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Introductory Chapter: Serious Pollution of Soil and Groundwater and the Necessity of Bioremediation

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1. Introduction

Earth has massive amounts of water resources, but drinking water accounts for only 0.01% of the total water. Human beings have taken good care of the use of our precious water resources and had benefitted sufficiently. The limited water resources, however, have reached a critical state. A report published by the United Nations in 2007 suggested that around 1.1 billion people live with serious water shortages and 1.8 million children die every year because they develop various diseases from drinking dirty water [1, 2]. To make matters worse, water shortages have already reached extreme levels for 660 million people living in approximately 30–40 countries. Moreover, the area where drinking water cannot be sufficiently obtained is constantly increasing.

It is estimated that over 60% of people will suffer serious water shortages by 2025. A serious shortage of food resources also occurs because crops cannot be grown in countries where there are water shortages or where water is polluted. The prospect of the eruption of international disputes, or even war, over water sources is also worrying. If the emission of harmful pollutants is not stopped and effective remediation is not performed as soon as possible, the global environment will fall into a terrible situation. As this is the introductory chapter of this book, the author introduces the most recent conditions of pollutants and the causes of pollution. Moreover, the author suggests the ideal bioremediation and phytoremediation processes to apply to large polluted areas.

2. Causes of the shortage of drinking water

One of the causes of the shortage of drinking water is the excessive use of river water. An increase in population caused an increase in industrial activities and food production, and

many large-scale projects that use irrigation water from rivers for agricultural land have been implemented. Moreover, a massive amount of domestic and industrial water has been used by an increasing population and as a result of the rapid development of world economies. The excessive use of water has caused a shortage of river water. In countries located at or near downstream basins, the shortage is especially serious because river water is excessively consumed by the countries located upstream. For example, Egypt is a country where the desert occupies 95% of the land and where the water of the Nile River is the sole water source. Since the countries located in the upstream area of the Nile River excessively consume water and pollutes the river, Egypt is now troubled by serious water shortages [3]. Similar problems have occurred in the countries located at the Indus river basin. In addition to these causes, increases in population and industrial activities have increased the amount of greenhouse gasses that cause global warming, and abnormal weather such as El Nino events occurs more frequently now. Droughts and flooding as a result of abnormal weather make it difficult to stock drinking water.

The deterioration of water quality as well as the amount is another cause of the shortage of drinking water. Living drainage and industrial wastewater that does not receive proper pre-treatment are increasing along with the increase in population. This wastewater is directly poured into rivers and the water quality decreases to inadequate levels and can no longer be used as drinking water [4, 5]. Moreover, excessively used herbicides and exhaust gasses containing various chemical compounds and heavy metals contaminates the soil and groundwater. In countries where the economy is rapidly developing, the deterioration of water quality from these causes is especially serious. Many farm lands are polluted by excessively used fertilizer and herbicides or heavy metals and can no longer be used. Fluorine and arsenic have contaminated the water in tube wells due to soil pollution, and inhabitants that drink from these wells often develop serious cases of poisoning [6, 7]. The typical pollutants are listed in **Table 1**, and the author has introduced each cause more precisely in the next section.

Main poisoning sources	Main chemical compounds	Serious contaminated sites	Remarks on risks to the environment
Acid rain	SO _x and NO _x	Urban places and thermal power stations	Death of fish and aquatic organisms in lakes and acid shock in forests
Insecticides	POPs (BHC, DDT) OPPs (fenitrothion, diazinon)	Agricultural land Agricultural land	Contamination of crops and drinking water, or direct absorption from polluted air
Herbicides	Atrazine, simazine		
Fertilizer	Nitrate nitrogen	Agricultural land	Eutrophication of soil and rivers due to excess nitrate nitrogen
Metalloids	As, F	Urban, mining, and metallurgy sites	Contamination of tube wells
Heavy metals	Pb, Cd, Hg, Cr (IV). etc.		Contamination of crops and drinking water or direct absorption from polluted air

Table 1. Pollution that occurs in widespread areas in developing countries.

