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Analysing the Environmental, Health and Economic Impacts of Acid Rain in the Niger Delta Region

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Abstract

The study analysed the environmental, health and economic impacts of acid rain in the Niger Delta Region. Survey research method was applied for the study whereby 400 copies of questionnaire were administered to the residents of the selected localities within the Niger Delta Region and 396 copies were retrieved and used for further studies. Descriptive statistics were applied for the data analysis. Results showed that males were 53% and females were 47% and majority (76.9%) were largely young and middle aged adults while all respondents were educated, although with different levels. Findings also revealed that 80.9% agreed that acid rain has led to reduction of soil fertility and agricultural productivity while 78.3% agree that acid rain contaminates surface and groundwater sources reflecting growing concern over the declining quality of drinking and domestic water. Furthermore, findings showed that the highest-rated impact is the increase in respiratory diseases such as asthma and bronchitis (80.8%) while economically, acid rain has caused damages to roofs, houses, and infrastructure, leading to high maintenance costs (69.7%) and reduction of farmland productivity and cash crop yield (67.7%). The study concluded that acid rain has led to environmental degradation which undermines livelihoods, and contributes to economic hardship in the Niger Delta. It is thus recommended among others that a comprehensive environmental health policy should be developed to address acid rain–related risks. In addition, government and oil companies should invest in public awareness campaigns, medical screening, and infrastructural resilience programs.

Keywords: Environmental impacts, Health impacts, Economic impacts, Soil fertility, Infrastructure, Livelihoods

Introduction

One of the most serious environmental problems caused by air pollution is the production of acid rain. From the earliest days of civilization, humans have exploited the planet's many resources (Mamta, 2016). Acidification of rain-water is identified as one of the most serious environmental problems of transboundary nature. Acid rain is mainly a mixture of sulphuric and nitric acids depending upon the relative quantities of oxides of sulphur and nitrogen emissions (Kumar, 2017). Due to the interaction of these acids with other constituents of the atmosphere, protons are released causing increase in the soil acidity. They have constructed facilities to take advantage of various forms of energy on Earth to make their lives easier (Kumar, 2017). The majority of today's electricity comes from power plants that burn fossil fuels like coal, oil, and natural gas. While this kind of development undoubtedly makes our lives easier, it also leads in pollution due to the discharge of harmful substances into the environment (Goselle, 2021). Air pollution has increased due to the increased release of gaseous and particle pollutants into the atmosphere from the combustion of fossil fuels in industry and transportation, as well as from industrialization and urbanization (Goselle, 2021).

Onu and Quan (2014) conducted a study to investigate the effects of acid rain in the Niger Delta region of Nigeria. They recognized that the hazard posed by acid rain is significant. The study enumerated concisely the adverse effects of the acid rain phenomenon in Niger Delta Nigeria, the trend of rain water acidity, the extent of impact with certain associated ailments and government abatement measures to curb or eliminate acid rain. Regression model employed to determine the correlations of gas flaring rate (since sulphur oxides, Nitrogen oxides, the precursors of acid rain emanate majorly from gas flaring and power plants) to rain water acidity, cough, diarrhoea and poverty gave an overall P value of 0.02 indicating a good significance level for the model.

Human anthropogenic activities since 1800 have resulted in the emission of great volumes of gaseous materials into the atmosphere (Efe and Mogborukor, 2008). The gases emitted from anthropogenic activities are notably carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFC) nitrogen oxide absorbs earth's radiation. The radiation has been implicated to degrade the environment with consequences for ground level temperature, deposition of acid rain and alterations of the world's climate (Dollah et al., 2023; Mamta, 2016). At the molecular level, carbon dioxide has been emitted in greatest volume, largely from clearing forest, burning of coal, and oil and gas flaring (Efe & Mubgoruko, 2012).

Mamta (2016)opined that the combustion of coal and other fossil fuels produces, as by-products, a wide variety of chemicals, including gases like sulfur dioxide and nitrogen oxides. These gases, which are emitted into the atmosphere may be carried up to hundreds of miles by air currents, and are often transformed into acidic compounds, which are then returned to the earth through acid rain. Fiza et al. (2021) conceptualized the precipitation associated with rain and snow that is highly contaminated by acidic compounds as wet acid deposition. However, when the hazardous substances are deposited as gases, aerosols and particulate matter of different sizes, it is called dry acid deposition, in high-elevation and coastal areas, they may be delivered through cloud or fog water, called cloud deposition (Efe & Mubgorukor, 2012).

The concept of acid rain can be traced to the works of Robert Augus in 1872, during the industrial revolution. Robert Augus defined acid rain as any acidic precipitation such as rain and fog that is contaminated by emitted SO_2, CO_2, and NOx from human activities takes place (Kumar, 2017). Larssen *et al.* (2006) argue that the emissions from burning of fossil fuel and other anthropogenic activities form the major sources of acid deposition in the Niger

Delta region. Lehmann et al. (2008) alluded that when hazardous gases are airborne, their extent of dispersion is a function of meteorological parameters. According to Larssen et al. (2006) the pollutants can travel several thousand kilometers through the atmosphere before deposition on vegetation and soil as wet or dry precipitation.

The deposition of acids onto lands manifest in widespread soil and surface water acidification. Through infiltration processes, acid rain also leaches various heavy metals from the soil into subsurface water, which impacts aquatic life (Seip, 2001). Acid rain also affects the flora and fauna on land as well as causing damage to sculptures and buildings.

Different sources have been implicated as the causes of acid precipitation in the literature, the work of Odjugo (2008) evidenced the difference between water collected from gas flaring location and the control, the work of Efe and Mogborukor (2008), reported that that gas flaring, bush burning, flumes from fairly used vehicles due to incomplete combustion and the widespread practice of waste incineration contributes enormously to the acidification of rainwater. The increased atmospheric concentration of carbon dioxide in recent years has also resulted in increased carbonic acid, which has been linked to the occurrence of acid rain in Nigeria (Efe, 2011).

