Preventive remediation methods minimize soil pollution

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Article Info

Article history:

Received Oct 21, 2022
Revised Nov 19, 2022
Accepted Dec 7, 2022

Keywords:

Products
Reactants
Respiration
Soil response
Toxicity

ABSTRACT

Soil quality is rich in various substances, as well as a rich variety of uses for life, which leads to the potential for pollution. Once soils are polluted, remediation is mitigative and must be carried out, which has been the focus of many studies so far. However, preventive remediation is the focus of the novelty of this study, which aims to prepare predictive methods. This is a literature review of various studies over the last ten years, which are related to soil quality indicators through the respiration process. Based on the soil microbial respiration process platform, which contains various substances, the results of this study found three preventive remediation methods, namely indicators of substance reactants, gas products, and toxicity to microbes. The three methods simply require measuring the parameters of biochemical oxygen demand, and chemical oxygen demand, in addition to specific measurements of carbon dioxide and microbial enumeration. The advantage of the preventive remediation method is the application of soil response indicators to various types and amounts of contaminants. The implementation of preventive remediation is prior to building infrastructure, which is able to predict changes in soil quality through monitoring, thereby minimizing the potential for mitigative remediation.

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1. INTRODUCTION

Among the media of living ecosystems, the soil has the smallest volume but is the richest in the content of abiotic and biotic elements [1]. The deepest soil microbial life detected is about 2 m from the soil surface [2] and varies from place to place. Aquatic biota lives as deep as the water mass profile. Air biotics are detected up to tens of meters above ground level. Meanwhile, the ocean area is about 70% of the earth's surface [3]. The data illustrates that the concentration of soil abiotic and biotic substances are the largest among water and air ecosystem media.

Physically, the soil is a collection of solid particles, which do not move like water and air. These physical properties make the soil not function as a transporter and diluent for a concentration of substances, as does water and air. Consequently, soils rely on the ability of the transformation process of substances at localized sites. When the concentration of soil contaminants exceeds the ability of the soil to treat them, soil pollution occurs. Contaminant control solutions from the source are effective [4]–[6], but it is not sufficient to prevent soil contamination. Insufficient solutions include the growth and development of population activities. The further growth and development of population activity cause a narrowing of the open land area. Therefore, the solution for the remediation of polluted soil in an increasingly limited area needs to be studied.

Remediation itself has so far been understood as a method of restoring polluted soil to its functional use [7]–[9], which is known as mitigative remediation. However, the understanding of remediation can be extended to preventive remediation. Preventive remediation is the restoration treatment of the soil before it was polluted. Preventive remediation indicates the need for predictive methods of soil ability to treat contaminants.

So far, the soil pollution status has been assessed based on the concentration of each contaminant parameter [10], [11], as well as for soil quality parameters. In real conditions, various contaminant parameters and soil quality are incalculable, especially with regard to organic contaminants [12], [13], so the assessment takes a long time and is expensive. Such parametric assessment is to deal with mitigative remediation.

Meanwhile, preventive remediation, where pollution has not occurred, requires predictive methods of soil quality. This shows that there is a methodological gap between mitigative remediation and preventive remediation. This methodological gap becomes the problem formulation of this study, namely the need for methods of measuring soil response to contaminants.

This literature review aims to identify soil response indicators and their potential applications to environmental problems. This is a methodological contribution in the form of soil biotic signals to contaminants. The benefit of this soil response indicator is for the development of application solutions to environmental problems on a wider scale so that mitigative remediation can be minimized. The author proposes a new methodological approach to implement preventive remediation, to maintain soil quality for sustainable use.

