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Diffuse Contamination; Generalities and Impact in the Colombian Context

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Abstract: Nowadays, soils are polluted by different agents, causing serious problems for the population. Among the different polluting agents, there are those of diffuse origin that by their nature are difficult to treat. Pursuant with the foregoing, the communities are exposed to different problems including those related to salubrity which makes it essential to monitor the way these agents act on the ground, taking into consideration the anthropic activities. This study outlines a mediation route that contextualizes this pollution phenomenon in the world and then appropriates it to the Colombian context, specifically to a case study where in turn, it is aimed at quantifying the impact produced by diffuse pollution, thus, obtaining a new indicator called the Resilience Indicator which with Fuzzy Logic techniques, enables support for making correct decisions.

INTRODUCTION

Diffuse pollution is defined as the discharge (continuous or intermittent) of pollutants into a surface body of water or underground water, via. indirect ways and from non-point sources which are not possible to identify and locate accurately, or whoever is responsible (Table 1)[1, 2]. Typically, in most countries, agricultural practices are considered the main sources of diffuse pollution[3].

Table 1 shows the human activities that contribute to diffuse pollution and the pollutants released. The impacts are caused by: surface runoff derived from precipitation in cultivated areas, drains that transport leached substances, excess irrigation fluids (salts, nutrients and pesticides), wastewater discharges (domestic, industrial and commercial), illegal discharge of polluted water, urban runoff from rooftops, streets, parking places, overload in sewage treatment plants (WWTP) that receive water from the sewage network, runoff from mines, quarries and wells, sediment dispersal contaminated and, finally, contamination by hazardous waste that is disposed of through underground discharges[4].

Table 1: Sources of diffuse pollution and discharged pollutants

Exercise	Contaminants
Farming	Phosphorus, nitrogen, metals,
Feedlots	pathogens, sediments, pesticides,
Irrigation	salt, BOD1, trace elements
Culture	(e.g., selenium)
Pastures	
Ieche production farms	
Orchards	
Aquaculture	

Food and Agriculture Organization of the United Nations (FAO), based on International Joint Commission, 1974 and other sources

Diffuse pollution from agriculture has been recognized as an important environmental problem that generates cumulative effects over long periods of time at the local, basin, regional, national, international and even global scales[5, 6]. It is influenced by many factors, such as climate, hydrology, land use and tillage management. But the change in land use is one of the most dominant factors and affects the transport characteristics of substances[7]. In general, cultivated areas are sources of diffuse pollution and grasslands, forests and wetlands serve as sinks for nutrients which then enter water bodies as runoff[4, 7].

With the development of intensive agriculture and the adoption of modern agricultural techniques, the problems caused by diffuse agricultural pollution are bound to increase[8]. This means that countries with the largest areas dedicated to agriculture and livestock will have a greater risk of generating diffuse pollution[1]. This pollution not only depends on human actions but also about the fragility of the surrounding ecosystems, the proximity to aquifer recharge areas, the risk of soil erosion and the easy access of runoff to surface waters.

Although, nutrients can promote crop growth and improve soil fertility, excessive inputs of nutrients can lead to increases in the concentration of dissolved nutrients (nitrogen and phosphorus) in surface waters which accelerate eutrophication and degradation processes in water quality[2, 3, 9]. The mobilization of these pollutants depends on several factors such as the topography of the slope, the relief, the infiltration capacity (texture and structure of the soil), the intensity and duration of the rains and the type of aquifers (free or confined)[7].

Soil properties are closely related to diffuse pollution and nutrient transport[9]. The depth of the soil in terms of organic matter and the hydraulic conductivity, give a signal of the water storage capacity in the soil and greater propensity for runoff[3, 9].

All the impacts caused by diffuse pollution are a major problem that threatens the health and resistance of socio-ecological systems[1, 4, 10]. Ecosystems are degraded, the abundance of species is affected, there is loss of biodiversity, changes in the composition of the community occur, there is direct loss of sensitive habitats and deterioration of ecosystem goods and services[5, 11, 12].

MATERIALS AND METHODS

Diffuse pollution sources are characterized by not being measured and monitored (FAO). For this reason, to minimize and eliminate diffuse contamination, environmental quality standards, control and sanction procedures must be formulated in the affected areas. In other words, adopt codes of good practices that provide enough information for each agricultural or forestry producer to prevent them.