Buba (2003), argue that studies on the impact of acid rain is largely delimited to the Niger Delta region of Nigeria, which is justified by the widespread flaring of gases and other oil and gas related activities. Akoma (2021), argued that beyond the activities of oil and gas companies in the Niger Delta region that emits substantial amount of hazardous soot into the lower atmosphere, the activities of artisanal refineries are equally pervasive. However, their impacts and contribution to the reported acidity of rainfall is not investigated in the literature. Efe (2011) argue the need to extend the studies on acid rain beyond the foci of the Niger Delta region, and also canvassed the need for more localized investigation to expose the micro-climatic, health and economic implication of acid rain in the Niger Delta region.

There are several sources of acid rain and among them is gas flaring which is very common in the Niger Delta. Gbafade and Gowon (2002) asserted that gas flaring is a major cause of acid rain in the Niger Delta region of Nigeria and called for more studies to regularly assess the issue of acid rain and its causes not only in the region but over the Nigerian landscapes. Sulphur dioxide (SO_2) and oxides of nitrogen to some extent are the primary causes of acid rain. These constituents interact with reactants present in the atmosphere and result into acid deposition (Efe, 2011). The natural sources of sulphur pollutants are oceans and much smaller extent from volcanic eruptions (Kumar, 2017). The man-made sources of SO_2 emissions are the burning of coal and petroleum and various industrial processes (IPCC, 2001). Other sources include the smelting of iron and other metallic (Zn and Cu) ores, manufacture of sulphuric acids, and the operation of acid concentrators in the petroleum industry (Kumar, 2017). The levels of NOx are small in comparison to SO_2, but its contribution in the production of acid rain is increasing. The degree of acidity is measured by pH value; it is shorthand version of potential hydrogen (Bakpo&Emejuru, 2019).

Many studies have studied acid rain in the Niger Delta, but the scope of investigation is not always representative of the areal coverage of the region and the spatial analysis of the severity of acid rain is less found in the literature. Thus, the present study sought to analysing the environmental, health and economic impacts of acid rain in the Niger Delta Regionwith a view to providing actionable recommendations to minimize the associated impacts.

Methodology

The study was carried out in the entire Niger Delta Region. The Niger Delta region is located between Latitudes $5^0$31N and $5^0$33N and Longitudes 5^0 30E and 5^0 32E. One third of the

region is made of wetlands and houses the third largest wetland forest in the world (Efe, 2010). The area is being endangered by gas faring and oil pollution (Mogborukor et al., 2024). The region experiences subequatorial climate that is now influenced by gas flaring. For instance, mean temperature generally ranges between 35°C and 37°C. Rainfall amount is over 300cm without a distinctive dry season, with monthly rainfall (January – December) averaging 2.5cm. Rain occurs every month of the year, but of varying duration. Primarily, rainfall is controlled by two air masses, the South-West monsoon which derives its origin from the sub-tropical high pressure belt over the Southern Atlantic Ocean. Across the different ecological zones, the Niger Delta is home to diverse assemblages of not evaluated, data deficient, least concern, near threatened, vulnerable, endangered and critically endangered wildlife species. Agbagwa and Ndukwu (2014), have noted that some of the threatened species mostly by oil and gas exploration, which have been previously reported in International Union for Conservation of Nature (IUCN) red list are the pygmy hippopotamus (Choeropsis liberiensis), manatees (Trichechus senegalensis), maritime hippopotamus (Hippopotamus amphibious), Nile crocodile (Crocodylusniloticus), slender nosed crocodile (Crocodylus cataphractus) and dwarf crocodile (Osteolaemus tetraspis). Ohimain (2003) also reported that such wildlife species as the Cape clawless otter (Aonyxcapensis), African palm nut vulture (Gypohierax angolensis), fire-footed squirrel (Funisciurus pyrropus), Hammerkop (Scopus umbretta), African fish eagle (Haliaeetusvocifer), Sclater's guenon (Cercopithecus sclateri), sitatunga (Tragelaphus spekei), white throated monkey (Cercopithecus erythrogaster), which occurred in the area required conservation. With continuous gas flaring activities and associated acid rain, these fauna diversities which abound in this region will be extinct. The Niger Delta region is African largest Delta with the largest mangrove forest. The region is ecologically, politically and economically diverse with oil and gas exploration, farming, manufacturing lumbering, fishing and artisanship as some of the numerous economic activities. The multiplicity of inland water ways has made water transportation a major source of income in the riverine communities.

The study adopted survey research method whereby copies of structured questionnaire were administered to residents of the selected study locations. Questionnaire was administered in selected communities to evaluate the perception of the people on their lived experiences and use of water from different sources. Questionnaire was specifically to make inquest into the source of water available for residents, the mode of water treatment and the water borne diseases experienced in recent years. To determine the sample size for the distribution of the questionnaire, the study area was delineated into quadrant. After delineating the area into quadrants, the sampled quadrants was divided into three each based on level of development. This was the rural, semi-urban and urban areas of Ondo, Delta, Cross River, Abia and Rivers States from the Niger Delta Region. This brought the number of sampled stations to 15. Similarly, the affected population within the spectrum of the rural, semi-urban and urban areas was determined by conducting a census of the affected households. Thereafter the Taro Yamane equation was deployed to get a sizable sample size which was 400. This was later divided among the population of the sample locations using the proportional assumption. The population of the calibrated area is estimated to be 2566704. Copies of questionnaire were administered to sampled population that is representative of the population in the Niger Delta region. The study collected a total of 400 samples from the Niger Delta States based on the quadrants. To determine the sample size for questionnaire administration, the Taro Yamane's (1967) sample determination formula was employed. The formula is stated as follows:

$$\boldsymbol{S} = \frac{\mathrm{N}}{1+\mathrm{N}(\mathrm{e})^2} \qquad \text{(Equ. 1)}$$

where:

S = Sample size

e = Margin of error assumed (0.05)
1= Theoretical constant
n = Population

$$\frac{3738704}{1 + 3738704(0.05)^2}$$

$$S = \frac{3738704}{1 + 3738704(0.0025)}$$

$$s = \frac{3738704}{9{,}346.8}$$

S= 400

The sample size for the study is 400.

