

Assessment of Causes of Land Oil Spills from TANESCO Power Distribution Systems Attributing to Environmental Degradation in Tanzania

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Abstract

Mineral oil is essential for cooling and insulation of transformers from Tanzania Electric Supply Company (TANESCO) power distribution systems. However, oil spills from transformers pose environmental hazards such as human health effects on nervous systems, weakened immunity, cancer in digestive system, liver and skins. The aim of this study was to investigate the land oil spills from TANESCO power distribution systems attributing to environmental degradation at Karatu district in Arusha region, Tanzania. The study employed the method of quantitative data analysis. Data collection tools included observations, testing, measuring parameters, office records, structured interviews and questionnaire. Data analysis was performed on subsets of transformer external failure-related causes of land oil spills and the results illustrated the majority (74.07%), and internal causes revealed the minority (25.93%). Data analysis was performed on subsets of land surface-based effects of oil spills. The variables for defective transformers were fitted with distributions, while Xlstat software was used to generate result spreadsheets of defective transformer oil spills data based on the fitted distributions. Regression models were developed to validate future events based on historical oil spill events within the case study area. The general results indicated vandalism was leading in causing transformer oil spills by 60.46%. Effects of transformer oil spills include various harms to plants, soils and water. Human beings are also affected through respiratory, skin and digestive-related diseases. It is concluded that transformer oil spills degrade the environment by posing health risks to human beings and biodiversity. This study recommended the Ministry responsible to put policy in place for control of transformer mineral oil spills and provide education for capacity building to both TANESCO employees and the power consumers.
Keywords: TANESCO power distribution systems, land oil spills, environmental degradation

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1. Introduction

Electricity is essential for the development of residential, commercial, manufacturing and processing sectors. However, there are some challenges facing TANESCO in delivering its services for development in different sectors. These challenges include the following among others. According to Jevtić, *et al.* (2024), oil spill from transformers can pose environmental problems such as physical harm and toxicity to wildlife, destruction of critical habitat, destruction of food chains and ecosystem, affecting biodiversity and breeding, long term contamination of water, poisoning, as well as reproductive problems.

Distribution of electricity in Tanzania started with the establishment of the power utilities Dar Es Salaam Electric Supply Company (DARESCO) and Tanganyika Electric Supply Company (TANESCO) in November 1931. According to TANESCO (2023), transformers, Medium Voltage (MV) lines, Low Voltage (LV) lines and consumers that form the electric power distribution systems have increased drastically in recent years following the introduction of rural electrification projects in the year 2008 prompted by the country's goals to attain middle-income status by 2025 (URT, 2020). The current statistics in Karatu district indicate that MV line 33 kV is 581.24 km, the number of distribution transformers has reached 186, and power consumers over 20 900 of Tariffs T0 and T1 (TANESCO, 2023). Further, 21 distribution transformers of sizes ranging from 50 kVA to 500 kVA were found to have internal failure-related causes. Meanwhile, 65 distribution transformers of the same ranging sizes were found to have external failure-related causes. External and internal failure-related causes, making a total of 86 defective transformers between 2013 and 2023, were found with oil leaks and spills (Vankore & Nikam, 2024) at different places (Table 1).

Table 1. Defective distribution transformers with leaked oil spills at Karatu district

Transformer description	**Parts per transformer sizes**					**Total**
Individual Power Capacity (kVA)	50	100	200	315	500	
Existing transformers (Qty)	55	51	37	32	11	186
Defective Transformers (Qty)	22	17	19	17	11	86
Oil per Transformer (Ltr)	206	309	412	515	618	2,060
Total leaked Oils (ltr)	4,532	5,253	7,828	8,755	6,798	33,166

The 50kVA transformers are mostly available (55) as found in the power distribution systems when compared with others, followed by those of 100kVA (51). However, the total amount of leaked oils from the defective 50kVA and 100kVA transformers (9,785ltr) is comparatively less than those of 200kVA and 315kVA defective ones put together (16,583ltr). This implied that the larger the oil-immersed distribution transformers, the more was the leaked mineral oils. The increase of oil leaks appeared to be gradual, but as per this trend, more extension of the MV line implies more oil spills if the causes are not combated (Figure 1). The evaluation of power distribution systems has proven instrumental in recognizing construction methodologies, maintenance approaches, and various irregularities that could lead to oil spills. This assessment (Tontus, 2020) enabled the screening of power distribution system (Tanwar1 & Choubisa, 2017) populations to ascertain the extent and intensity of transformer oil spills, with the results serving as a foundation for developing mitigation strategies (Alloisio & Borghesi, 2019) against environmental degradation (Kumari, 2024). These strategies can be utilized as a framework for forecasting potential oil spill incidents both within the designated study area and in other locations.