2. RESEARCH METHOD

Understanding soil response indicators adopts the definition of ecological indicators from an ecosystem service point of view [14], land management effect [15], and determination criteria [16]. This understanding can be simplified into an indicator of measurable soil quality parameters due to biological processes. The biological process of soil is respiration, and partly photosynthesis if there are autotrophic biota, especially in the soil surface layer. Taking into account environmental applications, such as the disposal of substances and/or waste into the soil, which can reach the groundwater table, the process of soil respiration in (1) [17] becomes the focus of developing this soil response indicator. In anaerobic soil conditions, (2) applies. Anaerobic conditions often occur when the soil is saturated with water.

$$nME + C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + nME \tag{1}$$

$$nME + C_6H_{12}O_6 + H_2O \rightarrow 3CO_2 + 3CH_4 + H_2O + nME \tag{2}$$

In (1) and (2), the reactants and products of nME represent various kinds of contaminants, both organic and inorganic substances, either as a single substance or as mixtures in waste. In real-world practice, changes in soil quality, containing various types and amounts of nME, can be simplified using the following method: i) Reactants indicator through changes in the ratio of biochemical oxygen demand (BOD)/chemical oxygen demand (COD). Fluctuations in soil quality changes can be expressed by fluctuations in the BOD/COD ratio. The more toxic nME to soil microbes, the lower the BOD/COD ratio; ii) Products indicator undergoes gaseous concentration and/or volumetric changes. Fluctuations in changes in soil quality can be expressed by fluctuations in gas concentration and/or volume. The more toxic nME to soil microbes, or the more stable the soil quality, the lower the gas volume; and iii) Toxicity to microbes. Fluctuations in changes in soil quality can be expressed by fluctuations in structural and/or functional changes in microbes.

The three methods need to be accompanied by BOD and COD concentration data to confirm the classification of soil quality as toxic, biodegradable, or stable.

3. RESULTS AND DISCUSSION

The results of this literature study are three indicators of soil response when exposed to environmental pressure and their application in preventive remediation. The results of this literature study are three indicators of soil response when exposed to environmental pressure and their application in preventive remediation. Figure 1 presents a typical tool for measuring the indicators.

The choice of which method to use is adjusted to the intent and purpose of using land as an infrastructure medium. However, in general, the reactant method is suitable for applications at the infrastructure planning stage, for example, the selection of a landfill site for waste disposal. The product method can be applied to the planning stage application in site selection and operational stage as a soil quality monitoring mechanism, for example in tailings disposal sites.

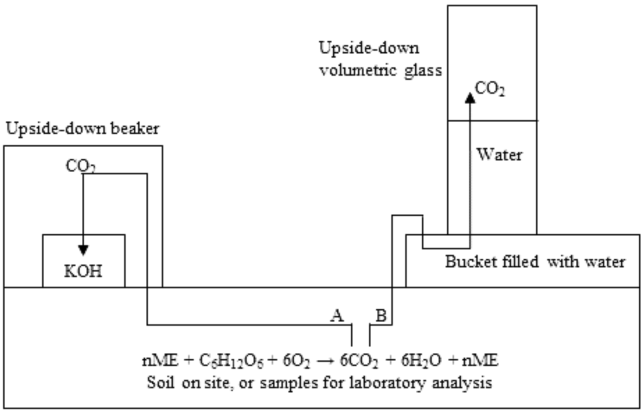

Figure 1. Soil respiration indicator measurement

3.1. Reactants indicator

The process of soil respiration represents the transformation of organic matter $C_6H_{12}O_6$ by soil microbes into gas CO_2. The organic substance is measured as BOD [18]–[22]. Meanwhile, the soil can be exposed to organic substances that are difficult to decompose by microbes (nME), which is measured as COD [23]. Thus, in a soil sample the concentration of COD is measured, part of which is BOD.

Research on liquids has shown changes in the BOD/COD ratio to be a measure of the effect of contaminant toxicity on microbes in response to changes in respiration rate, or gaseous products [24]. The classification of toxic liquids is expressed as a BOD/COD ratio close to 0.1 where each parameter has a concentration of more than 500 mg/L. The stable liquid is expressed as a BOD/COD ratio close to 0.1 where each parameter has a concentration of less than 100 mg/L. The definition of stable quality [25], [26] is the insignificant change in BOD concentration due to the small BOD concentration. Between the two classes is a class of substances that can be decomposed by microbes or called biodegradable.

Soil as a solid can be measured by the content of BOD and COD parameters through the soil solution extraction method [27]–[29]. The method of measuring these two parameters shows an increase in their use in relation to the need for solutions to the problem of soil pollution [30]–[33], and there is a strong correlation between water oxygen demand BOD and sediment SOD [34], [35]. Therefore, changes in the soil BOD/COD ratio can be used as an indicator of soil response. The method of analysis of BOD and COD is the laboratory, and the results are expressed as the concentration of organic substances with units of mg/kg or the like. The BOD/COD ratio is the calculation of the two parameters. The measurement of these parameters can be obtained after 5 days according to the standard method of measurement [36].