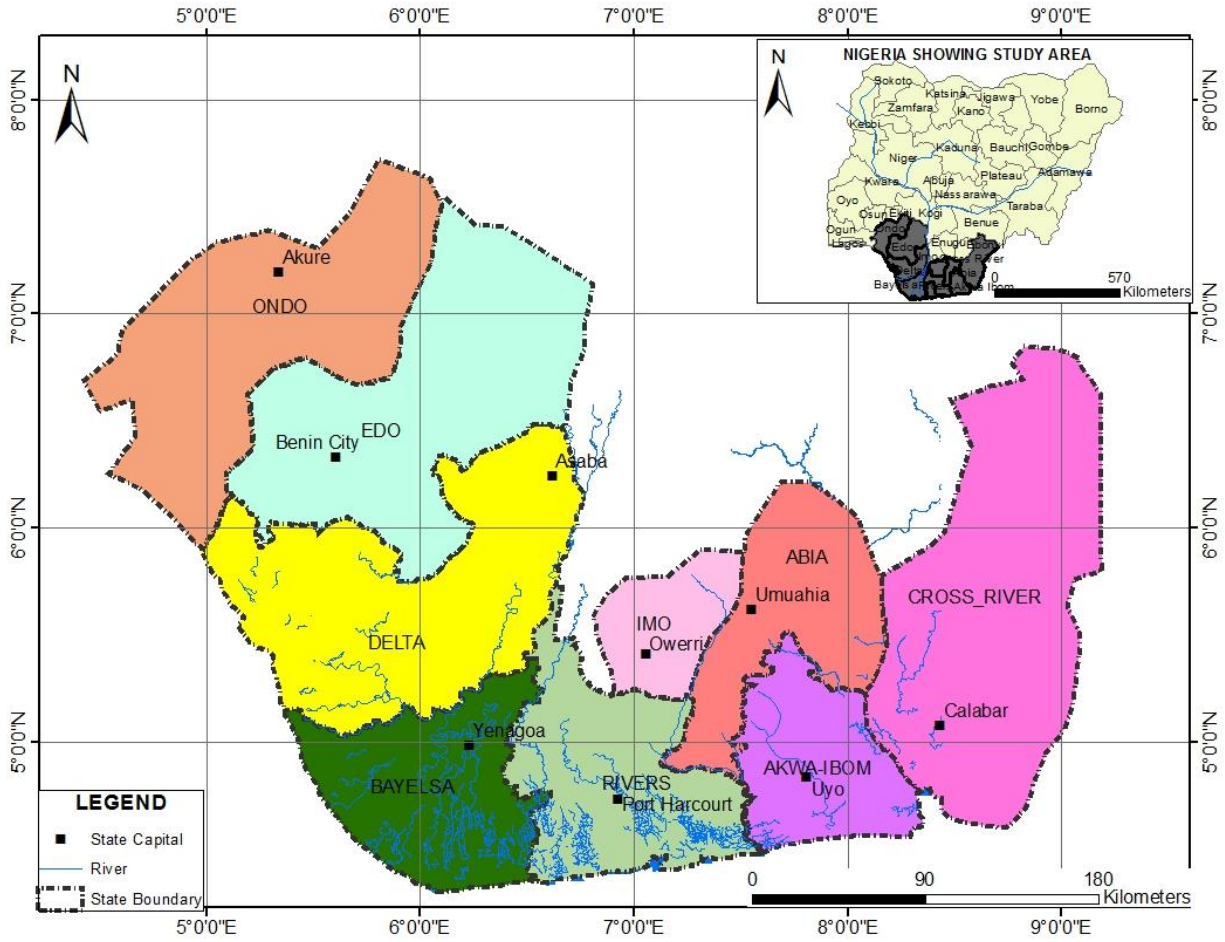

Figure 1: Niger Delta Region Showing the Sample Quadrants

The validity of the questionnaire ensured through expert review and pilot testing while the reliability of the questionnaire was analyzed using Cronbach's alpha. Descriptive statistical analysis was used for data analysis.

Results and Discussions

Socio-Demographic Characteristics of Respondents

It was discovered that out 400 copies of questionnaire administered, only 396 copies were returned and used for further analysis. Thus, it was observed that of the total respondents, 53% were males and 47% were females (Figure 2). In terms of age as presented in Figure 3, the respondents are largely young and middle-aged adults. Those between 21–35 years make up the largest group (40.4%), followed by ages 36–50 (26.5%) and 51–65 (15.2%).

Respondents under 20 years (11.4%) and those above 66 years (6.6%) form the smallest groups, showing that the sample is dominated by economically active individuals. Marital status distribution as revealed in Figure 4 shows that half of the respondents are married (50.5%), while singles account for 30.3%. Smaller proportions are divorced (5.1%), widowed (7.6%), and separated (6.6%). This pattern suggests a predominantly family-oriented population.

Regarding occupation as presented in Figure 5, trading and business activities engage the largest portion (24%), followed by students (22.7%), civil servants (16.4%), farmers (15.2%), and artisans (12.6%). A smaller group (9.1%) falls under "others." This indicates a mixed population with strong representation from both formal and informal sectors.

The educational status of respondents as presented in Figure 6, shows that the respondents are relatively well-educated. Holders of B.Sc degrees constituted the highest percentage (25.3%), followed by SSCE (22.7%), OND/Diploma (17.7%), and HND (15.2%). Only 7.6% have primary education, while 11.6% possess postgraduate qualifications. This pattern shows a population with a strong academic background, possibly influencing awareness and participation levels in community or environmental matters. The years of residence of respondents as shown in Figure 7 reveal that a majority (29.3%) have lived in their area for more than 20 years, suggesting a stable and long-term community. Another 20.2% have stayed for 11–15 years, while 18.9% and 17.7% have resided for 6–10 years and 16–20 years respectively. Only 13.9% are relatively new residents (1–5 years). This implies that most respondents have long-standing familiarity with local conditions and community dynamics.

