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Methodology for the economic estimation of the environmental damages caused by land, soil and air pollution in Kenya: a review of previously used methods

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Abstract. Environmental compensation is a form of payment for pollution of nature and the environment and the destruction of land, plants or animals. One of the challenges in ensuring waste management in Kenya is how to measure the negative effect of industrial activities and waste on the environment, economy, and human health. Although the amount of compensation should be established on the basis of the environmental-economic assessment of the appropriate environment, it should also be sufficient to implement measures aimed at restoring, reproducing and improving this environment. Kenya has not yet developed a clear legal framework for compensation for environmental damage even through it has a clear and elaborate Environmental Management and Coordination Act for the protection of the environment. Previous studies on the cost of environmental damage in Kenya have successfully used two methodologies: emergency costs and soil, air, and water pollution. This works examines the essence of these methods, as well as the possibility of their application in assessing the cost of damage to the environment as a result of human economic activity.

Keywords: environmental damage, emergy synthesis, environmental costs, pollution

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Методология экономической оценки ущерба окружающей среде, причиненного загрязнением земли, почвы и воздуха в Кении: обзор ранее использованных методов

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Аннотация. Экологическая компенсация – это форма оплаты за загрязнение природы и окружающей среды, а также за уничтожение земли, растений или животных. Одна из проблем управления отходами в Кении заключается в отсутствии единого инструмента измерения негативного влияния промышленной деятельности и отходов на окружающую среду, экономику и здоровье человека. Хотя размер компенсации должен устанавливаться на основании эколого-экономической оценки окружающей среды, он также должен быть достаточным для реализации мер, направленных на восстановление, воспроизводство и улучшение этой среды. Кения еще не разработала четкую правовую основу для компенсации за экологический ущерб, несмотря на наличие подробного закона об управлении окружающей средой и координации для защиты окружающей среды. В предыдущих исследованиях стоимости ущерба окружающей среде в Кении успешно использовались две методологии: затраты на чрезвычайные ситуации и загрязнение почвы, воздуха и воды. В статье рассматривается сущность этих методов, а также возможности их применения при оценке стоимости ущерба окружающей среде в результате хозяйственной деятельности человека.

Ключевые слова: экологический ущерб, производство эксергии, экологические издержки, загрязнение

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Introduction

Sections 78 and 93 of Kenya's environmental legislation provide for air quality standards and prohibit the release of chemicals, hazardous substances and materials or oil into the environment and liability for spills, respectively[1]. These sections provide that a person convicted of a crime must pay the cost of cleaning

[1] Environmental Management and Coordination Act 1999.

up the pollution, as well as any costs that may be incurred by any government agency or the agencies in rehabilitating the environment destroyed or damaged by the released wastes.

The environmental impact is expressed in a number of costs. On the one hand, this is economic damage from a negative impact on the environment, on the other, the cost of preventing pollution or implementing environmental protection actions. From the point of view of rational management of production activities, it is essential, firstly, to determine the optimal ratio of these two types of costs, and, secondly, to rationally take them into account when assessing the efficiency of enterprises. For this, it is necessary to estimate as accurately as possible the quantitative damage caused by the industry to the environment. The economic assessment of enterprises' damage to the environment is carried out based on mathematical modelling methods, generalized indirect estimates, specific damage (calculation for a mono-pollutant), or direct calculation. The practice of calculating the prevented environmental damage is also used to assess the negative impact.

Environmental damage can negatively affect a large number of species, their habitats and ecosystem functions, as well as human consumption or non-consumption values. However, in practice, ecosystems are a rather complex concept, and therefore it can be significantly challenging to understand and calculate the degree of environmental damage. The problem with calculating damage arises in connection with environmental damage, and the benefits of resources or services obtained as a result of remediation activities carried out as a result of damage compensation require specific professional skills from the equivalence analysis team.

Methodology for calculating damage to land resources from environmental pollution

Land valuation is carried out in different ways and is divided into zones depending on the type of use, purpose and distance from settlements or densely populated areas. When calculating the economic assessment of damage that can be caused to land by economic activities, direct damage can be determined by multiplying the area affected by economic activities by the base price of land in the relevant region. To calculate the indirect damage, it is necessary to determine the economic damage from a decrease in livestock productivity as a result of narrowing of pastures and a decrease in the number of crops and vegetables, hay and forage caused by shearing agricultural land area.

Deficiency-related damage. Direct damage includes areas that will be damaged by direct industrial impact, as well as areas covered by roads, paved areas and other industrial facilities. The economic value of land affected by direct scarcity is measured by the value of the lost economic opportunity that should have been obtained if the land in question was used for another purpose (or for its previous purpose).

