STOP THE ROT

Report II: Rapid corrosion of handpumps

ACTION RESEARCH ON HANDPUMP COMPONENT QUALITY AND CORROSION IN SUB-SAHARAN AFRICA

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Cover Photo: Removal of corroding riser pipe in Hoima District, Uganda in 2012 (*source*: Larry Bentley). In 2018 the Government of Uganda issued a directive to prevent further use of galvanised iron riser pipes throughout the country.

This report is dedicated to Dr Otto Langenegger

Working for the World Bank in West Africa in the late 1980s, Dr Otto Langenegger observed handpump corrosion and started to make observations and take measurements. I thank you for taking such a strong personal and professional interest in this topic and documenting it so thoroughly. Your extensive work on the topic of handpump corrosion over 30 years ago and your descriptions and findings have been invaluable

Thank you for making contact back in 2019.
And thank you for the delightful discussions that we have had in our face-to-face meetings.
You have inspired me greatly!

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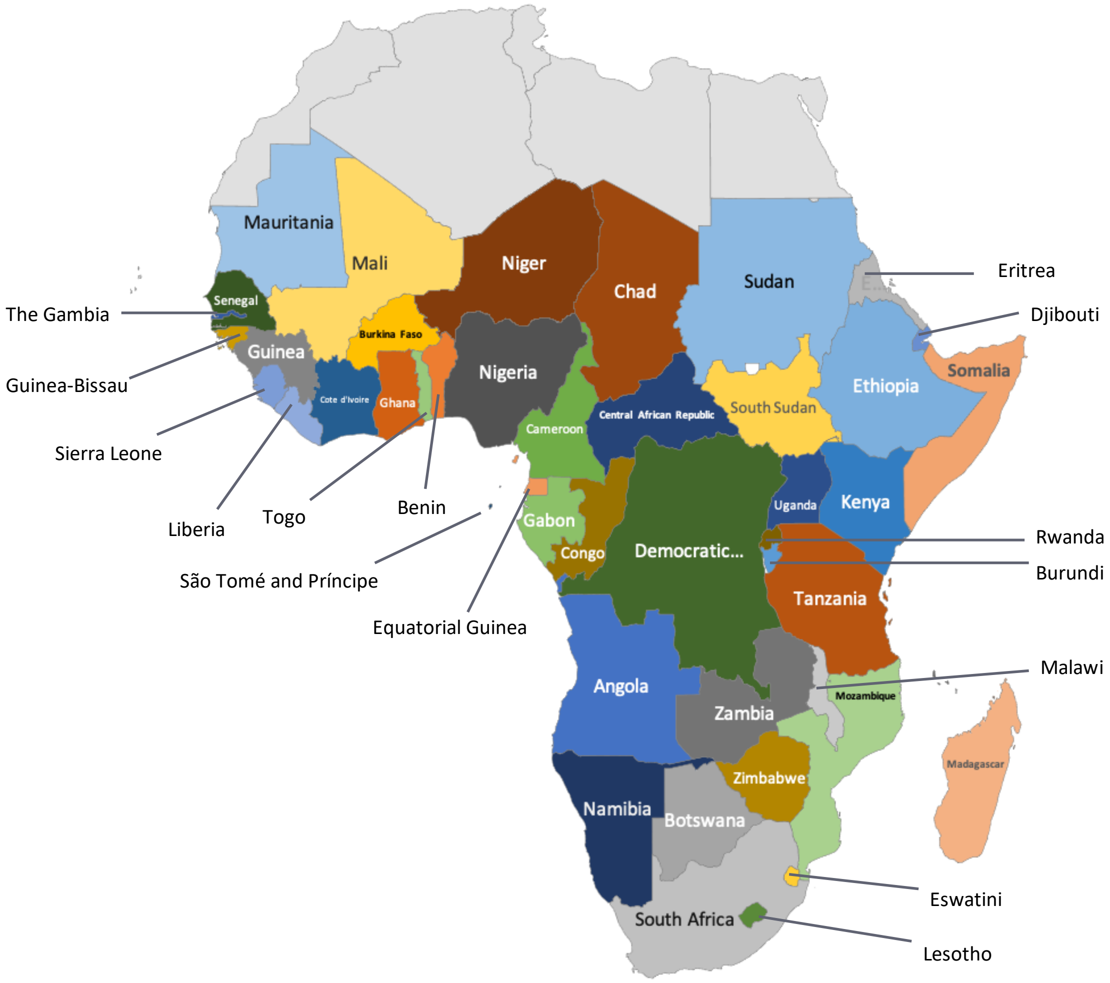
ABBREVIATIONS AND ACRONYMS