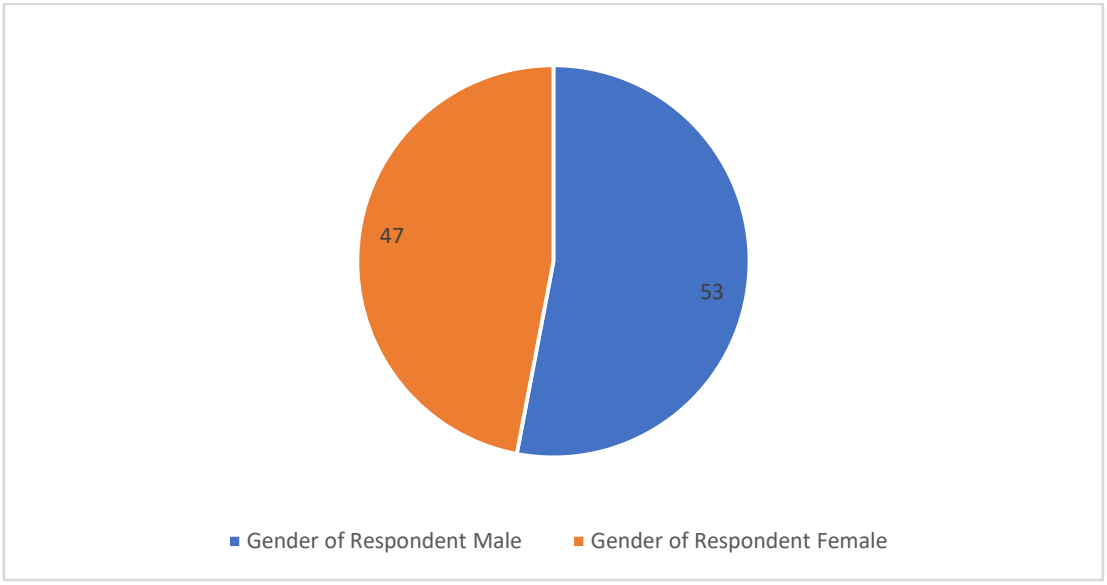

Figure 2. Gender Distribution of Respondents

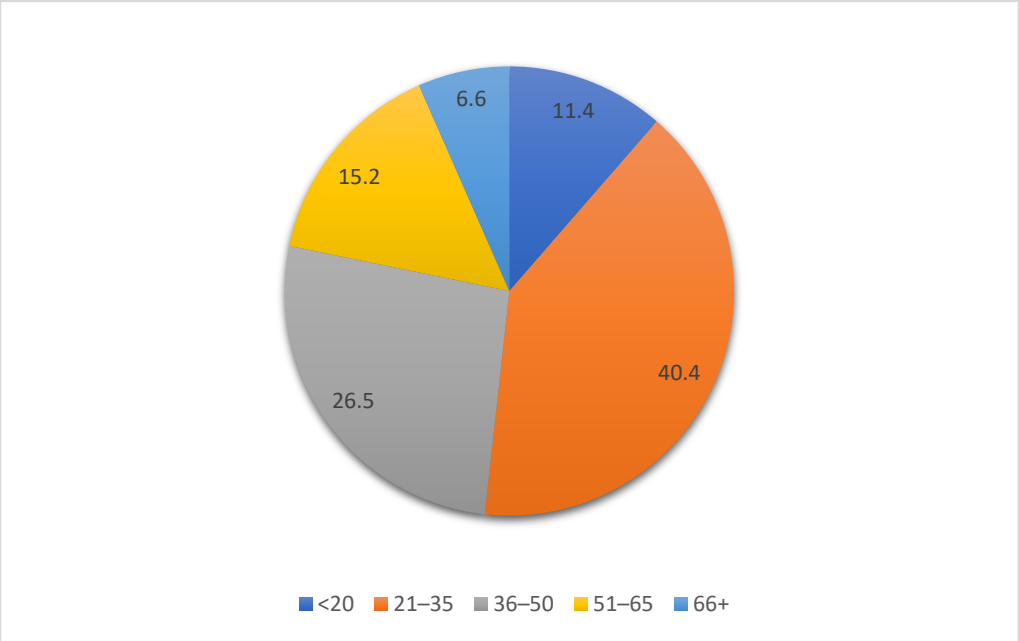

Figure 3. Age distribution of respondents

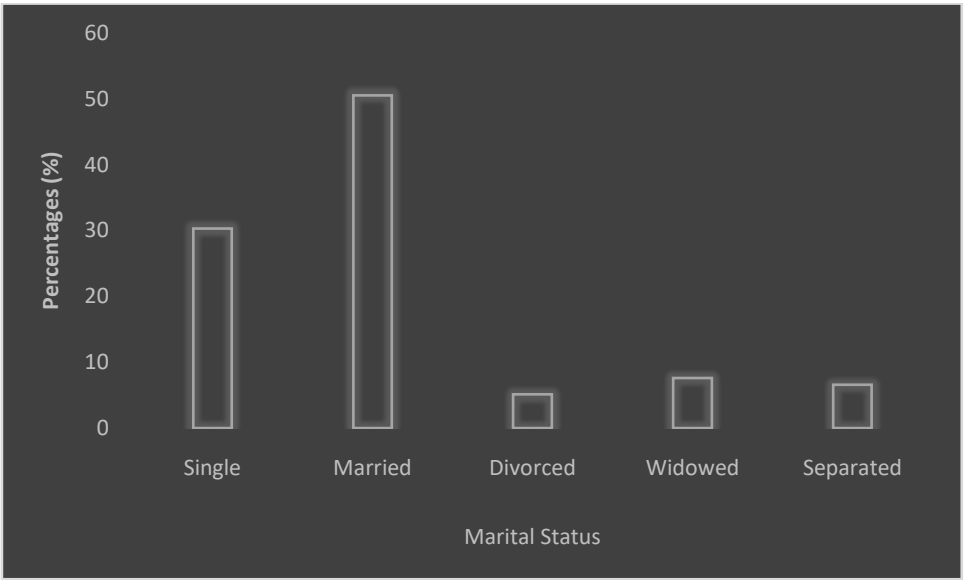

Figure 4. Marital status of the respondents

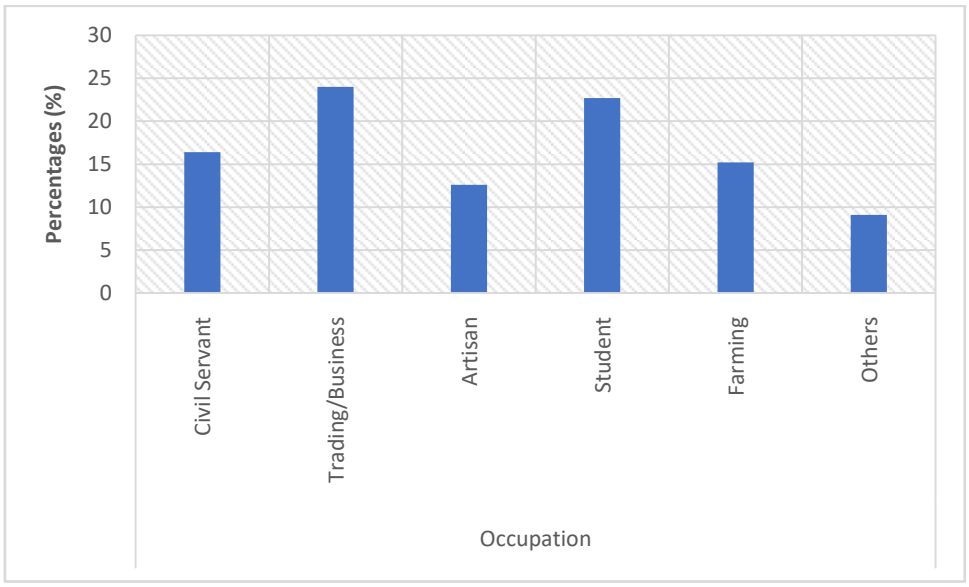

Figure 5: Occupation distribution of the respondents

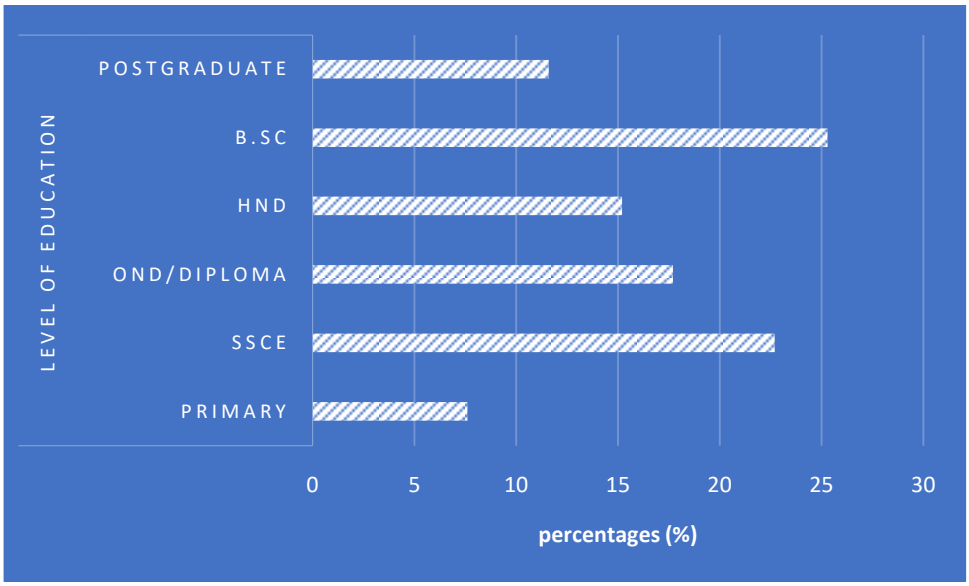

Figure 6. Education distribution of the respondents

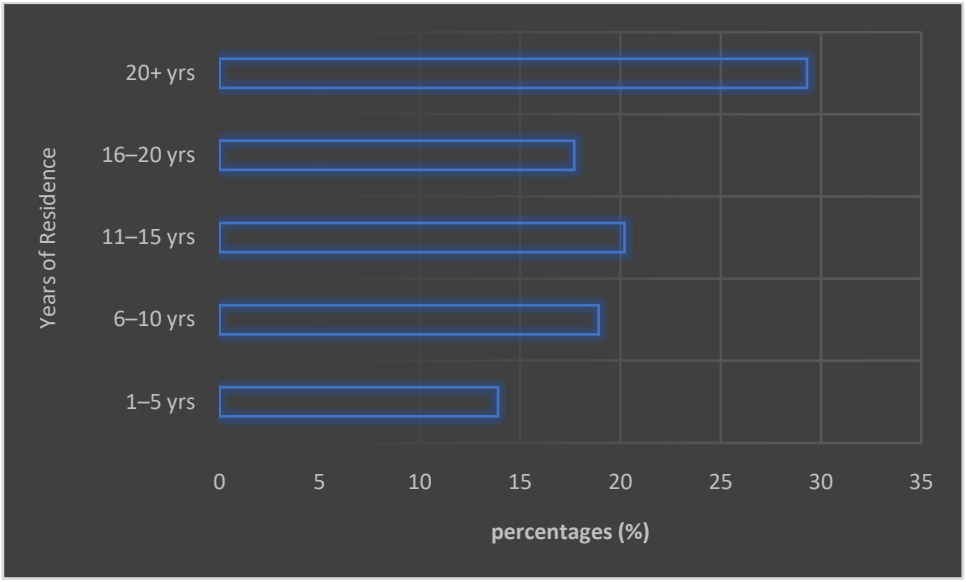

Figure 7. Years of residence of respondents in the study area

The environmental, health and economic impacts of acid rain in the Niger Delta region

Table 1 presents the respondents' perceptions of the environmental impacts of acid rain across the Niger Delta region. The responses show a consistently high level of agreement among participants that acid rain has adverse effects on soil, water, vegetation, infrastructure, and biodiversity. Weighted mean (WM) scores for all items range between 3.96 and 4.10, which indicate a strong agreement trend on the listed environmental consequences.

The highest-rated impact is the reduction of soil fertility and agricultural productivity (WM = 4.1), with 45.5% of respondents strongly agreeing and 35.4% agreeing. This suggests that many residents observe or experience declines in crop yields and soil quality attributed to acidic precipitation. The corrosion of roofing sheets and building materials follows closely (WM = 4.08), where over 80% of respondents (42.9% strongly agree, 37.9% agree) believe that acid rain accelerates structural deterioration, a well-known issue in many industrial and oil-producing areas of the Niger Delta. Similarly, 41.7% strongly agree and 36.6% agree that acid rain contaminates surface and groundwater sources (WM = 4.03), reflecting growing concern over the declining quality of drinking and domestic water. The perceived threat to biodiversity (WM = 4.01) and the acidification of rivers and creeks (WM = 3.97) further highlight awareness of ecological harm, particularly the vulnerability of aquatic habitats and forest ecosystems.