Huang *et al*.[9], carried out an analysis of the spatio-temporal distribution of diffuse pollution in agricultural regions, to understand the distribution of Nitrogen (N) and Phosphorus (P) and the effects on the eutrophication of rivers, lakes and estuaries. The modeling was done with the SWAT tool (Soil and Water Assessment Tool) which is commonly used for scenarios with conditions of land use and soil properties at the scale of hydrographic basins, to determine combined and independent effects. This type of analysis is important for the sustainable management of water resources.

Turunen *et al*.[12], compared the effects of diffuse pollution and the alteration of hydromorphology in a stretch of the river. The results showed that diffuse pollution causes more damage to habitat and biodiversity than hydromorphological alteration. The four groups of organisms studied (diatoms, macrophytes, macroinvertebrates and fish) were impacted by the increase of fine sediments, nutrients and temperature. After the classification of sites impacted by diffuse pollution, restoration zones of the habitat structure were identified to improve the ecological condition of the boreal streams.

In the UK, diffuse pollution has also been a relevant environmental and political challenge. Collins *et al*.[13], developed a platform aimed at the agriculture sector for the monitoring of pollutant emissions, through the implementation of control measures to reduce diffuse pollution. The platform has a combination of models to simulate sediment, phosphorus and nitrate and ammonia, methane and nitrogen emissions in water and gas emissions in the air where future scenarios of the movement of pollutants can be predicted simultaneously.

Likewise, it is proposed that farmers should be key agents for environmental solutions to protect and improve ecosystem goods and services (biodiversity, water and air quality). However, the transfer of innovation from science to the farmer has been criticized in the context of farmer's ability to generate their own knowledge and action plans to combat diffuse pollution; therefore, voluntary action is necessary on the part of farmers in the context of environmental regulation and government subsidies[10, 13].

Thomas *et al*.[3], identified areas of critical diffuse pollution sources in agricultural watersheds where there was a greater probability of surface runoff and transport of pollutants. Cartographic field trips were carried out in which vulnerable points were identified where diffuse pollutants could be transported between fields or delivered to the open drainage network, respectively. These identified areas would in the future be subject to mitigation measures and best management practices that reduce diffuse pollution. For example, riparian buffer measures (sediment and nutrient traps, sustainable urban drainage systems, artificial wetlands, permeable reagent interceptors, modification of open ditches) that are designed to prevent surface runoff and reduce the delivery of pollutants. The use of buffers next to bodies of water may offer a greater opportunity, both to protect the water and to conserve the habitat[11].

Ouyang *et al*.[7], analyzed the sediment cores of two rivers in a small agricultural basin in China. The cores reflect a history of diffuse contamination due to the accumulation of pollutants over time. Sediment plays a stable indicator for the loading and transport of pollutants such as nutrients. Understanding diffuse pollution loads and sediment pollution in an agricultural watershed can provide information on water quality management.

The Soil and Water Assessment Tool (SWAT) was used to assess diffuse pollution problems at different scales and environmental situations. SWAT simulates watershed nitrogen and phosphorous loads and has been applied to watersheds around the world for the past several decades. It was confirmed that the characteristics of vertical variation of nitrogen and phosphorus in sediments are related to the expansion and intensification of agriculture in some hydrographic basins[7].

Agricultural diffuse pollution is an especially serious problem for water quality management in China[7]. Water resources have been affected by excessive applications of inorganic fertilizers and pesticides. But it is much more serious in the northern region as groundwater quality is deteriorating due to high nitrate concentrations[14].

Zhang *et al*.[5], carried out the modeling of multiple pollutants (Water: nitrate, phosphorus and sediment in water. Air: ammonia, methane and nitrous oxide) in England and Wales to characterize the annual losses of pollutants and thus design mitigation options. Some mitigation measures were the following:

- Efficient nitrogen use plants
- Calibration of the fertilizer spreader
- Use a fertilizer recommendation system
- Integrate compost and manure nutrient supply
- Do not apply manufactured fertilizer in high risk areas
- Avoid spreading manufactured fertilizers to fields in times of high risk
- Use nitrification inhibitors

Derksen *et al*.[15] reported that diffuse contamination can also occur from pharmaceutical products. These products are widely used in the human health sector and in animal husbandry and are excreted through faeces and urine and end up in the aquatic environment by discharge to the wastewater by surface runoff and by leaching through the ground. There are several risks to which aquatic organisms are exposed such as ecotoxicological effects that can be evidenced by biological toxicity tests and the development of resistance of some microorganisms.