ANSI	American National Standards Institute
DRC	Democratic Republic of the Congo
EC	Electrical Conductivity
FCDO	Foreign, Commonwealth & Development Office
GI	Galvanised Iron
HPB	Handpump Boreholes
JECFA	Joint FAO/WHO Expert Committee on Food Additives
JICA	Japan International Cooperation Agency
JMP	Joint Monitoring Programme
KEFINCO	Kenya–Finnish Cooperation Project
NGO	Non-governmental Organisation
PMTDI	Provisional Maximum Tolerable Daily Intake
ppm	Parts Per Million
PB	Pumpenbose
PVC	Polyvinyl Chloride
RWSN	Rural Water Supply Network
SIDA	Swedish International Development Agency
SOMAP	Sustainable Operation and Maintenance Programme (Zambia)
SS	Stainless Steel
SSA	Sub-Saharan Africa
UNICEF	United Nations Children’s Fund
UPGro	Unlocking Potential of Groundwater for the Poor
UPVC	Unplasticised Polyvinyl Chloride
WHO	World Health Organization

MAP SHOWING COUNTRY NAMES AND LOCATIONS



SUMMARY

In January 2021, *Ask for Water* GmbH and Skat Foundation, under the Rural Water Supply Network (RWSN), launched a 15-month initiative called 'Stop the Rot'. It set out to document the scale and extent of rapid handpump corrosion and the use of poor-quality handpump components in sub-Saharan Africa (SSA) and to bring about actions to address these problems. The term 'rapid corrosion' emphasises that the pumps are not able to meet their expected design life due to high rates of corrosion. The two interlinked issues of rapid corrosion and poor-quality components contribute to low performance, rapid failure of handpumps and poor water quality, all of which can result in abandonment of the handpump sources and thus force users to return to using contaminated or distant sources. These issues are recognised as problematic by some water sector practitioners and organisations, but have in general been poorly documented.

Corrosion is the attack of the surface of materials by chemical processes and affects concrete, glass, plastic and materials that contain iron. In water supply distribution systems, corrosion is the partial dissolution of the materials that make up the treatment and supply systems. In certain circumstances, all water can be corrosive. Corrosion may lead to structural failure and leaks, as well as deterioration of chemical and microbial water quality. The World Health Organization (WHO) does not provide guideline values for iron in drinking water. The WHO acknowledge that corrosion control is an important aspect of the management of a drinking water system but does not explicitly refer to corrosion concerns in the case of handpumps or sources that rely on other groundwater water-lifting technologies.

Research into corrosion in West Africa within the Handpumps Project of the World Bank in the 1980s concluded that: (i) total iron concentration in natural groundwater is rarely greater than 1 mg/l; (ii) corrosion is usually the cause of the red water (iron) problem in handpump-equipped wells; (iii) galvanisation does not protect rising mains and pump rods from corrosion under the prevailing groundwater conditions in the subregion (pH < 6.5); and (iv) the less a corrosion-affected handpump is used, the more serious the iron problem becomes. All of these observations still hold true. In addition to low pH levels, high salinity and high chloride levels can also accelerate handpump corrosion, but less documentation on these phenomena is available. Recent research indicates that there may also be leaching of lead into groundwater from brass/bronze components.