3. Pollutants causing serious damage

3.1. Acid rain

One of the pollutants causing serious environmental pollution is acid rain. Sulfur and nitrogen oxides (SO_x and NO_x) are excessively exhausted from factories and cars and acidify rain. In the USA and European countries, in the 1970s, serious acidification of soil and lakes by acid rain occurred in association with economic development. In those days, acid rain at pH 2–3 was recorded in several areas in the United States, and the harmful effects on the ecosystem were observed in the acidification of lakes in European countries. Mg⁺ and Ca²⁺ ions, which are important minerals to build bones, were leached from lakes by acidification. Fish are most sensitive to the loss of those ions, and many species of fish with bending bones or abnormal structures appeared in acidified lakes including Little Rock Lake in Sweden [8]. The investigation conducted on 3821 lakes in Norway, Sweden, and Finland suggested that many species of fish living in those lakes had disappeared due to acidification [9].

Acid rain induced the acidification of soil as well as lakes. Soil particles charge negative under normal conditions and can maintain a sufficient amount of minerals for the growth of plants. However, the acidification of soil promotes the leaching of minerals such as Mg²⁺ and K⁺ from the soil and the accumulation of harmful metal ions in the soil. Furthermore, the acidification of the soil decreases soil microorganisms that degrade sediments and supply the soil with nutrients, and it also decreases microorganisms that assist with the absorption of nutrients and the adjustment to normal pH values. With the decrease of minerals, microorganisms in the soil can finally cause serious damage to plants. Acid shock, the phenomena where all trees in a forest suddenly wither, had unfortunately occurred in several forests in North America and Europe [10, 11].

Once aquatic organisms and fish have died or forests have been lost to acid shock, it takes several decades for it to return to its original state. Therefore, remediation by neutralization is necessary before serious damage occurs. The neutralization of acid with calcium carbonate and calcium hydrate powder is a general and inexpensive procedure [12, 13]. Several projects to neutralize lake water were conducted by spraying the powder from a small ship or helicopter. For instance, 3 million dollars were invested in the neutralization of lakes with calcium carbonate powder in Sweden. Recently, the acidification of lakes and soil has considerably improved in the European Union (EU) and North America due to the efforts to decrease the emission of SO_x and NO_x and the implementation of projects to neutralize lakes.

On the other hand, the problem of acid rain has gradually occurred in countries in Asia, Africa, and South America. For example, Asian countries including China, India, and Vietnam have realized remarkable economic development during the last half century. The development of industry and an increase in the demand for cars and electronics has caused the release of more emissions containing SO_x and NO_x. Huge amounts of dust containing PM 2.5 and photochemical smog often appear in urban areas in China and India [14]. As acid rain continuously falls in those areas and effluent control of SO_x and NO_x by treaties or directives does not function sufficiently, it is difficult to stop or decrease those emissions. Therefore, a

serious condition that is similar to that of Europe and the USA in the 1970s will occur in the near future in those countries. The neutralization of soil and lakes by using microorganisms [15, 16] may be necessary until emissions can be controlled successfully.

3.2. Agricultural chemicals

Pesticides are often used excessively because they generally enhance the productivity of crops. Excess use, however, has harmful effects on the soil. Persistent organic pollutants (POPs) such as dichlorodiphenyltrichloroethane (DDT) and benzene hexachloride (BHC) had been used most frequently as an insecticide in the 1980s. POPs were stable and stayed in the soil for long periods of time [17] and excess use caused the contamination of groundwater and plants. Several studies reported that birds and fish accumulated POPs in their bodies, and milk from cows that ate contaminated straw contained POPs. Thus, the production and use of POPs were banned at the Stockholm Convention on Persistent Organic Pollutants held in 2001, except for its use to kill mosquitoes carrying malaria. Organophosphorus pesticides (OPPs) such as parathion and diazinon were developed as substitutes for POPs. OPPs were thought to be safe because the length of time that they remain in soil was much shorter than that of POPs. However, contamination of drinking water by OPPs was reported in the European Union (EU) in the 2000s. As OPPs inhibit acetylcholine receptors in nervous systems, drinking water containing OPPs may have toxic effects on the nervous system [18]. Thus, the EU banned the use of OPPs, although they are still used in other countries.