Acid rain's contribution to the decline of fisheries and aquatic life (WM = 4.06) also stands out, confirming the community's observation of reduced fish availability and aquatic ecosystem imbalance. Respondents also link acid rain to long-term degradation of farmlands (WM = 4.01) and increased flooding and erosion (WM = 3.96), both consequences of weakened soil structure and poor vegetation cover. In a nutshell, the pattern of responses indicates strong public awareness and consensus that acid rain poses a serious environmental threat in the Niger Delta. The uniformly high weighted means above 3.9 and the dominance of agreement responses above 75% across all items suggest that acid rain is not only recognized as an environmental issue but also seen as a direct driver of ecological and infrastructural deterioration in the region.

Table 1: The perceived environmental impacts of acid rain in the Niger Delta region

Environmental Effects of Acid Rain	Strongly Agree F(%)	Agree F(%)	Disagree F(%)	Strongly Disagree F(%)	Neutral F(%)	Total (%)	WM
Acid rain reduces soil fertility and agricultural productivity in the Niger Delta.	180 (45.5)	140 (35.4)	35 (8.8)	20 (5.1)	21 (5.3)	396 (100)	4.1
Acid rain contaminates surface and groundwater sources in the region.	165 (41.7)	145 (36.6)	40 (10.1)	22 (5.6)	24 (6.1)	396 (100)	4.03
The corrosion of roofing sheets and building materials in the Niger Delta is caused by acid rain.	170 (42.9)	150 (37.9)	35 (8.8)	21 (5.3)	20 (5.1)	396 (100)	4.08
Acid rain damages forest vegetation and natural habitats in the region.	150 (37.9)	155 (39.1)	45 (11.4)	26 (6.6)	20 (5.1)	396 (100)	3.98
The biodiversity of plants and animals in the Niger Delta is being threatened by acid rain.	160 (40.4)	150 (37.9)	40 (10.1)	24 (6.1)	22 (5.6)	396 (100)	4.01
Acid rain contributes to the acidification of rivers and creeks in the Niger Delta.	155 (39.1)	150 (37.9)	45 (11.4)	26 (6.6)	20 (5.1)	396 (100)	3.97
Acid rain leads to the decline of fisheries and aquatic life in the region.	170 (42.9)	145 (36.6)	35 (8.8)	24 (6.1)	22 (5.6)	396 (100)	4.06
The long-term degradation of farmlands in Niger Delta communities is linked to acid rain.	160 (40.4)	150 (37.9)	40 (10.1)	26 (6.6)	20 (5.1)	396 (100)	4.01
Acid rain increases environmental hazards such as flooding and erosion by weakening soil structure.	155 (39.1)	150 (37.9)	50 (12.6)	21 (5.3)	20 (5.1)	396 (100)	3.96
The scenic and aesthetic quality of the Niger Delta environment is being degraded by acid rain.	165 (41.7)	140 (35.4)	45 (11.4)	24 (6.1)	22 (5.6)	396 (100)	3.99

Table 2 presents respondents' views on the perceived health impacts of acid rain in the Niger Delta region. The data show that most respondents strongly agree or agree that acid rain has several direct and indirect health effects, with weighted means (WM) ranging from 3.96 to 4.08. This pattern of responses indicates that the population perceives acid rain as a growing environmental health concern in the area. The highest-rated impact is the increase in

respiratory diseases such as asthma and bronchitis, which recorded a weighted mean of 4.08. Here, 42.9% of respondents strongly agree and 37.9% agree, representing over 80% overall agreement. This suggests that exposure to acidic pollutants in the air, mainly from gas flaring and industrial emissions, is widely believed to worsen respiratory health in communities across the region.

Another major concern is the contamination of drinking water, with 40.4% strongly agreeing and 36.6% agreeing that the consumption of acid-contaminated water causes stomach and digestive issues (WM = 4.00). This perception is consistent with the high acidity and pollutant concentrations recorded in the rainwater and surface water samples across the Niger Delta. The effects of acid rain on skin and eyes were also strongly recognized, as 41.7% strongly agree and 37.9% agree that acid rain exposure leads to skin irritations and eye problems (WM = 4.05).

Long-term exposure to acid rain was also linked to cardiovascular and neurological issues (WM = 3.96), supported by 39.1% of respondents strongly agreeing and 37.9% agreeing. This reflects growing awareness that prolonged exposure to acidic pollutants and heavy metals from acidified environments could have more complex health outcomes beyond respiratory irritation.

Similarly, 40.4% strongly agree and 37.9% agree that acid rain weakens the immune system, increasing vulnerability to infectious diseases (WM = 4.01). This implies that residents believe chronic exposure to acidic pollutants can compromise general health and resistance to illnesses.

The contamination of food sources, such as crops and fish, also emerged as a serious public health concern, with 42.9% strongly agreeing and 36.6% agreeing that this poses a major health risk in the region (WM = 4.07). This reflects the understanding that acid rain affects agricultural and aquatic ecosystems, introducing harmful substances into the food chain.

Overall, the responses portray a consistent pattern of high awareness and concern among residents about the health consequences of acid rain. The weighted means above 3.9 and agreement levels above 75% across all indicators highlight a strong consensus that acid rain contributes to a broad range of health challenges in the Niger Delta, affecting air, water, food, and general well-being.