In India, there is great concern about sources of agricultural diffuse pollution because agriculture and rural activities remain dominant. Surface washing of pollutants from agricultural sources becomes the important factor during flood flows, application of chemical fertilizers and pesticides and other agricultural chemicals[8].

Panagopoulos[16], performed a modeling to predict Nitrogen Nitrates ($N\text{-}NO_3$) and Total Phosphorus losses (TP) in each of the agricultural Hydrological Response Units. It was observed that eutrophication phenomena were evident in a reservoir and estuary and that the prediction of nutrients was important for the protection of a habitat of species that are in danger of extinction.

Chiew and McMahon[17] presented the estimation of long-term runoff and diffuse pollution loads in urban areas. Local data, runoff models and water quality data published in the literature can be used to estimate the likely range of diffuse pollution load generated by a basin. However, water quality characteristics and concentrations can vary considerably between basins. In conclusion, runoff volumes and pollution loads increase considerably when a basin is urbanized[17, 18].

Therefore, population growth and increased agricultural productivity in many developing countries are, to some extent, counterproductive to the natural environment. The growth of megacities in developing countries represents a massive problem of diffuse pollution that, to a certain point, can be attributed to the failure of rural agriculture to feed and economically sustain the urban and rural population[16, 18].

Stevens and Quinton[19] investigated diffuse pollution mitigation options applied in combinable cropping systems. The measures studied were waste management, no-tillage, riparian buffer zones, contour grass strips and constructed wetlands and a wide range of atmospheric and water pollutants were considered as nitrogen, phosphorus, carbon and sulfur. Legume species in particular offer the advantage of fixing atmospheric nitrogen in the soil and potentially providing additional nitrogen for the next crop. The research concludes that there is no single mitigation option that will reduce all pollutants.

Puttock *et al*.[20], studied the activities of the North American beaver (Castor canadensis), in agricultural landscapes of the lowlands of the United Kingdom and other places in Europe where cases of diffuse contamination occur. This species can profoundly alter the structure and function of the ecosystem when they carry out the construction of dams. These actions have a great impact on the regulation of nutrients on the management of water resources, on the flow regimes and water quality. With the monitoring of nutrient concentrations in the water inlet and outlet, it is suggested that the role of beavers plays an important function in the provision of ecosystem services in addition to reducing the flow velocity, maintaining base flows.

In developed countries, mechanisms have been designed to control non-point discharges; apply a combination of different types of instruments to productive practices; that the tools are related to environmental conditions, that they can be enforced and that they are capable of being monitored in time and space. Economic incentives (taxes and subsidies) on inputs and products and regulations on inputs and processes have also been proposed[1, 10].

Agricultural practices must be oriented towards more sustainable forms of land and water use; but this is a great challenge because producers are generally not willing to change their practices unless they gain some economic advantage. The integrated management approach of aquatic ecosystems and their corresponding basins must go beyond the uses that are given to water, to include ecosystem restoration and land use planning throughout the basin[1].

RESULTS

In Colombia, the following studies related to diffuse pollution have been carried out:

In the páramo of the Guavio region (Cundinamarca), diffuse contamination is one of the factors that limits the transition towards an ecological management in livestock agriculture. Because there is a general lack of protection of the environment, due to the harmful chemicals used such as genes from Genetically Modified Organisms (GMOs). Diffuse pollution is caused by chemical treatments in neighboring conventional farmer's fields or by other more or less close economic activities such as industry. Air and water serve as vehicles for contaminants that appear later. This causes a significant loss of income for the organic producer.