The excessive use of herbicides also causes serious soil pollution. The herbicides that are used most frequently are triazine herbicides such as atrazine and simazine which were developed in the 1970s, and have been used in Europe and the United States. However, frogs with deformed fingers were found in a paddy field where atrazine had been used at a high concentration, and it was clarified that they functioned as an endocrine disrupter. Other researchers warned that the decrease of frogs all over the world may be caused by the excessive use of atrazine. Based on these reports, the EU decided on an upper limit for the use of atrazine in fields and the Environment Protection Agency (EPA) in the United States legally regulated the maximum amount (3 ppm) of atrazine in drinking water. However, atrazine and simazine are still widely used outside of the EU and polluted paddy fields are increasing [19, 20].

In order to decrease the harmful effects, insecticides and herbicides were exchanged for low persistence products. Pyrethroid analogs (chrysanthemic acid and pyrethrolone) and nicotine analogs (imidacloprid) were developed to decrease the persistence and toxicity, and they are widely used. Moreover, studies that aimed to decrease the amount of herbicides were also conducted. For example, the Monsanto company developed genetically modified organisms (GMOs) that were resistant to Roundup, which was an herbicide containing glyphosate isopropane as its main component. The amount of Roundup used could be decreased by the use of the GMO, although the decreased amount was much less than expected. Other groups developed insecticides that could attach to leaves more tightly to decrease the necessary amount. Nevertheless, in spite of these efforts to decrease the amount of insecticides and herbicides, farm fields where crops cannot be grown anymore are rapidly increasing, and this is becoming a serious problem in many countries especially in Asia, Africa, and South America

[21–23]. To make matters worse, a huge amount of POP stock produced before the Stockholm Convention on Persistent Organic Pollutants still exist, and POPs are still used in several areas in Asia. According to the assessment of FAO/UNEP/WHO, 1–5 million people have received health damage, and several thousand die every year because of soil pollution [24].

3.3. Harmful metals

Harmful metals are also causing serious pollution on a global scale. For instance, arsenic (As) is found in arsenopyrite, and sulfide minerals composed of ferric and arsenic are widely present in soil. Concentrations of As are 2–23 $\mu\text{g/g}$ in soil and 0.005–0.1 $\mu\text{g/m}^3$ in the air. Until the 1980s, products using As were not frequently found and those concentrations were sufficiently low and adhered to safety levels. However, As production rapidly increased because Ga-As and Se-As semiconductors were widely used in cellphones, personal computers, and other appliances, and the mining industry that had to produce As were rapidly increasing accompanied by the increased demand. As a result, huge amounts of crude ore, sediments, wastewater, and emission gasses containing As contaminated rivers, groundwater, and soil [25, 26]. Serious health damage has occurred in inhabitants living in areas that surround mining industries.

Furthermore, high concentrations of As are observed in groundwater in several Asian countries including Vietnam, Thailand, India, and China [27–29]. Many people in those countries use water in tube wells as drinking water, but high concentrations of As have contaminated these wells. In the guideline of the World Health Organization (WHO), the concentration limit of As to avoid harmful effects is 10 $\mu\text{g/L}$, but the groundwater in those tube wells often exceed 50 $\mu\text{g/L}$. India and Bangladesh are especially troubled by the contamination. Serious groundwater pollution by As in West Bengal prefecture has been reported and approximately 8 million inhabitants in the prefecture are exposed to the risk of arsenic poisoning. The person who noticed arsenic poisoning as a result of drinking groundwater from tube wells in the prefecture had not reported it until 1983, and the data suggested that the concentration of As in groundwater in the tube wells has been gradually increasing after 1983. Arsenopyrite may be melted by the acidification of soil and release As, although the cause of the increase has not been sufficiently elucidated.