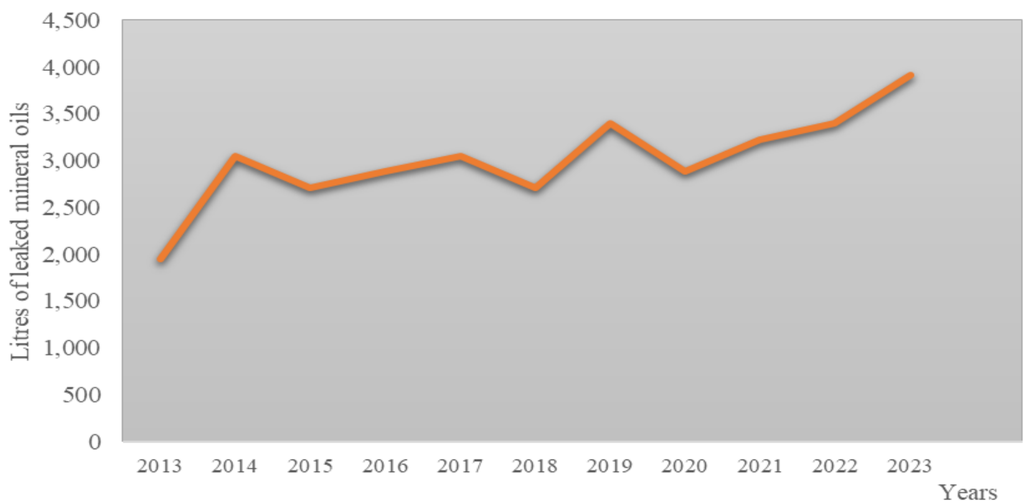

Figure 1. Leaked transformer mineral oil

2. Power distribution systems

Power distribution system is the final stage in the delivery of electric power carrying electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage (Tanwar1 & Choubisa, 2017). Assessment of power distribution systems focused on construction practices, maintenance strategies and vandalism cases to identify anomalies posing land oil spills.

2.1 Construction practices

Karatu district has one two MV line with route lengths exceeding the recommended 200 km (TANESCO, 2024) and many secondary substations. A 33 kV Manyara line (343.10 km) that supplies the Karatu district and a portion of Monduli district has 115 secondary substations, and a 33 kV Ngorongoro line (238.14 km) that supplies Karatu and Ngorongoro district has 71 secondary substations (TANESCO, 2023). Wooden poles from eucalyptus and pine trees used in power distribution systems are treated using Copper Chrome Arsenic (CCA) (Singh & Page, 2016) or creosote (Smith, 2023) to stay longer in the field without rotting as the preservatives protect the wood against various attacks like fungus, wood borers and other insects and the worst effects of weathering. The overall measurements of the Copper Chrome Arsenic (CCA) and creosote retention by (X-ray Photoelectron Spectroscopy) XPS and vernier calliper indicated deviation of the readings from the accepted specs to signal that CCA and creosote preservatives were insufficient. Further, some wooden poles indicated that the plants were prematurely harvested. Insufficient preservative treatment and premature tree harvesting have contributed to the quick rotting of the wooden poles found at secondary substations, leading to fallen transformers, broken High Voltage (HV) and LV bushings, and oil spills. The construction of MV lines include horizontal, triangular and vertical overhead conductor styles. The construction manual requires that conductors be equally spaced from 3′11″ to 4′3″ for 33 kV power distribution lines to enhance a balanced power system (TANESCO,2024). Further, taking note of the recommended spacing of MV line conductors for 33 kV lines in the construction manual, it was observed that the 7′ length of the galvanized steel cross-arm commonly applied mathematically disagrees with reality. The calculation indicated that for the galvanized steel cross-arm having a length of 7′ for 33 kV lines, the actual spacing between conductors is nearing 3′ 2″ instead of 3′11″. Suppose the spacing was intended to avoid the possible overcurrent due to induced emf between conductors. Another observation was unequal spacing between line conductors. The middle conductor for horizontal style was not fixed at the centre of the two outer conductors between successive spans as required during the implementation of previous projects. In such case, one of the causes for the failure of distribution transformers is the narrow line spacing between conductors due to the application of short galvanized cross-arms or unequal line spacing between conductors. This could superimpose emf induction between conductors and cause a severe overcurrent in adjacent phases, especially at peak load. The overcurrent is likely to stress the transformer windings, generate excessive heat with gases released pushing out the gaskets and allowing oil to penetrate outside the transformer tanks.