This study finds that communities in over 20 countries in SSA still face the problem of rapidly corroding handpumps (see Figure S1 below). Evidence includes academic research, reports (both old and more recent) and observations that have been shared. To date, there have been relatively few systematic studies of this problem.

There may be cause for optimism in some countries where, despite aggressive groundwaters, the 'iron problem' seems to have been addressed (notably The Gambia and Ghana). In some countries governments are taking action to prevent rapid corrosion, such as by banning or trying to prevent the use of galvanised iron (GI) pipes (e.g. Uganda, Zambia and Chad). However, the problem seems to be continuing in many other countries, with varying levels of documentation and research. In Niger, for example, there was a corrosion problem in the past but the current status is simply not known. In Burkina Faso the rapid corrosion problem is well documented but there is a lack of action. There are numerous other countries where the phenomenon has been observed and documented to a limited extent.

The combination of GI pipes or rods and water with low pH will cause the GI components to rapidly corrode. There have been observations of components requiring replacement within a few months to a couple of years, whereas they should last eight to 10 years. While there has been confusion about whether iron observed in groundwater is coming from the aquifer, or caused by the corrosion of the pump itself, simple tests do exist to determine the source. These involve measuring the change of colour in the pumped water.

Preventing rapid corrosion of handpumps may not be as simple as it may appear. A key aspect is ensuring that materials other than GI for riser pipes and pump rods are used in water with low pH levels. Alternatives include certain grades of stainless steel (SS) or, for riser pipes only, unplasticised polyvinyl chloride (PVC). However, the International Specifications and Indian Standards for the India Mark pumps do not include these options and so guidance is quite limited.

Furthermore, there are indications that the SS option may cause rapid corrosion of the water tank, while PVC can break and problems are faced with maintenance due to rethreading challenges. Where water levels allow, the corrosion-resistant option of the Afridev pump provides an alternative to the India Mark pump. There are also alternative corrosion-resistant propriety handpumps on the market (i.e. designs that are not in the public domain). Motorised pumps may also be an option, provided that non-corrosive riser pipes are installed. However, introducing a new pump into any setting requires consideration of capital and maintenance costs, supply chains for pumps, and spares and maintenance skills.