Coal fuel is the third most important cause of As pollution. The content of As in coal fuel used at Guizhou in China is 100–9600 ppm; however, the As content in coal fuel is usually 1–10 ppm, and therefore, the inhabitants have developed serious As poisoning. The Chinese government has now banned the mining of such low-quality coal. Demand for coal fuel is increasing and is accompanied by the development of economies in Asia. Poisoning by As is also increasing in countries where coal is the main fuel source. Furthermore, coal fuel causes fluorine poisoning as well as As poisoning. In some areas in Sichuan and Guizhou in China, coal containing very high levels of fluorine (500 mg/kg) is used, and the inhabitants have developed fluorine poisoning. According to the report of the Chinese Ministry of Health in 1997, around 20 million people developed fluorosis caused by the use of coal as a fuel source. Moreover, many people who drank groundwater from tube wells in India also developed fluorosis in addition to arsenic poisoning.

Other forms of health damage are caused by pollution from harmful heavy metals such as lead, cadmium, mercury, and hexavalent chromium [30–34]. For instance, contamination by lead and cadmium has recently become serious. Lead poisoning has historically occurred through the organic lead exhausted from cars using lead gasoline (gasoline containing tetraethyl or tetramethyllead) in the 1970s, but from 1980 to 1990, lead gasoline was banned in many countries and changed to lead-free gasoline. As a result of this policy, the lead concentration in the air decreased to the normal level, and the problem was solved. However, lead poisoning became a problem once again. More than 80% of the lead currently utilized is for lead-acid batteries which are used as car batteries. The production amount of lead-acid batteries is rapidly increasing due to the increased demand for cars. In many metallurgy and mining industries, exhaust gasses and wastewater containing high concentrations of lead are directly exhausted without any pretreatment or with insufficient pretreatment, and low-quality ore and used sludge are left on the soil [35, 36]. Therefore, serious lead poisoning has developed in areas surrounding metallurgy and mining industries. The cause of contamination by cadmium is similar to that of lead. Cadmium is mainly used in Li-Cd batteries for home appliances, and the demand is rapidly increasing. As the recycling ratio of Li-Cd batteries is low (around 20%), cadmium poisoning has been reported in various areas as well as in those surrounding mining industries. Burnt ash and incombustible garbage including waste from electrical and electronic equipment (WEEE), metal plates, and pipes also contain heavy metals [37]. The amount of WEEE is steadily increasing at a rate of 5%, and it was approximately 9 tons in 2005 in the EU [38].

Unfortunately, the Japanese have experienced several tragedies resulting from heavy metal poisoning. A Japanese mining company eliminated cadmium waste into nearby rivers and the inhabitants developed “ouch-ouch disease,” which exhibited symptoms such as dizziness, leg pain, and fragile bones. In another case, a company eliminated waste containing methylmercury into a nearby river and it resulted in a form of neuroparalysis named “Minamata disease.” Recently reported metal contamination of groundwater and rivers in China and India is much worse than the case in Japan. Therefore, we have to pay attention to this problem and perform countermeasures as soon as possible.

4. Countermeasures to remediate pollution occurring on a global scale

4.1. Best countermeasures for eliminating pollution from soil and groundwater

Contamination of soil and groundwater has worsened in countries in Asia, South America, and Africa as described in Section 3, and therefore, those countries have to take effective countermeasures without delay. The best countermeasure to stop the progress of such contamination is to decrease the emission of pollutants with strict legal regulation and treaties.

We can remark on the case of acid rain as a successful model case. In order to improve the problem of acid rain, the Canada-U.S. Air Quality Agreement had decided on the restriction

of SO_x emissions and acted accordingly. As a result, the pH of lakes increased gradually. In the lakes of Killarney Park, the pH value of the lake water increased to nearly 6.0 with the decrease of air pollutants in Sudbury [39], and the acidification of soil in forests such as Boemina Forest and lakes in Europe such as Finishing lake was gradually improved as a result of the decrease in air pollution. Moreover, the convention on Long-range Transboundary Air Pollution (LRTAP) which was attended by 48 countries was conducted in 1983, and the emission of polluted air was more strictly controlled. These efforts had good results in the decrease of damage done by acid rain [40].