Based on the rotating ellipsoid method and mean potential method regarding the calculation of single and multiple rods earthing resistance in one-layer soil types (Malanda*, et al.* 2018), tests from recently commissioned projects having four secondary substations at Wards of Endabash and Endamarariek indicated to have an insufficient earthing system to the distribution transformers, whereby earth resistance measurements to depth of 1m in different soil types had resistance above 170 Ω on MV and 30 Ω on LV side (sandy soil) during dry season (Table 2) instead of the all-time recommended 7.5 Ω and 2.5 Ω respectively (TANESCO, 2024).

Table 2. Measurements of earthing resistance values at various soil types

Soil type	**Ward**	**Voltage (kV)**	**Transformer (kVA)**	**Earthing resistance (Ω)**	
				MV side	LV side
Clay	Endabash	33	100	33.23	21.13
Gravel		33	100	61.26	26.14
Sandy	Endamarariek	33	100	172.22	30.20
Silt		33	100	52.10	22.15

The substandard earthing system leads to power distribution transformers being easily struck by lightning; hence the occurrence of oil spills as found at various secondary substations. Further, some span lengths are incredibly long. As such, the sag towards the ground between two successive poles is lower than recommended. Results from at least four spans measured along the MV lines at Wards of Mang’ola and Rhotia indicated span lengths exceeding 50 metres as recommended for safety purposes (TANESCO, 2024). Long spans crossing over the roads were touched, and conductors broken by high trafficking lorries Moreover, MV lines constructed along the roadsides had some poles knocked by vehicles driven by reckless drivers causing the fall of nearby distribution transformers that pose oil spills. Most poles erected alongside the road were not protected by guards whatsoever (Table 3).

Table 3: Span lengths exceeding standards at various places in Karatu district

Ward	Transformers	Span from transformer	Span length (m)	
			Standard	Measured
Mang'ola	100 kVA, 33 kV	2	50	75
	100 kVA, 33 kV	3	50	68
Rhotia	100 kVA, 33 kV	5	50	70
	100 kVA, 33 kV	7	50	80

2.2 Maintenance strategies

The maintenance strategies found are Run-To-Failure (RTF), Preventive Maintenance (PM), Predictive Maintenance (PdM) and Proactive Maintenance (PaM) as defined by (Mkilania & Mjema, 2012). The RTF (46.67%) carried out when there were a total failure and no power to consumers. As such, the transformer might have been reported overloaded or had its supporting poles rotten, but no immediate efforts made to replace the rotten poles or shift some of the connected power consumers to the nearby transformer to avoid overloads. Eventually, the overloaded transformer busted or fell down for rotten poles, posing land oil spills. Although efforts are made to replace the then rotten poles or busted transformer through RTF, the oil spills had already spread. This meant replacement of the rotten or broken poles was done at worst case scenario for lack of the essential items in warehouses. Inspection reports on sampled feeders indicated a substantial number of secondary substations had their pole supports rotten to signal for transformer fall, leading to broken bushings, the situation that causes land oil spills. Rotten poles adjacent to and those supporting the transformer at secondary substations would fall easily through strong winds as natural calamity or knocked by vehicles. The PM (23.33%) and a bit PdM (20.00%), with a combined 43.33%, were next to RTF. The remaining 10.00% was literary, referred to as PaM (Table 4).

Table 4 Matrix summary of power distribution maintenance strategies

Maintenance strategy	Frequency	Proportion (%)
RTF	28	46.67
PM	14	23.33
PdM	12	20.00
PaM	6	10.00
Total	60	100.00

The PM, defined as periodic maintenance (Mageme, 2017), involve such activities as checking the oil level, replenishing and improving transformer earth resistance, tightening loose parts of CBs and replacement of oil, cleaning connecting lids of auto re-closers, installation of transformers to relieve loads of others in the circuit. Predictive Maintenance (Manikandan & Duraivelu, 2021) was rarely applied in the distribution systems. Accordingly, three respondents (19.84%) out of 15 could define the predictive strategy based on tools and equipment. The equipment was serviced beyond their predetermined mileage and time of service such that certain sounds, smells, and vibrations were used to detect the unavoidable limitation of services. No predictive devices (Shil & Anderson, 2019) were installed on the power distribution system to sense and give feedback to responsible personnel. Neither were personnel assigned for predictive maintenance. 10.00% of respondents were well informed on proactive maintenance based on construction and maintenance manuals provided for operations to improve equipment conditions and degradation rate through better design, installation procedures, failure analysis, quality, and scheduling in power distribution systems. Few respondents are aware that Reliability Centred Maintenance (RCM), failed parts analysis that included Root Cause Failure Analysis (RCFA) and Failure Mode and Effect Analysis (FMEA), reliability engineering, age exploration and recurrence control were rarely applied in power distribution systems. The study focused on the assessment of transformer failure through diagnostic testing, internal inspections, teardown inspections and failure analysis (Jaspreet & Sanjeev, 2016).