Perez *et al*.[21] analyzed water pollution by diffuse sources in the sugarcane industry for this they analyzed the investigations carried out in the last 53 years on the Cauca River. The presence and concentration of nutrients in the Cauca River is due to anthropic sources precisely from agricultural runoff waters with a high presence of Nitrogen and Phosphorus, fundamental components of fertilizers and fertilizers, showing that this body of water is not a source of water. Clean according to the Trophic Contamination Index (ICOTRO). Diffuse pollution becomes an important factor impacting the health of the inhabitants who use water for human consumption from the Cauca River or its tributaries[22].

The country faces a great challenge from the environmental authorities to implement policies of Integral Management of Water Resources (IWRM) and promote in farmers strategies that allow reducing their extension and magnitude such as efficiencies in irrigation systems, lining of channels, implementation of sprinkler and drip systems and even the change of crops. In addition to detailed studies of pollutants such as agrochemicals and heavy metals[21].

In the Vieja River, high values of *E. coli* have been found in streams influenced by pastures. This information supports the idea that livestock systems generate significant diffuse pollution and that protected riparian zones contribute to reducing the entry of these pollutants into water sources[23].

In the RAMSAR la Cocha wetland (Nariño), diffuse pollution is caused by activities from agriculture 4% and livestock 11% where potato planting and the presence of cattle and minor species such as pigs, contribute to increase the processes of alteration of the natural conditions of the ecosystem[24].

The MolinosVillamaría River (Caldas, Colombia), requires to be subjected to studies that evaluate the diffuse contamination of avermectins in the soil, in order to establish sustainable strategies for the application of livestock waste. The avermectins (ivermectin, abamectin and doramectin) are veterinary drugs and emerging contaminants, widely used as antiparasitics due to their wide spectrum of activity against ecto and endoparasites and their high efficacy. They are highly insoluble in water and are mainly excreted in unmetabolized feces. In general, the soil is the first affected when slurry contaminated with drugs of these characteristics are deposited on the soil. Faeces contaminated with avermectin residues have negative effects on invertebrate animals that inhabit the soil and therefore affect, The Biodiversity. In addition, the dynamics of the soil can cause these pollutants to be dispersed through it to other systems such as groundwater and aquifers[14].

DISCUSSION

In Colombia, the following studies related to diffuse pollution have been carried out:

In the paramo of the region of El Guavio (Cundinamarca), diffuse contamination is one of the factors that limits the transition towards an ecological management in livestock agriculture because there is a general lack of protection of the environment due to the harmful chemicals used, such as Genes from Genetically Modified Organisms (GMOs). Diffuse pollution is caused by chemical treatments in neighboring conventional farmer's fields or by other, more or less close, economic activities such as industry. Air and water serve as vehicles for pollutants that appear later. This causes a significant loss of income for the organic producer[25, 26].

Perez *et al*.[21] analyzed water pollution by diffuse sources in the sugarcane industry and for this purpose they analyzed the investigations carried out in the last 53 years on the Cauca River. The presence and concentration of nutrients in the Cauca River is due to anthropic sources precisely from agricultural runoff waters with a high presence of Nitrogen and Phosphorus, fundamental components of fertilizers and fertilizers, showing that this body of water is not a source of clean water, according to the Trophic Contamination Index (ICOTRO). Diffuse pollution becomes an important factor affecting the health of the inhabitants who use water for human consumption from the Cauca River or its tributaries.

The country has a great challenge, from the environmental authorities to implement policies of Integral Management of Water Resources (IWRM) and to promote in farmers strategies that allow reducing its extension and magnitude such as efficiencies in irrigation systems, canal lining, implementation of sprinkler and drip systems and even the change of crops. In addition to detailed studies of pollutants such as agrochemicals and heavy metals[21].

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On the other hand, evaluating the impact of diffuse pollution and better still, quantifying said impact is not an easy task, therefore, using fuzzy logic rules, several factors are involved that finally yield a numerical weighting called the resilience indicator. This indicator reflects the capacity of the soil to adapt or resist diffuse pollution according to a scale defined by the author and experts through the Delphi methodology which integrate two macroeconomic variables (Gross Domestic Product and population growth rate) and a variable called the vulnerability indicator, calculated from a model called IVAFIC[24] and that determines the impact factor of the soil against various anthropic activities that generate this kind of diffuse pollution (Fig. 1).