We can also remark on the directives of WEEE in the EU as another successful example. The EU has created several countermeasures to solve the problems of increased garbage containing harmful metals. First, the EU promulgated the Directive of End-of-Life Vehicles (ELV) in 2000, which necessitated the recycling of ELV to prevent the illegal dumping of used batteries. Second, the EU promulgated two directives, the WEEE Directives and the RoHS Directive, in 2003. Recycling of WEEE was obligated, and the amount of harmful metals used in WEEE was strictly restricted by those directives. The target products of the RoHS Directives were expanded to approximately 20,000 products by the revised RoHS Directive (RoHS2) in 2011. Countries exporting electric appliances to the EU had to follow these strict directives. As a result of these strict directives, the ratio of recycling of lead-batteries was over 90%, and substitutes without harmful metals such as alkaline batteries, lead-free solders, and lead-free glass have been developed.

In spite of the countermeasures in the EU, 44.7 million tons of WEEE were discarded globally in 2016 and, according to a report by Kokuren University in Japan, this amounts to an increase of 8% from 2013. The total ratio of the recycling of WEEE is only 20%. The result suggests that further efforts to decrease WEEE are necessary in other countries as well as in the EU. Similar directives to that of the EU are promulgated in several countries in Asia. However, it is difficult to keep pace among Asian countries where economies have rapidly developed and emission control is insufficient because the development of the economy is more important than environmental problems. If strict regulation by legal countermeasures is not conducted as soon as possible, there is no doubt that soil and groundwater will fall into a dilapidated state in the near future.

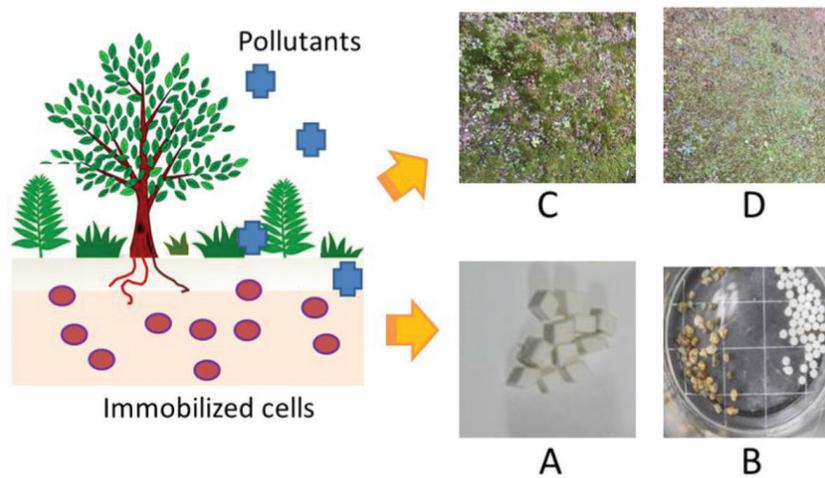
4.2. Best process to remediate the serious pollution of soil and groundwater

Once groundwater and soil have been fatally polluted, several decades are needed for it to recover even if the emission of pollutants can be stopped by strict directives and treaties. Therefore, the remediation of soil and groundwater must be implemented in parallel with efforts to decrease emissions. Various remediation processes such as bioventing, bioremediation with Fenton reactions, and oxygen release compounds (ORC) have been developed, and those conventional processes are successfully applied to contamination spread in a narrow area [41, 42]. However, they are inadequate when pollution has spread in a large area because they are expensive processes. Novel and inexpensive bioremediation processes that can be applied to pollution spread on a global scale must be developed.

An outline of the ideal bioremediation process for contamination of a massive area, which is recommended by the author, is shown in **Figure 1**. In order to realize such a remediation process, the zone where remediation is performed is an important factor. Emission gasses containing various harmful pollutants contaminate the air, fall on the soil as rain, and penetrate the soil surface. This process first causes the accumulation of pollutants in the shallow layer of the soil. Following this process, the polluted zone is gradually expanded to a deeper zone of the soil, and pollutants finally reach the deepest zone where groundwater is present.

