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Investigation on the Causes of Failure and Repair of Manual Water Pump

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Abstract Manual water pumps are crucial in providing reliable water supply, particularly in rural communities where electricity supply is unavailable. However, their frequent failures and subsequent need for costly repairs have often resulted in community frustration and abandonment. This study investigates failure of manual water pump systems, encompassing experiments such as tensile strength testing, optical microstructural analysis, X-ray fluorescence (XRF) elemental analysis, weight loss trials, and water quality assessment. The outcome of the Ultimate Tensile Strength (UTS) for the New and Old Pipe Samples was 392.57 N/mm^2 and 371.22 N/mm^2 respectively. Optical microstructural analysis reveals that older galvanized pipes have larger grain sizes, potentially increasing susceptibility to corrosion. XRF analysis uncovers differences in elemental composition between old and new galvanized pipes, particularly higher zinc concentrations in the old pipes, suggesting more effective galvanization. Weight loss experiments demonstrate accelerated corrosion rates in old pipes, underlining the impact of aging and the need for corrosion protection measures. Water quality analysis indicates stable element concentrations (Na, Mg, Mn) but slight variability in iron levels, raising concerns about potential contribution of corrosion to water pollution. By investigating the factors contributing to pump malfunctions and improving maintenance practices, this study contributes significantly to the global effort to combat the water crisis. Furthermore, the selection of suitable materials for pump installations is explored to mitigate corrosion-related challenges, particularly concerning galvanized pipes.

Keywords: Corrosion, Galvanised pipes, Manual pump, Microstructure, Tensile strength, Water quality
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I. Introduction

All mankind, regardless of location, depend on water and there is no viable substitute for it. The human body is susceptible to quite a number of ailments that might be fatal if there is no enough clean water available for drinking. Muscle twitching, nausea, rapid pulse, seizures, dizziness, fainting, loss of consciousness, red, hot, and dry skin, hallucinations, constant indigestion, and heart burn, are just few of the illnesses that the body can be affected with in cases of severe dehydration. As such, the positive and negative effects of water intake are evidently clear [1]. By 1854, the link between water and the spread of cholera during an outbreak in London was established [2-3].

Availability of clean water is a crucial global issue, and different groups and governments are actively attempting to address it. The United Nations General Assembly on the 23 of December 2003 announced that 2005 to 2015 is "the International Decade for Action "Water for Life" [4]. The United Nations has identified clean water and sanitation as essential human rights, and the Sustainable Development Goals (SDGs) include a specific target to ensure universal access to safe and affordable drinking water for all by 2030. Many countries and

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organizations have made commitments to support this goal, and progress are being made at increasing access to clean water in many parts of the world. However, there are still significant challenges to overcome. According to the World Health Organization, 2.2 billion people lack access to safe drinking water [5].

Human has devised several ways to make provisions for sufficient clean water supply. Among these is use of water pumps, either powered manually or using electricity. Hand pumps are water-lifting devices that can be operated manually to withdraw water from surface water sources, groundwater and reservoirs, or to pump water into distribution systems [6]. The poor attention on operation and maintenance of the water systems (handpumps) usually leads to their dysfunction or deterioration thereby prompting premature replacement of their components, which most at times results in significant losses [7]. Manual pumps sometimes have limitations in serving large communities and require frequent maintenance. However, the manual water pumps are seen to be cost-effective in providing quick access to water and reducing the risk of accidents, where there is no electricity supply. Electric pump sets on the other hand, are constrained by electricity supply, making manual hand pumps efficient in rural areas with consistent water demand.

However, manual pumps are prone to failure and often require maintenance [8-9], often leading to frustration among communities and abandonment of the pumps as shown in Figure 1. Understanding the causes of failure and effective remediation are crucial to ensuring the sustained functionality of these essential devices. This study delved into the intricacies of manual water pump systems, investigating the underlying reasons behind their failures and exploring practical repair and maintenance strategies. By focusing on this critical aspect of water infrastructure, this project seeks to contribute to the sustainability and resilience of manual water pump systems and, in turn, enhance access to clean water for communities in need.