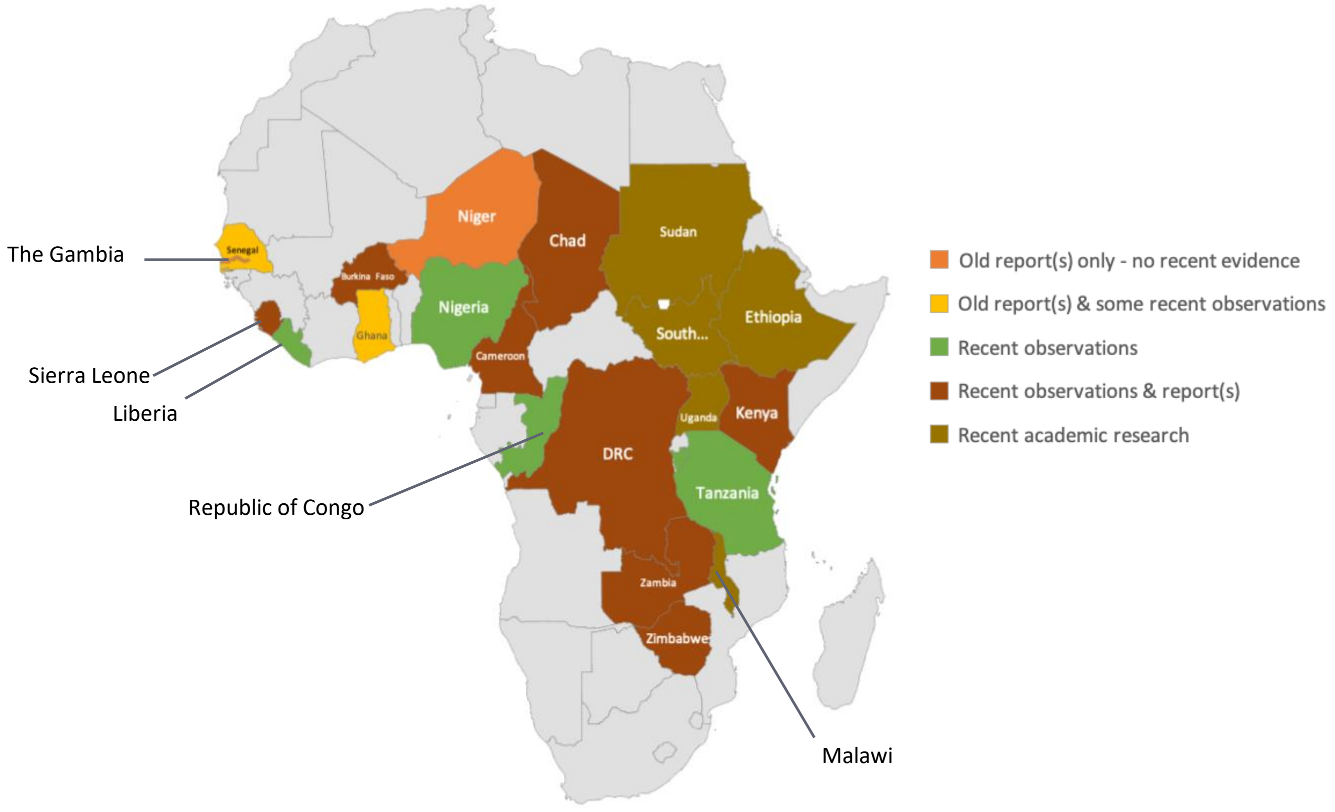


FIGURE S1 COUNTRIES WITH EVIDENCE OF HANDPUMP CORROSION

Despite its prevalence, rapid corrosion of handpumps is a topic that has remained on the margins of many in-country water supply policies and programmes. Despite the fact that handpumps will continue to remain important for decades to come – particularly for remote, rural populations – the rapid corrosion problem barely features in global discourse. The realities faced by many users have simply not been sufficiently heard. If the 'iron problem' continues to be ignored, those living in areas where groundwater has a low pH, high salinity or high chloride will simply be left behind and countries where this is widespread may actually witness drinking water supply coverage levels declining over time.

Rapid corrosion is not only an issue for handpumps, but also potentially for the riser pipes in motorised pumps used for point sources, or which feed into reticulated systems. The realities of rapid corrosion of all groundwater systems need to be better understood and taken into consideration in project design and implementation. Notably, corrosion is not simply confined to rapid or early-life corrosion. All components that are submerged in, or and out of, water will eventually corrode, and so corrosion must be considered as part of the long-term maintenance of handpump (or motorised pump) water supplies.

In order to take the issues raised by this study forward, it is recommended that:

- **RWSN, other global platforms and international agencies** should use the information in this report, as well as the other two reports from the Stop the Rot initiative, as a basis for raising awareness of:

  - The ongoing reliance on handpumps in SSA, despite growing interest in groundwater systems that use other energy sources, including solar, and in piped supplies.
  - The phenomenon of rapid handpump corrosion, including the causes, effects, impacts and mitigation measures (together with their ongoing challenges).
  - The importance of determining whether rapid handpump corrosion takes place in all SSA countries.
  - The need to consider corrosion as part of the long-term maintenance of all water supplies that rely on groundwater, including handpumps.
- **Donor/funding agencies** should:
  - Ensure that their grantees are aware of rapid corrosion of handpumps, report on it when it is observed or suspected (through monitoring or when undertaking rehabilitation programmes) and support the grantees to understand more about the extent of the problem and actively seek solutions.
  - Support academic organisation(s) to develop a continental map and national maps that illustrate the likelihood of low pH values in SSA, incorporating data on population densities where this is available.
  - Consider funding organisations and/or consultants to:
    - Document what has reduced or mitigated handpump corrosions in those countries where it has been addressed.
    - Investigate the performance of handpumps whereby components have been replaced in order to prevent rapid corrosion and examine whether the new solutions are viable in the short, medium and long term. Studies should include examination of possible galvanic corrosion of tanks and cylinders or failing UPVC.
    - Document what is happening in countries where there is limited evidence of rapid handpump corrosion, which may be currently ignored.
  - In all cases, the information should be made available in the public domain.
- **National governments and their development partners, as well as other implementing organisations** should:
  - Ensure that assessment and post-construction monitoring mechanisms incorporate questions about user perceptions of water quality such as taste, smell and appearance and, if concerns are raised, follow up with studies to identify the cause of the problem (which may include rapid corrosion). Ensure that any studies are placed in the public domain.
  - Consider the options available to prevent rapid corrosion or to mitigate its effects, such as installing a corrosion-resistant option of the Afridev pump (if required pump depth allows), installing another corrosion-resistant pump, use of SS pump rods and riser pipes or use of UPVC riser pipes and SS pump rods for the India Mark pumps, use of a motorised pump with non-corrosive riser pipes. If there is no option but to use GI pipes and rods, these need to be replaced more frequently.
  - It may be necessary to review handpump standardisation policies and standards across the country. In case changes to the components are made that are not in the International Standards, there should be monitoring of pump performance before widescale rollout. Note that any changes in standardisation policy will require investments and support to ensure the availability of spare parts, and to ensure that handpump mechanics, drillers and pump caretakers are trained in the installation and maintenance of variants of existing pumps or new types of pump.
  - In the case of new sources, or for rehabilitation, always undertake water quality testing (including pH, electrical conductivity and turbidity) prior to installation to determine whether the groundwater source is aggressive and likely to cause rapid corrosion of GI pipes, pump rods and the pump cylinder.
- **Lead international agencies** should form an action group on handpumps (perhaps incorporating other groundwater lifting methods). The action group should comprise not only international agencies, but individuals and organisations that are trying to preventing rapid corrosion of handpumps in-country. The action group should:

  - Provide a platform for learning and exchange on handpump issues (including corrosion) and advocate for investments into studies that examine the effectiveness of alternatives to the installation of GI riser pipe and pump rods.
  - Engage in policy dialogue with governments, donor agencies, non-governmental organisations and academics that are working in the countries where rapid corrosion has been identified as a problem.
  - Where appropriate, make policy recommendations.
- **The WHO** should expand its guidance on corrosion control to include corrosion mitigation measures for handpumps (and other groundwater lifting installations) in their next update of the 'Guidelines for drinking-water quality' and incorporate this issue into the next edition of their 'Guidelines for small drinking-water supplies'.

INTRODUCTION

In January 2021, *Ask for Water* GmbH and Skat Foundation, under the Rural Water Supply Network (RWSN),[1] launched a 15-month initiative to document the scale and extent of rapid handpump corrosion and the use of poor-quality handpump components in sub-Saharan Africa (SSA) and to bring about actions to address these problems. These two interlinked issues contribute to poor handpump performance, rapid handpump failure and poor water quality, all of which can ultimately lead to abandonment of the handpump sources, thus forcing users to return to contaminated or distant water supplies. The initiative is referred to as 'Stop the Rot'.

This is the second of a set of three reports produced by the initiative. It provides an introduction to the topic of corrosion and its causes, and an overview of the effects of handpump corrosion, reflecting on over three decades of experience. It also collates experiences of handpump corrosion in select SSA countries, detailing concerns alongside what has been learned and achieved to date to address the problem. Report I estimates the reliance on handpumps in SSA,[2] reviews the literature on handpump functionality and performance, and synthesises information on handpump technical quality from a number of studies and assessments. Report III reflects on the existing guidance to quality assurance of handpump components and includes a collation of examples of poor quality. The third report also examines handpump supply chains through a case study of Zambia.