At the deeper and deepest zones, the oxygen concentration and the amount of microorganisms are very low, and large-scale equipment and high pressure pumps that supply oxygen and microorganisms are very expensive and are necessary in the remediation process. Therefore, the remediation of pollutants is extremely difficult once pollutants reach the deeper or deepest zones. On the other hand, remediation at the shallow layer of the soil has many advantages [43]. The addition and control of both nutrients and microorganisms to the soil is very

Bioremediation and phytoremediation process of soil



Phytoremediation process of river

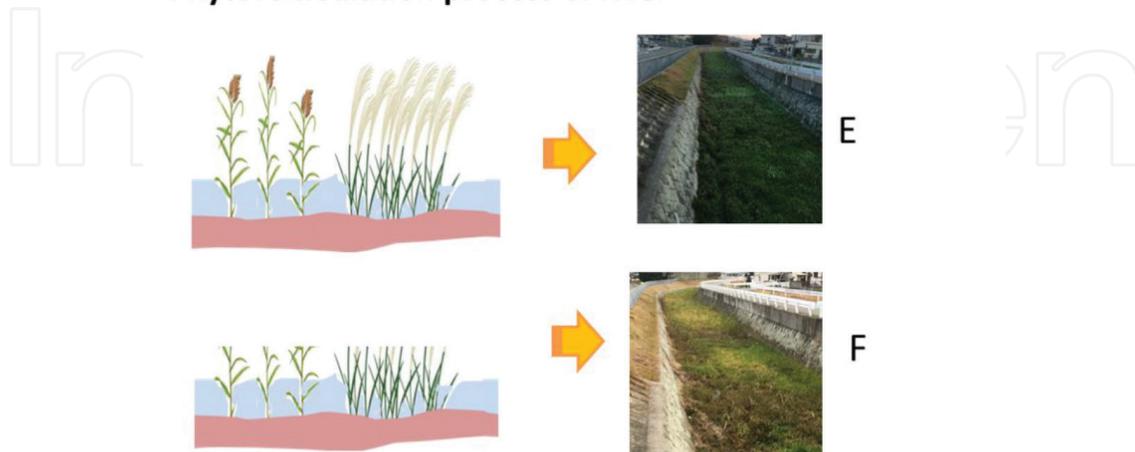


Figure 1. Scheme of the ideal bioremediation and phytoremediation process in soil and rivers. A and B, BSPs and alginate gels immobilizing microorganisms; C and D, mosses and cover grasses (after mowing) covering the soil surface; E and F, plants in a river before and after mowing.

easy at the shallow layer because sufficient oxygen is present in the zone, and nutrients and microorganisms can be supplied by using a normal sprayer. Furthermore, since plant roots that may absorb pollutants cannot reach under several meters of soil, remediation at the shallow layer is absolutely necessary in the case of phytoremediation. These aspects suggest that the removal of the pollutants at the shallow layer of the soil is an absolute requirement in order to realize the ideal remediation process.

As rain transports pollutants to a deeper zone, the retention time of pollutants in the shallow layer of the soil is not long. Therefore, a device is necessary to implement the rapid removal of pollutants within the shallow layer. To realize this, microorganisms showing abilities of degradation and absorption of pollutants must be immobilized at high densities in the shallow layer. Several kinds of immobilization technology can be used for this purpose, and immobilization with alginate gel or κ -carrageenan gel is the general procedure. The advantage of this method is that it can be applied to various kinds of nonfloculent microorganisms. Otherwise, in the case where the microorganisms show characteristics of flocculent or fungi-like shapes, biomass-supported particles (BSPs) (photo A in **Figure 1**) and self-immobilization methods (BSIS) are more useful and inexpensive processes [44–46]. For instance, when *Bacillus subtilis* cells, which secrete a viscous polymer, were self-immobilized by just spraying them onto the soil, the cells were immobilized at high densities and the rapid degradation of herbicides could be realized within the shallow layer. This method can be applied to massive areas because of the simple protocol and inexpensive apparatus. Therefore, self-immobilization methods may be best for the degradation of chemical compounds. However, in the event of the removal of harmful heavy metals, microorganisms must be collected from the soil after the absorption of metals. In such a case, immobilization with alginate gels is more prominent than the self-immobilization method because microorganisms immobilized with alginate gel can be easily collected from the soil using a sieve as shown in photo B in **Figure 1** [30].