Figure 1: Typical Images of Abandoned Manual Water Pumps

II. Materials and Method

A. Materials and Equipment

The selected manual water pump for this study is located within the prestigious University of Ilorin, Ilorin, Kwara State, Nigeria (with latitude 8.483966 and longitude 4.673264 as its coordinates). The selected manual water pump exhibits typical features and components commonly found in manual water pump systems. It also has a history of frequent failures or issues that require repair. This study employs a case study approach to analyse the causes of failure and repair of a specific manual water pump. By using a faulty manual water pump as a case study, the variables behind its failure were carefully examined, the repair procedure was comprehensive, and useful lessons that may be applied to comparable circumstances were derived.

Standard tools, equipment and materials were employed in the study to facilitate data collection and testing using standard tensile testing procedures and repair. These include adjustable wrench (to loosen and remove corroded or stuck fittings, such as pipe connections or valve handles), socket and ratchet (to remove bolts, nuts, or other fasteners holding the pump's components together), pliers (to grip and bend small objects like wires or fittings, and to loosen stuck parts), screwdrivers (to remove screws, clips, or other fasteners securing the pump's components).

Other materials employed include hammer (to tap or dislodge corroded parts and drive fittings or fasteners into place), punch (to remove old or corroded parts, such as pipe fittings or valve seats), Teflon tape (to seal threaded connections and prevent leaks during reassembly), WD-40 penetrating oil (to loosen stuck parts and protect metal components from corrosion during dismantling), beakers, ethanol solution, and concentrated acids (H_2SO_4, KCl) (for preparing weight loss experiments and corrosion analysis and Atomic Absorption Spectrometer (AAS) (used for elemental analysis of underground water samples)

B.

i. Data Collection

On-site inspections were conducted to evaluate the physical condition of the manual water pump before and during the dismantling process. Observations focused on symptoms of pipe damages due to wear, corrosion and breakage that could indicate potential failure points. Figure 2 shows some components of the hand pump.

Figure 2: Components of Dismantled Hand Pump (a) Discharge Pipe, (b) Suction Pipes with Sockets, (c) Pump Cylinder, and (d) Connecting Rod with Socket

ii. Material characterization

In addition to on-site observations, material characterization tests were conducted on some components of the pump. Galvanized pipes were removed from the dismantling machine and new ones were purchased. Both were characterized for tensile strength, microstructural, chemical, and corrosion properties.

For tensile strength test, the procedures in ASTM E8 were carefully followed ensuring adherence to recognized testing standards and maintaining data accuracy and reliability. Optical microstructural analysis was carried out on samples with cut dimensions of 15 x 15 mm. X-ray fluorescence (XRF) analysis was conducted to obtain their elemental compositions.

The weight loss experiment utilized new and old galvanized pipe samples. 12 beakers were used for preparing solutions including acidic H_2SO_4 solutions at 20%, 40%, and 60% concentrations and base/salt solutions (KCl) at the same concentrations. The procedure encompassed sample preparation by cutting the pipes, and pickling in ethanol solution in separate beakers. The coupons were dried and initial weight (W_1) measurements was taken. The coupons were thereafter immersed in separate beakers, and left for 24 hours. The coupons were thereafter removed, rinsed in distilled water, dried and reweigh to obtain final weight (W_2). Weight loss rate was estimated using Equation 1.

$$Percentage\ weight\ loss\ (g/hr) = \frac{W_1 - W_2}{Exposure\ time} \quad (1)$$

For the water analysis, underground water sample was collected after the installation of the manual water pump. In order to determine the concentrations of Lithium, Sodium, Magnesium, Calcium, Manganese, and Iron in the underground water sample. Concentrated nitric acid was used for digestion of the water sample and elemental analysis was carried out using Atomic Absorption Spectrometer (AAS).

C. Repair Procedure

The repair process aimed to not only restore functionality to the manual water pump but also to introduce enhancements to its durability and performance. A systematic disassembly and reassembly process was thereby employed.

Each component of the manual water pump was carefully disassembled using appropriate tools such as wrenches, pliers, and screwdrivers. Special attention was given to identifying common failure points, such as worn-out seals, corroded pipes, and damaged valve mechanisms. Detailed observations and measurements were made to assess the condition of critical components. Parts with severe wear or corrosion were documented and compared with new components to analyze the extent of degradation. Corroded metal surfaces were cleaned using WD-40 and abrasive pads to remove rust and improve the adhesion of protective coatings. Damaged threads and fittings were reconditioned using punches and chisels where necessary to ensure proper alignment during reassembly.