Based on analysis of the most recent data published by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) through the Joint Monitoring Programme (JMP), it is estimated that 18.5% of the population in SSA rely on about 700,000 handpumps to provide them with their main drinking water supply. Handpumps have revolutionised access to safe, reliable water supplies in low-income countries, particularly in rural areas, providing a viable alternative to contaminated surface water and open wells. However, limited ability to transport large quantities of water coupled with a lack of storage capacity at the home means that water from a handpump is usually fetched on a daily basis (Curtis, 1986).

It has been estimated that between 16% and 58% of handpumps in SSA countries are non-functional, varying by country and definition (Foster, Furey et al., 2019; Danert, 2022a). Concerns over low performance, breakdown and abandonment of handpumps have been raised for decades. A breakdown of even a short duration can result in the use of unsafe surface water supplies or require users to spend more time collecting water from a more distant source (Anscombe, 2011; Thibert, 2016). Water service failure impacts negatively on health and can inhibit other human development gains (Hunter et al., 2009; 2010; Baguma et al., 2017). Handpump breakdowns can also lead to overcrowding at neighbouring improved sources and even to conflict (MacDonald et al., 2019).

Water services underperform and fail for a variety of reasons. In the case of handpumps, all components need replacement at some stage, and fast-wearing parts need to be replaced more frequently. The use of substandard components undermines performance. Such components may wear very rapidly, break prematurely or cause another component to fail. Furthermore, if components of inappropriate material are installed in aggressive groundwater, they will rapidly corrode. The term 'aggressive' refers to the ability of the groundwater to corrode, disintegrate and deteriorate materials it is in contact with. All components that are permanently submerged in, or in and out of, water will eventually corrode, but the lifetime of a pump is shortened significantly when galvanised iron (GI) pump rods and riser pipes are installed in water with a pH of less than 6.5.[3] The result is that the water, when pumped after a period of rest, is turbid, reddish in colour, has an unpleasant taste and can stain. In these circumstances, pump performance will diminish quickly and the pump can fail prematurely.

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[1] The RWSN developed out of the Handpump Technology Network.

[2] This study includes Sudan within its definition of SSA. Several island states (Cape Verde, Mayotte, Mauritius, Reunion, Seychelles and St. Helena) have not been included due to a lack of data on groundwater point sources.

[3] pH measures the relative concentration of hydrogen ions in water and indicates whether the water will behave like an acid or alkaline solution. The pH range is 0–14, with 7 indicating a neutral solution.

Water supply practitioners have been concerned with the related challenges of: (i) ensuring the quality of handpump components; and (ii) preventing rapid corrosion of certain components since the 1980s. The consistent quality of handpump components and the use of appropriate materials is underpinned by national and organisational policies and practices. Since the shift away from the centralised, hardware-based water supply projects of the 1980s, the challenges of rapid corrosion and poor-quality components have largely been neglected. Exceptions include efforts in some countries to mitigate rapid corrosion (notably Uganda), interest to understand and/or address the corrosion challenge by select organisations,[4] and attempts to improve quality assurance within the supply chain by some organisations. Reflecting the reduction of interest in handpump technology by international donors from the mid-2000s, the RWSN is no longer involved in handpump quality assurance or design modifications, and international handpump standards committees are no longer active.[5]

Judging from the concerns about rapid handpump corrosion and poor-quality pump components raised regularly within the online discussions of the RWSN Sustainable Groundwater Development group,[6] these two challenges remain prevalent. However, relatively little academic research on rapid handpump corrosion or handpump component quality means that the extent and scale of these problems is not well documented. Given the ongoing extensive use of handpumps in SSA, and concerns about low functionality, it is perplexing that only a few international development partners (including the UK Foreign, Commonwealth & Development Office – FCDO, Japan International Cooperation – JICA) and UNICEF, a few governments and non-governmental organisations (NGOs) (including WaterAid and Inter Aide) are actively engaging in the related challenges of handpump quality and rapid corrosion. Neither are these topics prominent in global political dialogue.