2.3 Vandalism cases

Other transformer external failure-related causes were noted when the transformer tank was pierced, its cork underneath was removed, and bushing gaskets failed to enable the mineral oil flow out. It could be realized that there was vandalism for the removed or pierced cork prompted by black markets of transformer mineral oil sold as cooking oil for frying potato chips, fuel for vehicles and as medication of wounds (Kirunguru, *et al.,* 2018).

2.4 Manufacturing defects

Meanwhile, some transformers were found with unsatisfactory tank welding. Due to the influence of external environment, temperature, experience skills, welding materials, plates and other factors, the quality results after welding must be satisfactory to avoid welding cracks and blisters, which cause oil leakage. Transformer leaks were most commonly caused by degrading cork gaskets, holes radiator fins or steel tank.

2.5 Summary of Causes of Land Oil Spills

Land oil spills from power distribution systems were summarized as internal-related failures, with 24.42% being a combination of lightning (3.49%) and overloads (20.93%), external-related failures making 75.58% being a combination of vandalism (60.46%), improper construction practices (5.81%), improper maintenance strategies (6.98%) and manufacturing defects (2.33%) (Tables 5).

Table 5. Matrix summary of land oil spill causes

Causes of failure	Frequency	Proportion (%)
Improper construction practices	5	5.81
Improper maintenance strategies	6	6.98
Lightning	3	3.49
Manufacturing defects	2	2.33
Overload cases	18	20.93
Vandalism cases	52	60.46
Total	86	100.00

3. Effects of Land Oil Spills from Power Distribution systems

Oil leaked defective transformers on clay, gravel, sand, silt, gullies, ponds and swamps influenced by improper land surfaces, improper soil types and improper screed concretes. The movements of land oil spills towards humans were observed from internal and external transformer failure related causes.

3.1 Oil leaked defective transformers on clay, gravel, sand, silt, gullies, ponds and swamps

Distribution transformers on improper soil types were 42 (48.84%) followed by improper land surfaces 31 (36.05%) and improper screed concrete 13 (15.11%). The fact is that most human settlements in Karatu district are located on the foots of Mbulumbulu Hills (Rhotia ward), beside lake Eyasi (Mang'ola) and lake Manyara (Endamarariek) where soil types were mostly clay with inclined land surfaces. Secondary substations constructed near gullies, ponds and swamps could stream oil spills (Table 6).

Table 6: Oil leaked defective distribution transformers at soil and water places

Transformer locations	Improper soil types	Improper land surfaces	Improper screed concretes	Total
Clay soils	13	9	4	26
Gravel soils	6	5	2	13
Sandy soils	9	7	3	19
Silt soils	10	7	3	20
Gullies	1	1	0	2
Ponds	2	2	0	4
Swamps	1	0	1	2
Total	42	31	13	86
Proportions (%)	48.84	36.05	15.11	100.00

3.2 Movements of land oil spills towards humans

The movements of land oil spills towards humans were observed from internal and external transformer failure related causes. Meanwhile, the effects of land oil spills towards animals and humans were observed from the transformer corridors, which covered the land surfaces over which the distribution systems were installed. The movements can be presented as a chain starting when the mineral oil leaks from the distribution transformers with fumes directly reaching the animal and human body through inhaling the atmospheric air or contact the leaks on the ground or nearby objects. The oil leak droppings to the ground are absorbed into plants, soils and inland waters. When absorbed into plants, animals and humans are indirect recipient of mineral oils when taking plants for living as food stuff. The same happens to oil leaks reaching the inland water bodies, which are indirectly transferred to animals and humans when drinking the polluted waters (Figure 2). As described earlier, plant food uptake through roots and leaves in the xylemic and phloemic processes, offers a chance for such polluted plants to indirectly reach animals and humans when taking the leaves and roots as foods. People around places with oil spills when interviewed they disclosed only the effects of power blackout as a result of distribution transformer mineral oil vandalism or leaks due to technical faults as explained earlier.