The results obtained in a case study such as that of the municipality of Pauna, in Boyacá, Colombia, allow us to estimate a vulnerability index of -3.69 which according to the scale defined[24, 14, 28], must be understood as reversible medium negative impact (Fig. 2). The data for the Gross Domestic Product population growth rate has been taken from historical values of the study area[26].

Now, by integrating these three factors, using various membership functions typical of the Fuzzy Logic model, a final value can be calculated which as we have mentioned, has been called the Resilience Indicator (IR) which, in this case, yields a value 0.275 on a scale ranging from 0-0.5. The IR obtained allows us to infer that the soil

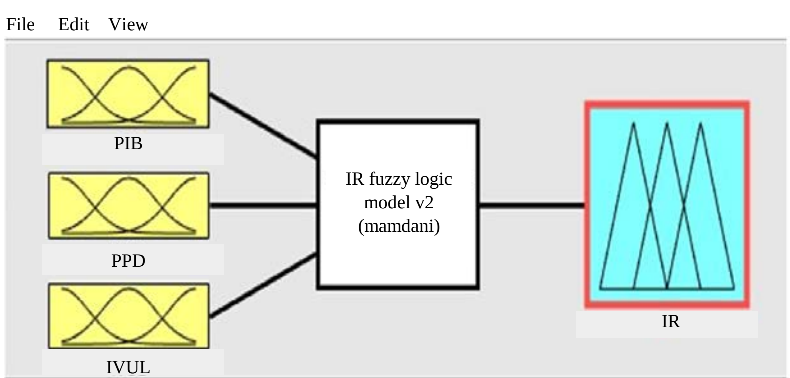

Fig. 1: Modeling scenarios

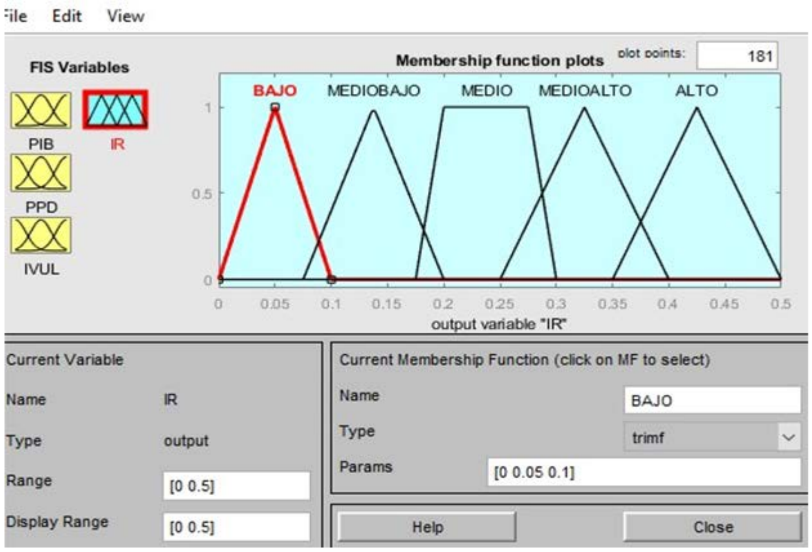

Fig. 2: Parameters of population growth rate

Fig. 3: The conditions of adaptability to diffuse pollutants

in the study area is just above an average state which means that the conditions of adaptability to diffuse pollutants are moderately sustainable and that clear policies should be defined that enable better anthropic practices that tend to reduce the level of impact, ensuring better health conditions throughout the area (Fig. 3).

CONCLUSION

Diffuse pollution is a current problem which prevails mainly in undeveloped countries where livestock and agricultural activities are carried out. Although, several researchers are carrying out modeling, pollutant monitoring and mitigation alternatives, there are still a series of barriers to diminish it as well as the voluntary acceptance of farmers to implement pollution reduction measures, lack of responsibility towards water and air pollution, resistance to recognition of the diffuse contamination problem, costs and practicality of measures, lack of clear and consistent guidance for farmers and lack of solid evidence on the effectiveness of alternative or improved practices[13].

The Resilience Indicator (IR) is a support instrument for decision-making by the environmental authority to the extent that this IR allows identifying micro zones according to the degree of affectation and thus adequately distribute the efforts to solve this kind of problems caused by diffuse pollution.

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