Upgraded cylinder component (Figure 3) and highly durable galvanized pipes (Figure 4) were installed to reduce the likelihood of future corrosion. Teflon tape was applied to all threaded connections to enhance sealing and prevent leakage under varying operational pressures. Reassembly was conducted in a step-by-step manner, ensuring all seals, washers, and joints were properly placed. Thereafter, the repaired system underwent comprehensive testing, including a functional test to verify smooth operation and water discharge (as shown in Figure 5). Leakage test to check for leaks at connection points during operation, and a load test to assess performance under varying usage conditions, ensuring the effectiveness of the repairs and improvements were carried out.

Figure 3: Installed Upgraded Cylinder

Figure 4: Repair and Assembling of (a) New High-durability Galvanized Pipes (b) Cylinder Insertion into Borehole

Figure 5: Testing of the Repaired Hand Pump

III. Results and Discussion

This section presents the results of various experiments carried out on the old and new galvanized pipes from tensile test, optical microscopy, X-Ray Fluorescence, weight loss and water analysis.

A. Tensile Strength Test

The outcome of the tensile test performed is presented in Table 1

Table 1: Tensile Strength Result

Pipe Name	Force at Peak (N)	Stress at Yield (N/mm²)	Area (mm²)	Strain @ Peak (%)	Force @ Upper Yield (N)	Strain @ Yield (%)
New	15702.5	392.4	40.0	6.6	15697.4	6.5
Old	13568.2	321.9	36.6	7.3	11765.5	3.8

From the above table, the average UTS of both old and new pipes were determined using equation 2.

$$Ultimate\ tensile\ strenght, \sigma = \frac{\text{Force at Peak}}{Area} \quad (2)$$

The average UTS for old pipe samples is 371.22N/mm^2, while that of the new pipe samples is 392.57N/mm^2.
Also, average Yield Strength (YS) obtained for the old pipe samples is 321.900N/mm^2, while the average YS for the new pipe is 392.434N/mm^2. Notably, the average UTS and YS values of the newly installed pipe samples exceeded those of the old pipe samples from the failed pump. The values suggest that the new pipes exhibit superior material quality and increase durability. The selection of these pipes for repair will ensure enhance safety and longer maintenance intervals in water pump applications due to their superior properties. Stress-strain curves of tested pipes are shown in Figure 6.

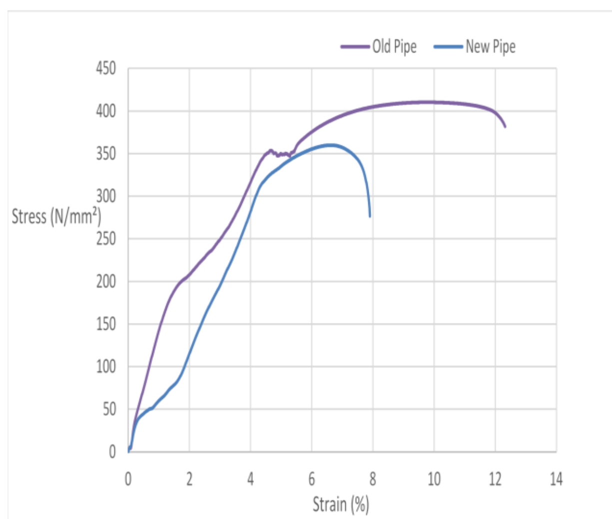
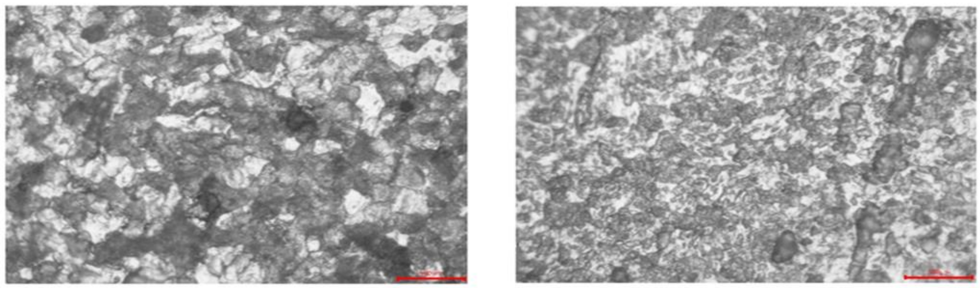