If absorption processes can be implemented by covering the surface of the soil as well as at the shallow layer, more prominent remediation processes can be constructed. Mosses may be applied to this process as shown in photo C in **Figure 1**. The advantages of mosses are: (1) they can cover the ground completely without disturbing the flow of rain water, (2) they can grow at a faster rate with little water, and (3) they have advantages in the reuse of metals because they can accumulate metals at high concentrations. In fact, *Scopelophia cataractae* and *Funaria hygrometrica* that are known as hyperaccumulators of metals could accumulate copper and lead at very high levels [47, 48].

Many perennial plants can accumulate metals in their stems and leaves and can reproduce them after the removal of stems and leaves. As pea sprouts can accumulate several heavy metals, it may be one of the desirable plants. Mamenae, the young herbs of pea sprouts, can recover in a week after mowing, and therefore, a continuous adsorption process can be constructed. Moreover, there are many wild grasses known as “ground cover” that are shown in photo D in **Figure 1**. They can cover the ground completely and grow even after mowing. Additionally, they are very strong in harsh climates. Therefore, they may be the best plants to use to realize a continuous process. The plants that can accumulate components in the roots at high levels may also be useful. For example, *Allium cepa* produces onions. If the gene coding adsorbent can be expressed in onions, an inexpensive phytoremediation process can be realized.

In the case of river remediation, another concept is necessary. Once domestic and industrial wastewater containing huge amounts of pollutants is directly discharged into rivers, it is extremely difficult to remove the pollutants. Therefore, the establishment of pretreatment equipment is necessary to remove the pollutants. Many countries, however, cannot afford the cost of waste processing. Inexpensive remediation processes for river pollution must be developed before pollutants deal fatal damage to the living things in the rivers and to the inhabitants near rivers. Plants that can live in rivers may provide effective processes, although it is difficult to realize. Photos E and F in **Figure 1** show the scheme of such a process (this river is not being used for phytoremediation, and therefore, this photo is merely an image for the sake of comprehension). The plants shown in the photos can live in rivers where the depth of the river water is 20–30 cm, and can live after being mowed every 6 months and grow again. These plants can live in rivers for many years. Inexpensive pretreatment processes for river pollution may be realized by using this process.

4.3. Best microorganisms and plants to remediate pollution of soil and groundwater

In order to realize remediation processes for pollution spread on a global scale, it is also important to choose microorganisms and plants with the best capacities. Many microorganisms that are exceptional at degrading or removing pollutants have been discovered. For example, fungi that could neutralize acid by secreting basic compound was discovered [45]. Those fungi may effectively neutralize acidified soil and lakes. Additionally, many microorganisms that show increased abilities to degrade triazine pesticides such as atrazine and organophosphorus herbicides such as diazinon have been discovered, along with many microorganisms that can absorb heavy metals [49–52]. Their degradation pathways or mechanisms of absorption were elucidated, and many genes for degradation have already been cloned. Moreover, many plants that can effectively absorb and accumulate metal ions have been discovered and those plants are known as hyperaccumulators [53, 54]. For example, *Rinorea nicolifera*, which was recently discovered in Western Luzon, Philippines, could accumulate unusually high amounts (18,000 ppm) of nickel [55].