Pollution-related damage. In general, land pollution can be divided into 5 levels. The concept of an acceptable pollution level means that the soil's chemical content does not exceed the safe exposure level. The five levels of land contamination are: 1) unpolluted; 2) slightly polluted; 3) notably polluted; 4) seriously polluted; 5) dangerously polluted.

Estimating the cost of soil erosion. The value of the soil can be quantified using various methods. The highest estimated cost is based on the market value of replacing free services provided by degraded soils (for example organic additives, fertilizers); some equate the costs of downstream rehabilitation, such as dredging a reservoir, with external costs [1]. Others draw inferences about costs based on the value that consumers place on non-degraded land. Finally, the quantification of environmental services is usually realized through studies to estimate the peoples' willingness to pay for the soil's services [2]. The objective, for each of them, is to estimate the value that can allow comparison with market prices. Previous studies of the cost of environmental damage in Kenya have successfully used two methodologies: emergency costs and soil pollution [3].

Methodology for calculating damage to a land plot using the emergy synthesis process

Emergy is the energy indirectly or directly used to generate a product or service [4]. Since each input to the process is itself a product of energy conversion, the occurrence is usually referred to as energy memory. The units refer to a reference energy source (typically solar energy). The emergent unit is the solar emjoule (sage). This unit indicates that emergence arises from energy flows but is qualitatively different. In particular, emergy considers energy losses (losses of the 2nd law) during the successful conversion of standard (solar) energy into other forms of energy. The available energy after each transformation has properties that qualitatively distinguish it from heat.

In the past, the emergency welding method has been used to estimate soil loss in Kenya (the author refers to the open patch panel by [3]). Their study noted that sharply accelerated soil loss is prevalent throughout Kenya, especially in the western counties where high rural population concentrations, harsh climatic impacts, and delicate soils converge. At the national level, 25 to 180 million tons of soil is lost annually due to erosion [5]. This flow has been quantified to include other aspects of the economic/ecological system for direct comparability, assuming that mitigation investments will be required to understand the problem's magnitude better.

In Kenya, the emergy synthesis has been applied to economic/ecological systems at three scales, that is, starting with the vast scale and gradually localized systems. During the emergy synthesis study, [3] developed The National Assessment to quantify land degradation's significance to the national economy. They also created conditions for smaller assessments for three counties in Kenya's western region.

An unanticipated synthesis of regions, countries, and land uses (all on an annual basis) has been standardized to convey summarized information about the energy base for economic and environmental conditions [6; 7] this standard with five analytical steps [6] for details) was followed by [3] in their study:

1) compilation of transboundary flows, an internal transformation of economic and environment and resource depletion through erosion, deforestation, and mining;

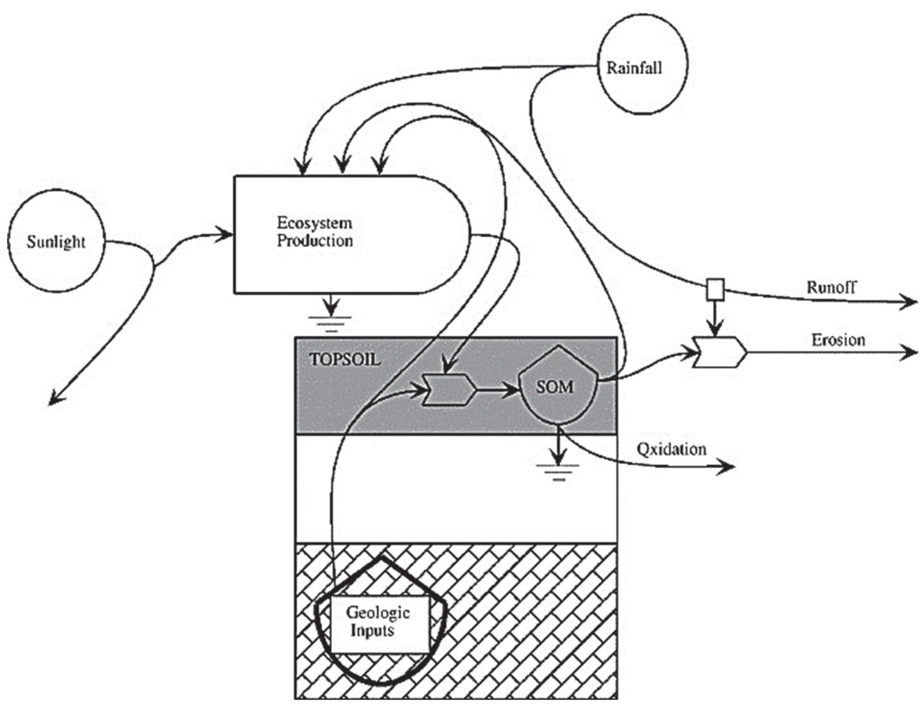
2) data collection – identifying sources of data on transboundary flows and rates of depletion of domestic natural capital;