Table 2. The perceived Health Impacts of acid rain in the Niger Delta region

Health Impacts of Acid Rain	Strongly Agree F(%)	Agree F(%)	Disagree F(%)	Strongly Disagree F(%)	Neutral F(%)	Total (%)	WM
Acid rain increases the prevalence of respiratory diseases (asthma, bronchitis) among residents of the Niger Delta.	170 (42.9)	150 (37.9)	35 (8.8)	20 (5.1)	21 (5.3)	396 (100)	4.08
The consumption of acid-contaminated water causes stomach and digestive health problems in the region.	160 (40.4)	145 (36.6)	40 (10.1)	25 (6.3)	26 (6.6)	396 (100)	4
Acid rain contributes to skin irritations and eye problems among exposed populations.	165 (41.7)	150 (37.9)	35 (8.8)	22 (5.6)	24 (6.1)	396 (100)	4.05
Long-term exposure to acid rain increases the risk of cardiovascular and neurological health issues.	155 (39.1)	150 (37.9)	45 (11.4)	26 (6.6)	20 (5.1)	396 (100)	3.96
Acid rain weakens the immune system and makes residents more vulnerable to infectious diseases.	160 (40.4)	150 (37.9)	40 (10.1)	24 (6.1)	22 (5.6)	396 (100)	4.01
Acid rain-related contamination of crops and fish poses a serious public health risk in the Niger Delta.	170 (42.9)	145 (36.6)	35 (8.8)	24 (6.1)	22 (5.6)	396 (100)	4.07

Table 3 presents respondents' perceptions of the economic impacts of acid rain in the Niger Delta region. The results reveal a general consensus that acid rain has substantial economic consequences, as all the weighted means (WM) are above 3.6, indicating agreement across the listed indicators. This pattern shows that residents are aware of the diverse ways acid rain affects their livelihoods, infrastructure, and overall economic well-being.

The most highly rated impact is the frequent replacement of building materials and vehicles corroded by acid rain, which recorded a weighted mean of 3.85. A total of 40.4% strongly agree and 30.3% agree that corrosion from acidic precipitation increases living costs. This reflects the financial strain households face in maintaining property and assets exposed to acidic environmental conditions, particularly in industrialized and oil-producing areas.

Closely following is the perception that acid rain damages roofs, houses, and infrastructure, leading to high maintenance costs (WM = 3.81). With 38.4% strongly agreeing and 31.3%

agreeing, over two-thirds of respondents acknowledge that corrosion and material degradation impose significant financial burdens on homeowners and communities.

The reduction of farmland productivity and cash crop yield also emerged as a major concern (WM = 3.79). About 36.4% strongly agree and 33.3% agree that acid rain reduces soil fertility and agricultural output, resulting in direct economic losses for farmers. Similarly, the effect on industrial operations is widely recognized, as 37.4% strongly agree and 31.3% agree that acid rain reduces industrial output and equipment lifespan (WM = 3.78). This suggests that the corrosive nature of acid rain undermines both agricultural and industrial productivity in the region. The decline in fishery yields due to acid rain was another frequently cited issue (WM = 3.70). About 34.3% strongly agree and 30.3% agree that acid rain has contributed to a fall in fishing income, likely due to acidification of water bodies and the resulting harm to aquatic life. Respondents also noted that loss of biodiversity affects tourism and eco-based livelihoods (WM = 3.69), which implies that acid rain's ecological damage extends to non-agricultural economic sectors.

In terms of household finances, 35.4% strongly agree and 32.3% agree that medical expenses for treating acid rain–related illnesses pose an economic burden (WM = 3.74). This aligns with earlier findings in Table 4.16, where respondents highlighted the health risks of acid rain. The perception that acid rain contributes to the loss of arable land (WM = 3.71) further supports the argument that the region's environmental degradation directly reduces farmers' economic resilience. Additionally, respondents believe acid rain leads to reduced property values and land devaluation (WM = 3.68), showing that it affects both tangible assets and long-term wealth accumulation. Finally, 36.4% strongly agree and 31.3% agree that acid rain contributes indirectly to poverty and unemployment (WM = 3.75), summarizing the cumulative socio-economic effects of environmental damage, the table reveals a widespread belief that acid rain imposes significant economic strain across multiple sectors. From household maintenance costs to reduced agricultural and fishery output, and from industrial degradation to rising medical expenses, acid rain is perceived as both an environmental and economic threat that deepens poverty and reduces sustainability in the Niger Delta region.

Table 3: The perceived economic impact of acid rain in the Niger Delta region

Economic Impact Statement	Strongly Agree F(%)	Agree F(%)	Disagree F(%)	Strongly Disagree F(%)	Neutral F(%)	Total (%)	WM
Acid rain damages roofs, houses, and other infrastructure, leading to high household maintenance costs.	152 (38.4)	124 (31.3)	48 (12.1)	36 (9.1)	36 (9.1)	396 (100)	3.81
The productivity of farmlands and cash crops is reduced by acid rain, causing economic losses for farmers.	144 (36.4)	132 (33.3)	52 (13.1)	32 (8.1)	36 (9.1)	396 (100)	3.79
Acid rain contributes to the decline of fishery yields, which reduces income for fishing households.	136 (34.3)	120 (30.3)	64 (16.2)	40 (10.1)	36 (9.1)	396 (100)	3.7
Frequent replacement of building materials and vehicles corroded by acid rain increases living costs in the region.	160 (40.4)	120 (30.3)	48 (12.1)	32 (8.1)	36 (9.1)	396 (100)	3.85
Acid rain negatively affects industrial output and equipment lifespan in the Niger Delta.	148 (37.4)	124 (31.3)	52 (13.1)	36 (9.1)	36 (9.1)	396 (100)	3.78
Loss of biodiversity caused by acid rain reduces opportunities for tourism and eco-based livelihoods.	128 (32.3)	132 (33.3)	60 (15.2)	40 (10.1)	36 (9.1)	396 (100)	3.69
The medical expenses of treating acid rain–related illnesses place an economic burden on households.	140 (35.4)	128 (32.3)	56 (14.1)	36 (9.1)	36 (9.1)	396 (100)	3.74
Acid rain contributes to the loss of arable land, making farmers economically vulnerable.	132 (33.3)	132 (33.3)	60 (15.2)	36 (9.1)	36 (9.1)	396 (100)	3.71
Communities affected by acid rain experience reduced property values and land devaluation.	120 (30.3)	136 (34.3)	64 (16.2)	40 (10.1)	36 (9.1)	396 (100)	3.68
Acid rain contributes indirectly to poverty and unemployment in Niger Delta communities.	144 (36.4)	124 (31.3)	52 (13.1)	40 (10.1)	36 (9.1)	396 (100)	3.75

Discussion of Findings

Regarding the environmental impacts, findings showed that respondents strongly agree that acid rain has severe environmental effects on soil, water, vegetation, infrastructure, and biodiversity across the Niger Delta. The high weighted means, ranging between 3.96 and