However, in the case of the remediation of a large polluted area, the capacities of those microorganisms and hyperaccumulators are insufficient. The author's rough estimate for lead and nickel suggests that the expenditure of plant growth is much higher than the gains of obtained metal, even if the best hyperaccumulators are used under ideal conditions. Therefore, microorganisms and plants that have even more excellent capacities must be developed. There are several advantages to the use of recombinant microorganisms and plants [56–58]. For instance, the capacity of degradation or absorption per cell in recombinant microorganisms can be enhanced several (or several 10) times, and its amount of expression can be freely controlled by using an adequate promoter.

Another advantage in utilizing recombinant microorganisms and plants is that their capacity for degradation or absorption can be maintained under harsh climates. The activity of microorganisms and the growth of plants are very sensitive to harsh climates, and this is a disadvantage of the biological process. Pollution spread over a large area has mainly occurred under severe climates such as acidic, cold, and dry weather, and this lowers the bioremediation efficiency. Therefore, the addition of the capacity to maintain high activity under harsh

climates by using gene technology is very important. In the case of cold climates where the activity of microorganisms is inhibited, the use of cold-resistant microorganisms may be adequate as a host strain for gene manipulation. Cold shock proteins may also be useful for the activation of microorganisms [59]. In the case of a shortage of rainfall, moisturizing of the soil is necessary in order to prevent fatal damage to microorganisms and plants. Polymers such as poly-glutamic acid, chondroitin, hyaluronic acid, and those microorganisms or polymers that are secreted from animal cells and microorganisms can be used as soil moisturizing agents [60]. Moreover, several plants can grow in dry climates. For instance, an aloe can grow with little water, accumulate huge amounts of moisture components in its leaves, and continuously grow new leaves without withering. Therefore, aloes have become a prominent host plant for gene manipulation.

The combination of microorganisms and plants as well as the enhancement of their capacity is important in the enhancement of effectiveness. Plants and microorganisms help each other live in natural places [61, 62]. For instance, plants grow by photosynthesis and their fallen leaves or withered plants are degraded by soil microorganisms. The degraded products become nutrients for microorganisms and plants. This energy cycling is necessary to realize the remediation process for long periods of time at a high level of performance. Therefore, the best selection and combination is necessary to realize the energy cycle of the coculture of microorganisms and plants at the polluted site. This is important for the construction of an effective process. In the case of the adsorption of harmful metal ions, synergy is especially important. Many microorganisms show high resistance to heavy metals and high abilities of adsorption, but the removal of microorganisms adsorbing metals from the soil is difficult. On the other hand, although the removal of plants absorbing metals from the soil is easy, resistance to heavy metals in plants is lower than that of microorganisms and they cannot absorb pollutants at the deeper zone (lower than 1–2 m in depth). Therefore, a combination of microorganisms and plants makes the remediation process more effective.

The removal efficiency of metal ions can be enhanced further by using the electric method. Recently, microorganisms that can generate a current have been reported [63–66]. Novel electric processes may be constructed by using those microorganisms, although it is not sufficient to utilize them as a power supply. These aspects suggest that synergetic utilization among plants, microorganisms, and chemical reactions are absolutely necessary to construct the best remediation processes. With the exception of the microorganisms listed earlier, there are many microorganisms that show specific characteristics, and they will become the fighting powers in the remediation process. The author expects that a process that will overcome the spread of serious pollution on a global scale will be developed in the near future.

5. Conclusion

In this introductory chapter, the present conditions of soil and groundwater pollution occurring all over the world, and the necessity of bioremediation have been introduced. Pollution in several Asian, African, and South American countries is much more serious than most people image, and there will be a shortage of food and drinking water in the world in the

near future. Strict restrictions by directives or international treaties are the only way to limit and lessen pollution, but the effort is currently insufficient. Therefore, large-scale projects for remediation must be performed in parallel with the effort to stop the emission of pollutants before it results in a fatal condition. Bioremediation and phytoremediation are the most prominent procedures for remediation, but the enhancement of performance is absolutely necessary to fight pollution on a global scale. The author thinks that (1) rapid remediation at the shallow layer of the soil, (2) the use of high-performance recombinant microorganisms that are resistant to harsh climates, and (3) synergy among microorganisms, plants, and chemical reactions that are necessary to realize such a remediation system.

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