Figure 6: Stress/Strain Curve of Old and New Pipe

B. Optical Microstructural Test

The micrographs of sample of old and new galvanized pipes are presented in Figure 7. Under identical magnification (50X), it becomes evident that the old galvanized pipes exhibit larger grain sizes compared to the new ones. This distinction is of considerable importance as it implies a higher susceptibility to corrosion for the old, galvanized pipes, given that larger grain sizes can facilitate the penetration of corrosive agents and weaken the material's structural integrity [10].



(a) (b)

Figure 7: Micrographs of (a) Old and (b) New Galvanized Pipes

C. XRF Analysis (X-Ray Fluorescence) Test

The results of XRF analysis carried out on the old and new galvanized pipes are presented in Table 2 and Table 3 respectively.

Table 2: Data from the New Galvanized Pipe

Element	%	+/-	%	+/-	
	First Point Values		Second Point Values		Average Concentration
V205	0.0	0.034	0.0	0.0	-
Mn3O4	0.114	0.067	0.0	0.0	-
MnO	0.106	0.062	0.0	0.0	-
Fe2O3	99.068	5.737	91.024	1.356	95.0460
Fe3O4	95.604	5.537	87.841	1.308	91.7225
FeO	89.369	5.175	82.112	1.223	85.7405
NiO	0.0	0.033	0.0	0.037	-
ZnO	37.981	5.027	45.058	1.18	41.52
V	0.0	0.019	0.0	0.0	-
Mn	0.082	0.048	0.0	0.0	-
Fe	69.278	4.012	63.653	0.948	66.4655
Ni	0.0	0.026	0.0	0.029	-
Zn	30.63	4.054	36.337	0.952	33.48

Table 3: Data from the Old Galvanized Pipe

Element	%	+/-	%	+/-	
	First Point Values		Second Point Values		Average Concentration
V205	0.0	0.175	0.0	0.175	-
Mn3O4	0.0	0.0	0.0	0.0	-
MnO	0.0	0.0	0.0	0.0	-
Fe2O3	4.186	0.134	4.217	0.323	4.2015
Fe3O4	4.039	0.13	4.07	0.312	4.0545
FeO	3.776	0.121	3.804	0.292	3.7900
NiO	0.117	0.029	0.098	0.01	-
CuO	0.15	0.055	0.15	0.016	-
ZnO	118.715	0.247	118.695	0.41	118.71
PbO	1.202	0.06	1.213	0.129	-
V	0.0	0.098	0.0	0.0	-
Pb	1.113	0.056	1.123	0.119	-
Mn	0.0	0.0	0.0	0.0	-
Fe	2.927	0.094	2.949	0.226	2.9380
Cu	0.12	0.044	0.12	0.013	-
Ni	0.092	0.023	0.077	0.008	-
Zn	95.738	0.199	95.722	0.331	95.73

As shown in tables 2 and 3, the concentration of zinc in the old pipes is higher in comparison to the new pipes. This discrepancy implies that the galvanization process applied to the new pipes may not have provided a sufficient zinc coating that may render them to be susceptible to corrosion. Conversely, the concentration of iron in the old pipes is noticeably lower when compared to the new pipes. This observation further underscores the potential susceptibility of the new pipes to corrosion, as higher iron content can contribute to increased corrosion rates [11-12].

D. Weight Loss Experiment

The outcome of the weight loss experiment carried out has been presented in Table 4. From the table, is evident that the rate of corrosion in the old, galvanized pipe samples is notably accelerated when compared to their new counterparts under identical exposure to both acidic and base solutions. This observation aligns with the corresponding higher percentage decrease in weight observed in the old pipes as opposed to the new ones. The differences in corrosion rates and weight loss between the old and new galvanized pipes underscores a critical aspect of this investigation into the causes of failure and repair of the manual water pump. It suggests that the aging of the galvanized pipes, as manifested in the old samples, has rendered them more susceptible to corrosion-induced deterioration. This susceptibility has been particularly pronounced in the presence of both acidic and base solutions [11-12].