3.2. Products indicator

Soil response indicators can also be approached through respiration products [37]–[40]. This method can be carried out by the two methods shown in Figure 1. Method A is chemically by capturing CO_2 into KOH solution, which reacts to produce K_2CO_3 precipitate according to (3) [40]–[42]. Method A can be carried out in the field, and it can be seen that respiration occurs in the presence of a precipitate in a KOH beaker and/or titration measurements to obtain the concentration value of CO_2.

$$KOH + CO_2 \rightarrow KHCO_3 + KOH \rightarrow K_2CO_3 + H_2O \tag{3}$$

Method B is physical with the pressure of CO_2 accumulation in the water column. Method B can be implemented in the field, and the volume of CO_2 is obtained. Under anaerobic soil conditions, the respiration products are CO_2 and CH_4 according to (2).

3.3. Indicators of toxicity to microbes

Measurement of soil BOD/COD ratio can be an indicator of contaminant toxicity for soil microbes. Referring to (1) and (2), the respiration process is carried out by microbes, either in the soil without or with plants in the rhizosphere.

Soil microbial responses to nME exposure are expressed in terms of microbial structural and/or functional changes [43]–[45]. Structural changes include a decrease in biodiversity, and functional changes are death. These changes can be measured through laboratory analysis within 1-3 days of incubation [46].

Based on the functional effects of microbial death, fluctuating changes in soil quality over time at the same place can be predicted using changes in gas volume in Figure 1 method B. When soil microbial death occurs, gas volume decreases or even does not form. Thus, soil microbial activity can be predicted by observing the rise and fall of the volume of gaseous products of respiration. Similarly, this toxicity indicator method can be used to compare soil quality between sites. Soil that has a small volume of gas is more polluted than soil that produces a large gas volume.

3.4. Applied remediation

Preventive remediation methods are applied to the soil bioremediation process. One can assess potential sites for soil contamination, for example, a waste dump. In that place, soil respiration equipment can be provided Figure 1 as a monitoring mechanism to obtain an early warning signal.

With the same application, a designer can place soil respiration apparatus in several places on a building plot. The test site that produces the greatest soil respiration is a potential priority for effluent disposal. This method is in the context of the selection of waste disposal sites.

The method also applies to the phytoremediation process. The use of plants for soil remediation does include the involvement of microbes in the root zone. Root microbial response to contaminant input also influences plant response to contaminants. In this phytoremediation, the maintenance of soil quality is strengthened synergistically by microbes and plants [47]–[49] as a mechanism for biodiversity [50], [51].

In addition to application in an open environment, preventive remediation can be applied to maintain the indoor quality of a building [52]–[54]. Buildings that use decorative plants can simultaneously use the soil in decorative plant pots as an indoor quality monitoring system. Preventive remediation becomes urgent to be implemented starting from the building design stage. The urgency related to indoor use time is approaching 80-90% of the time human presence is in the environment. This is also related to the prevention of sick building syndrome.

4. CONCLUSION

This study proposes the need for preventive remediation to minimize mitigative remediation. Preventive remediation methods were prepared using respiration indicators through reactants of various substances, gaseous products, and toxicity to soil microbes. The three indicator methods can predict the status of soil quality. The classification of soil quality becomes a criterion to explain the fluctuating changes in soil quality over time, and also to become a selection criterion between locations. This preventive remediation can be applied to the solution of environmental problems, from the infrastructure planning stage to operations as a monitoring mechanism. The limitations of preventive remediation can only be applied to bioremediation and phytoremediation because it uses indicators of biological processes. Therefore, preventive methods do not apply to physical and chemical remediation. It is recommended for further research related to acute toxicity in soil biota. The study of acute toxicity of single and mixed substances, as well as soil indicator biota, is a priority for the development of preventive remediation.

ACKNOWLEDGEMENTS

The authors would like to thank Institut Teknologi Sepuluh Nopember, Surabaya, and State Islamic University of Malang, Malang, for providing this research facility.

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