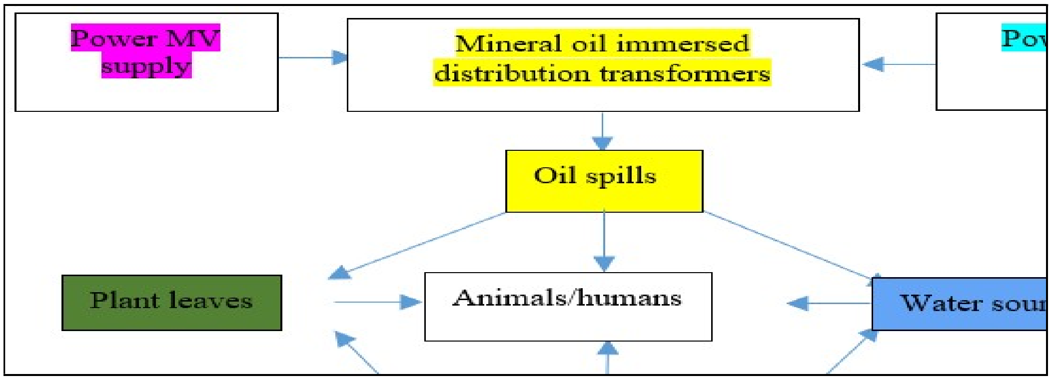

Figure 2: Land oil spills towards animals and humans

However, it was explained by expertise that oil spills have dangerous effects on humans. These effects include blurred vision and other eye problems, headaches, hallucinations, euphoria (sudden feelings of happiness), tiredness, slurred speech, brain damage, coma, convulsions and unusual deaths, nose sores and bleeds, ear infections, asthma, bronchitis, pneumonia and other respiratory diseases. As noted earlier, oil contains high levels of toxic chemicals, including mercury, which can have dangerous effects on humans that come into contact or ingest oil. Oil spill-cleanup workers, for example, suffer from damaged immune, respiratory and cardiac functions and carry high levels of toxicity that have long-term. The chemical reactions, fumes, and possible fires after an oil spill can contaminate the water and air and affect human health. Short-term health symptoms after exposure to an oil spill include memory loss, dizziness and irritability. No large animals were found trapped in selected oil spill places except remains of small organisms of the phylum Arthropoda, which included such familiar forms as lobsters, crabs, spiders, mites, insects, centipedes and millipedes (Plate 1).

Plate 1: Remains of millipedes on oil spills Remains of Nematoda from on oil spills

Remains of phyla Platyhelminthes (flatworms), Nematoda (roundworms) and Annelida (segmented worms), which are a familiar of earthworms were also found simply choked to death by the oil. There is an assumption that large animals not found in oil spill places, moved to other places but likely affected the same way small organisms were or when they ate the remains. Further, if they touched the oil, which finds its way into the skin fur and plumage of the animals it destroys the insulating ability of skin and fur-bearing mammals, and the water repellency of an animal skin hair or feathers, thus exposing these creatures to the harsh elements. Animals find it harder to regulate their body temperatures. Many baby animals starved to death since their parents could detect their natural body scent. Animals that preen themselves to get rid of the oil accidentally swallowed the oil and died due to the toxic effects. Oil is mixed into the water column; animals could come into contact with oil and were exposed in the intertidal zone. When exposed to oil, animals might experience reduced growth, enlarged livers, heart and respiration rate change, skin erosion, and reproduction impairment. In many cases, the animals became blind due to repeated exposure to the oil.

4. Conclusion

The final stage in the delivery of electric power carrying electricity from the transmission system to individual consumers is called power distribution system. It is made up of MV line, distribution substations or secondary substation and consumer loads. Construction practices and maintenance strategies are major external-related factors attributing to land oil spills when carried without specified standards. Although manufacturing defects and vandalism are also external-related factors posing land oil spills, they are a result of improper construction practices and maintenance strategies. Internal-related factors posing land oil spills; overloads and lightning, result from improper construction practices and maintenance strategies. Effects of transformer mineral oil spills degrade the environment by posing health risks to human beings and biodiversity.

The power utility (TANESCO) should base on the formalized applications rather than subjective decision for better results. It is also eligible for enacting regulations that provide conducive environment for employees to perform. Application of new technologies regarding construction practices and maintenance strategies in power distribution systems can provide little or no chance for vandalism cases. The Ministry of Energy must put in place policies for control of transformer mineral oil spills and provide education for capacity building to both TANESCO employees and members of the public.

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