3) stream aggregation/index development. Composite indices have been developed [7] to capture various aspects of the interaction between environment and economy;

4) system diagram design – use of energy systems language to describe the resource base;

5) tabular valuation – a standard accounting system is applied. Each resource flow is valued in physical units modified by appropriate conversion to adjust the energy quality.

Soil loss indices. The authors of [3] developed two new indicators precisely to quantify the loss of soil natural capital reserves in the context of Kenya's regional energy base. Generally, soil loss is considered a depletion of non-renewable energy reserves. However, grouping these streams with mined minerals and local fossil fuels ignores the direct ecosystem services these reserves contribute. Moreover, while the immediate economic benefits of fuel extraction or mining are clear, the benefits of degraded topsoil are not obvious. In [3] authors assumed that some of these flows can be prevented through more effective land administration policies.



Simplified schematic of topsoil genesis [3]

The first new index balances costs and benefits for agriculture. Soil intensity in agriculture (SIA) compares the yield of crops (livestock and cereals) to the product of eroded soil:

$$\mathrm{SIA} = \frac{Y_{ag}}{N_{0a}},$$

where N_{0a} – erosion; Y_{ag} – the output of income from agriculture.

The second new index links the developing foundations of the regional system to soil loss. The fraction of soil erosion use (FUSE) is expressed as a percentage of total use (U) due to erosion (N_{0a}):

$$\mathrm{FUSE} = \frac{N_{0a}}{U}.$$

Since erosion is an integral part of agricultural yields, the index's minimum is one. Large FUSE values designate high external costs to the economy whereas the values that are close to one imply a very harmful consequence on agriculture. The authors of [3] found out that both SIA and FUSE are independent of other typical regional analysis indices and can be calculated for all countries for which emergy assessments have been made for comparison purposes. Voluntary health insurance should differ significantly within and between regions and farming systems; identifying agricultural and/or livestock activities is not relevant at the local level. Also, to note is that SIA is the inverse of FUSE; this is not the situation on a larger scale, where (*U*) is not only used in agriculture.

Methodology for calculating damage from soil pollution

The correct and practical determination of soil pollution's degree and scale is a rather tricky task requiring a lot of effort, money, and a relatively long time. The damage from soil pollution is the basis for calculating the cost of cleaning or cleaning contaminated soils. Thus, there is a methodology for calculating the damage caused by soil contamination, which is applicable when it was impossible to calculate costs in Kenya directly.

The high content of polluting elements in the soil is not always associated with human activities and can sometimes represent a natural or litho-geochemical anomaly. So, the study of soil pollution should be done by a highly qualified and experienced soil scientist. The quality of work on assessing soil pollution will directly depend on the correctness of sampling, the reliability and accuracy of laboratory test results, the correctness of determining the contaminated site, and the conditions for processing the results.

Methodology for calculating the baseline assessment of soil pollution

When calculating soil pollution's ecological and economic assessment, the economic and environmental evaluation of the corresponding territory's soil is multiplied by the coefficient of soil pollution for each of the pollutants.

$$Esp = Es(Ksp(1)Kspr(1) \dots Ksp(i)Kspr(i),$$

where *Esp* – the basic environmental-economic assessment of soil pollution, Kenyan shilling (KES)/ha; *Es* – the basic ecological and economic assessment of the soil, KES/ha; *Ksp*(i) – the coefficient of soil pollution by each of the pollutants; *Kspr*(i) – pollution factor for each of the pollutants.

Soil pollution factor is calculated in two ways:

1) *calculation based on the degree of soil pollution:* soil pollution factor, *Ksp*(i) is equivalent to exceeding permissible level (2), exceeding threshold value (5) and exceeding dangerous value (10);

2) *calculation by precaution value:*

$$Ksp(i) = 1 + \frac{C(i)}{Cs(i)},$$

where $Ksp(i)$ – coefficient of soil pollution by a pollutant or element; $C(i)$ – the content of the pollutant or element; $Cs(i)$ – is the warning value of a pollutant or element.

Pollution factor. Since the adverse effects of different pollutants and elements are very different, there is a requirement to use a pollution rate correction factor, which depends on the contaminants and elements' specific properties.

