclamation. Furthermore, laser stimulation causes an increase in plant biomass as well as a greater uptake of specific components from contaminated water and soils. Changes in trace element concentrations in plants were also discovered as a result of using a photostimulation algorithm. Increased biomass production of various land and water plants under suboptimal conditions, such as in contaminated areas, could improve low-carbon energy production and sustainable development. New sources of coherent light can be proposed as a cost-effective and best-available technology for bioremediation, as well as biomass and bio-energy generation [42].
Laser biostimulation of inoculums of specific fungi can also aid in the stimulation of mycorrhizal moulds and the adaption of infected seedling roots to contaminated soil. Proper photostimulation of chosen moulds and bacteria inoculums could help speed up the biodegradation of some organic contaminants in water and soil [43-47].
Adaptation of different species of plants (e.g. reed *Phragmitesaustralis*, duckweed *Lemna minor,* and willow *Salix* sp) and water bacteria to suboptimal environmental conditions (e.g. various chemical,

contaminated soil and water) require additional energy. Empirically selected algorithms of irradiation of the above mentioned biological materials with low energy lasers (as sources of coherent light of high energy density) stimulate some enzymes and physiological processes of adaptation useful for more efficient application of plants for bioremediation of metal contaminated soil and wastewater, as well as for biodegradation of xenobiotic pollutants, like polyaromatic hydrocarbons (PAHs) [43, 46, 47].
As a result, laser stimulation is a new branch of environmental biotechnology in which coherent laser light is used to optimize natural processes such as metal bioaccumulation or xenobiotic bioremediation. Laser stimulation can be used to improve the efficiency of sewage treatment bioprocesses, the reclamation of polluted land, enhanced bioremediation capabilities, and the growth rate and resistance of irradiated plants to contaminants in the air, soil, and water.

8. Conclusions

Environmental and ecological security is of pivotal importance for regional sustainable development. This paper highlighted most critical environmental and ecological issues which Uzbekistan has been encountering since few decades. Biotechnology especially, environmentally clean laser bio-technology was proposed as one of the alternative and an effective key method for solving above mentioned environmental and ecological problems. Laser Biotechnology has tremendous potential for unique, efficient, eco-friendly and economically viable options for a more efficient wastewater treatment processes, soil reclamation, improvement of air quality, increase of bioremediation abilities and increase growth of energetic and food crops. Wide-scale application of laser biotechnology would be definitely useful in environmental engineering technologies, in particular for water and soil remediation, also for more efficient production of biological resources.

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