4.10, demonstrate strong consensus among residents that acid rain contributes significantly to environmental degradation. The fact that industrial emissions and gas flaring contribute significantly to acid precipitation in the Niger Delta is supported by the research of Efe's (2010) and Akpan and Ndoke's (2020). The sulphur and nitrogen oxides are released into the atmosphere by these sources. When these gases react with atmospheric moisture, they form acidic compounds that fall as rain, reducing soil pH and leaching essential nutrients. As noted by Obanijesu et al. (2011), continuous acid deposition in oil-producing communities has led to serious soil infertility and crop yield decline, which corroborates the high agreement among respondents regarding reduced soil fertility and agricultural productivity. The corrosion of roofing sheets and building materials, also rated highly by respondents (WM = 4.08), is consistent with field observations by Nduka et al. (2008), who found significant material degradation in urban centres like Port Harcourt and Warri due to acid deposition. Such damage increases maintenance costs and contributes to infrastructural decay. Furthermore, the contamination of surface and groundwater sources and the acidification of rivers and creeks observed in this study are in line with reports by Efe (2012) and Okoro et al. (2021), who confirmed that acid rain in the Niger Delta often carries heavy metals such as lead, zinc, and iron, which degrade water quality and pose ecological risks. The perceived decline in fisheries and biodiversity also mirrors findings by Odjugo (2008), who linked acidification of water bodies to fish mortality and loss of aquatic species diversity in polluted zones. The Niger Delta is one of the most acid-prone environments in sub-Saharan Africa due to constant gas flaring, industrial effluents, and weak environmental governance; and this fact is supported by the high level of environmental awareness among respondents of the havoc caused by acid rain.

In terms of health impacts, findings revealed that respondents perceived acid rain as a serious public health concern, with weighted means between 3.96 and 4.08 across all indicators. In line with studies on the health effects of acid pollutants, there is close agreement as to the acid rain-related problems that concern the respiratory system, the digestive system, and the skin. For example, Ede (2011) documented a rise in the prevalence of respiratory diseases like asthma and chronic bronchitis in the Niger Delta region due to gas flaring and industrial operations, which release sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter. This aligns with the view of the respondents that acid rain largely causes respiratory issues. Efe (2006) reports validate the reported contamination of drinking water sources and the attendant gastrointestinal and acidosis diseases. From acid rain and runoff, these studies identified that toxic metals could be mobilised into surface and groundwater, which is not safe for human consumption. These toxins have the potential to cause irritation of the gastrointestinal tract, stress the liver, and cause a multitude of issues with internal organs. Aghoghovwia and Okeke (2018) also found that people living in highly industrialised areas have a greater chance of developing dermatitis and redness of the eyes on contact with acidified rainwater. Our figures show that acid rain also relates to skin or eye irritations. In addition, there is growing health research evidence (Adejumo et al., 2014; Onyearugha and Uwakwe, 2020) associating chronic acid exposure with oxidative stress and systemic toxicity, supporting the fact that long-term exposure to acid pollutants can lead to cardiovascular or neurological disease. The contamination of food sources such as crops and fish, which respondents rated highly, further aligns with Odjugo (2008), who observed bioaccumulation of heavy metals in crops and fish from acidified ecosystems in the Niger Delta. This process poses long-term health risks since these metals enter the food chain and affect nutritional safety. Generally, the health-related findings from this study strongly confirm existing literature that acid rain in the Niger Delta region is a serious public health hazard,

exacerbated by unregulated industrial emissions, gas flaring, and poor environmental governance.

Findings as regards economic impacts **revealed** that respondents agree widely that acid rain has major economic consequences, as all weighted means are above 3.6. This finding supports previous research that links environmental degradation caused by acid rain to economic hardship and reduced livelihoods in industrialized regions. The most significant economic burden identified by respondents is the frequent replacement of corroded roofs, buildings, and vehicles (WM = 3.85), which is consistent with the findings of Efe (2010b) and Akpan and Ndoke (2020), who reported that corrosion and infrastructural decay are major financial challenges in Port Harcourt, Warri, and other oil-producing cities. Continuous acid deposition shortens the lifespan of construction materials, forcing residents to spend more on repairs and replacements.

The perceived reduction in agricultural productivity and cash crop yield (WM = 3.79) aligns with studies by Odjugo (2008), who found that soil acidification and nutrient depletion from acid rain reduce crop output, especially cassava, yam, and maize, which are key sources of income for rural households. The economic effect extends to the fisheries sector, where the acidification of rivers and creeks reduces fish populations, thereby diminishing fishing income. This observation supports Efe and Mogborukor (2012) who linked acid rain to declining fishery yields and disruption of aquatic livelihoods. Respondents also identified rising medical expenses and property devaluation as part of the economic toll of acid rain. These findings correspond with Aghoghovwia and Okeke (2018), who explained that communities exposed to acid pollutants experience increased household expenditure due to frequent hospital visits and property deterioration. Furthermore, the perception that acid rain contributes to poverty and unemployment echoes the broader argument by Akpoborie and Olorunfemi (2018) that environmental degradation in the Niger Delta undermines sustainable development and deepens socioeconomic vulnerability. Summarily, the economic findings of this study agree with the body of literature emphasizing that acid rain imposes multi-sectoral losses in affected regions. From the household level to industrial and agricultural production, the cumulative effect of acid rain weakens economic stability and intensifies poverty cycles in the Niger Delta.

Conclusion and Recommendations

The study concluded that acid rain has been perceived to cause major environmental, health, and economic threats in the Niger Delta. Environmentally, leading to reduction of soil fertility which has increased soil degradation, corrosion of infrastructure, contamination of water and threatening the survival of biodiversity. On health impacts, acid rain has been linked to increased respiratory diseases, skin and eye irritation, and contaminated food and water sources, reflecting awareness of exposure to acidic pollutants and heavy metals. Economically, acid rain has increased maintenance costs, reduced farm and fish yields, damaged infrastructure, and escalated medical expenses. This shows that acid rain has led to environmental degradation which undermines livelihoods, and contributes to economic hardship in the Niger Delta. It is thus recommended that a comprehensive environmental health policy should be developed to address acid rain–related risks. Government and oil companies should invest in public awareness campaigns, medical screening, and infrastructural resilience programs.

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