Pollution factor, *Kspr*(*i*)

Parameter	Coefficient, *Kspr*(*i*)
Arsenic (As)	3
Benz-(a)-pyren	3
Boron (B)	1
Cadmium (Cd)	2
Chrome	2
Circular-structured scented hydrocarbons (CSSH)	3
Cobalt (Co)	1
Copper (Cu)	1
Cyanide (CN)	3
Dioxin/Furan (PCDD/F)	4
Fluorine (F)	1
Lead (Pb)	2
Mercury (Hg)	3
Molybdenum (Mo)	1
Nickel (Ni)	1
Petroleum products	3
Phenol	2
Polychloridebiphenols (PCBs)	2
Selenium (Se)	1
Six-valence chrome (Cr6+)	2
Strontium (Sr)	1
Vanadium (V)	1
Zinc (Zn)	1

Calculation of the total damage to the environment from soil pollution. After determining the area of contaminated soil, and the depth of contamination, the total volume of contaminated soil could be determined. Besides, the volume of contaminated soil can also be expressed in terms of weight. The total environmental damage from soil pollution is calculated as follows:

$$X_{\text{Total}} = E_{sp} V_p K_t K_h 10^{-4},$$

where X_{Total} – total damage from soil pollution by chemical substances, KES; E_{sp} – the basic ecological and economic assessment of soil pollution, KES/ha; V_p – c ontaminated area covered with soil, m^2; K_t – calculation factor depending on the period of restoration of contaminated soil; K_h – calculated coefficient depending on the depth of soil contamination; 10^{-4} – factor for converting hectare to m^2;

$$K_t = 2.8228\ln(t) - 0.2318;\ K_h = 0.0052h + 0.9634,$$

where t – the period of recovery of contaminated soil by years; h – depth of soil contamination, hence

$$X_{\text{Total}} = E_{sp}V_p(2.8328\ln(t) - 0.2318)(0.0052h + 0.9634 \times 10^{-4}).$$

Methodology for calculating damage from water pollution

The damage caused by pollution of surface waters depends on the composition, content and virulence of pollutants, both directly and indirectly entering surface waters. Loss of environmental property is here defined as the damages and denotes a decrease in the value of the environment, including groundwater, surface water and sediment. Emissions of pollutants from the accident deteriorate water quality and reduce the value of surface waters.

$$L_{EP} = C_{SW} + C_{SO} + C_{GW},$$

where L_{EP} – loss of environmental property (KES); C_{SW} – cost of removing pollutants from surface water (KES); C_{GW} – cost of removing pollutants from groundwater (KES); C_{SO} – sludge removal cost (KES).

Since the volume of contaminated groundwater is usually not available, the volumetric coefficient of contaminated surface water was used to estimate this parameter, which can be easily calculated by summing the diffusion spread of pollutants. According to [8] a 1: 1 ratio is considered moderate. Removal of environmental pollutants can also be done by contacting appropriate environmental remediation consulting companies.

Methodology for calculating damage from air pollution

The damage caused to the environment by toxic substances released into the ambient air is calculated using the formula below. The amount of waste is also taken into account here:

$$X_{\text{Total}} = T_e \sigma f M K_1 K_2,$$

where X_{Total} – damage to the environment from emissions of toxic substances into the atmosphere (thousand KES/year); T_e – damage from 1 (one) standard ton of pollutant emissions into the atmosphere, KES/standard ton (measured by the amount of compensation to be paid for air pollution); σ – index of the relative hazard of air pollution in the pollution zone (depends on local characteristics); F – is a correction factor reflecting the air solubility of a mixture of substances emitted into the ambient air; M – is the recalculated annual amount of toxic waste emitted to the atmosphere from the waste source, standard tons/year; K_1, K_2 – coefficients reflecting the source of waste and the height of waste discharge respectively.

Conclusion

The system for assessing the impact of production activities on the environment should be aimed at solving the problem of the transition of mining enterprises to modern technologies for the extraction and processing of mineral raw materials that ensure a minimum negative impact on the environment. These tasks cannot be solved without a quantitative monetary assessment of enterprises' damage to the environment. The performance indicators of companies should be adjusted, taking into account environmental factors. When making investment decisions, it is necessary to assess the negative impact on the environment and calculate the prevented damage when implementing ecological investments.

Thus, when the factor of negative impact on the environment is included in the assessment of enterprises' actions, it is necessary to consider the decrease in payments for the negative impact, which is carried out by the method of generalized indirect assessments. The method of specific damage allows to assess the prevented damage, and the method of direct calculation – to include factors of negative impact in the analysis of business profitability.

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