Table 4: Weight Loss Experiment

New Specimen (Acid Solution)	Initial Value (g)	Final Value (g)	Weight Loss (g)	$Weight\ Loss\ Rate(g/hr); = \frac{Weight\ Loss\ (g)}{Exposure\ Time(24hrs)}$
Sum of A1, A2 & A3	15.06	13.09	1.97	**0.082**
Old Specimen (Acid Solution)	Initial Value (g)	Final Value (g)	Weight Loss (g)	
Total of A4, A5 & A6	17.99	12.72	5.27	**0.219**
New Specimen (Base Solution)	Initial Value (g)	Final Value (g)	Weight Loss (g)	
Total of B1, B2 & B3	15.34	15.26	0.08	**0.003**
Old Specimen (Base Solution)	Initial Value (g)	Final Value (g)	Weight Loss (g)	
Total of B4, B5 & B6	17.22	16.69	0.53	**0.022**

E. Water Analysis Test

The water analysis test has been carried out to ascertain not only its suitability for use including drinking but also to establish its properties with respect to its corrosive tendencies on the newly installed pipes. The water analysis result is shown in Table 5.

Table 5: Water Analysis Test Result

Li	Na	Mg	Ca	Mn	Fe
0.025, 0.044	1.998, 1.998	4.484, 4.484	6.006, 6.005	0.265, 0.270	7.927, 7.950

The examination revealed averagely, the consistent levels of Sodium (1.998), Magnesium (4.484), and Calcium (6.006) across readings, signifying stability in these elements' concentrations post-reinstallation of the pump. However, minor fluctuations were observed in Lithium (ranging from 0.025 to 0.044) and Iron (0.265 to 0.270) concentrations between readings, these changes were relatively insignificant over time. Overall, this consistency reflects a stable water chemistry profile, essential for various applications, including water supply systems. However, the persistent presence of Iron (7.927 to 7.950) raises concerns regarding potential corrosion in metal pipes within the system. As per World health organization (WHO) standards for drinking water quality, the Iron concentration surpasses the recommended levels, highlighting the necessity for periodic monitoring and management to avert possible corrosion-related issues, ensuring both water safety and infrastructure integrity. Iron is an essential element in human nutrition, particularly in the iron oxidation state. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability range from about 10 to 50 mg/day [13].

IV. Conclusion

This investigation delved into understanding the causes of failure and repair strategies for a manual water pump, focusing on galvanized pipe components and water chemistry. Through various tests including Tensile Strength, Optical Microstructural analysis, XRF Analysis, Weight Loss Experiment, and Water Analysis, crucial insights were gathered. These findings revealed stronger material properties, evidenced by higher Ultimate Tensile Strength (UTS) and Yield Strength (YS), while the presence of larger grain sizes in older pipes indicated a higher susceptibility to corrosion. Furthermore, the XRF Analysis highlighted better galvanization in older pipes but raised concerns about increased corrosion vulnerability in newer pipes due to elevated iron content. The Weight Loss Experiment accentuated accelerated corrosion rates in older pipes. Post-repair water Analysis displayed stable essential element concentrations but signaled the ongoing need for monitoring to prevent corrosion. Generally, these findings emphasize the necessity of consistent maintenance, enhanced protection measures for older pipes, and continuous monitoring of water chemistry to prolong the operational lifespan of the water pump system, providing valuable insights for maintenance strategies and material selection to mitigate failure risks and improve system durability.

For manual water pump installations, it is therefore recommended that corrosion-resistant alternatives like PVC and stainless-steel pipes should be considered to extend the system's lifespan. Thorough water analyses should be Conducted before installation to understand elemental composition, especially iron levels, aiding material choice and corrosion prevention. Regular maintenance schedules for inspections and early issue detection should be implemented. Suitable coatings or inhibitors should be applied for corrosion protection, especially on galvanized pipes. Stringent quality control in manufacturing should be advocated to meet corrosion resistance standards and reduce maintenance needs. Pump cylinder conditions should also be assessed so as to replace worn or corroded parts promptly.

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