This initiative sets out to investigate the scale and extent of rapid handpump corrosion in SSA, document handpump quality issues and better understand handpump supply chains, including quality assurance mechanisms. By involving and informing stakeholders in the research from the outset, the initiative has tried to catalyse action at global and national levels to reduce the incidence of rapid handpump corrosion and improve handpump components quality.

The scope of this initiative covers two public domain handpumps that are used extensively in SSA – the India Mark II Pump and the Afridev Pump, which are the community handpumps of choice by governments and development agencies in many SSA countries (MacArthur, 2015). It also incorporates learning from the Bush Pump. Other handpumps in the public domain, propriety pumps, including the Vergnet pump,[7] or locally made pumps for household use[8] are not covered by this study.

The study primarily used qualitative research methods, combining deductive and inductive approaches in analysing the limited information available. The research comprised a literature review, online exchange with water sector practitioners, an online survey, and discussions with select stakeholders both in groups and one-to-one. The author thus drew out key issues and experiences, and structured and re-structured the findings into the series of study reports as described above.

The literature review commenced with published and grey literature that was already known to the author, snowballing from these references. In order to augment the country data, searches of published and grey literature were undertaken through Google Scholar using select keywords.[9] These findings were enriched by questions on sustainable groundwater

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[4] Namely WaterAid, the British Geological Survey (BGS), UNICEF and Japan International Cooperation Agency (JICA).

[5] From 2010 to 2017, RWSN efforts with respect to handpump technologies were limited to documentation of the development of low cost handpumps (Baumann, 2011), public domain handpumps (Furey and Baumann, 2013) and research into handpump standardisation (MacArthur, 2015).

[6] https://dgroups.org/rwsn/groundwater_rwsn

[7] Vergnet Hydro (2021) estimates that they 110,000 handpumps have been installed, and the Vergnet is most likely the third most common pump in SSA, with distributors at least 16 SSA countries.

[8] There are also numerous homemade, or locally made pumps, such as the pitcher pump (common in Madagascar) and the rope pump, which have been developed for local manufacture. They usually lift water from fairly shallow depths and are designed for use by a single household or a small group of households rather than by a community.

[9] Keywords were combinations of corrosion/corrode/rust/rusting; handpump/hand pump and 'country name' in both English and French.

posed to the RWSN online community of 1,500 members via email, and an online survey that was sent out to all 13,000 RWSN members.

A reference group comprising stakeholders (from NGOs, donor agencies and academia) and consultants that were interested in the topic was formed, meeting every four months throughout the initiative to review the research progress and findings. The reference group members provided additional literature, reports and other related information.

Given the limited information available on this topic in the public domain, the author also asked other professional contacts for information and experience, alongside making announcements via the RWSN newsletters and the social media platform LinkedIn. A peer review process of the study report drafts was also undertaken involving reference group members and other water sector professionals.

One volunteer for RWSN undertook a specific study and provided data on rapid handpump corrosion in Cameroon and a student at Cranfield University based in Zambia is writing their MSc dissertation on the topic of corrosion with support from the author.

1. CORROSION EXPLAINED

Corrosion refers to the attack of the surface of materials by chemical processes. It not only affects ferrous materials (i.e. materials that contain iron), but also concrete, glass and plastic, among others. Corrosion of ferrous materials is in fact oxidation[10] of the metals to their natural state (Langenegger, 1994). In water supply systems, corrosion is the partial dissolution of the materials that make up the treatment and supply systems, tanks, pipes, valves and pumps. In certain circumstances, all water can be corrosive (WHO, 2017). Corrosion may lead to structural failure, leaks, loss of capacity and deterioration of chemical and microbial water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of water constituents, including lead and copper.

1.1 TYPES OF CORROSION

Box 1 provides a very short overview of the types of corrosion. However, it should be noted that 'the complex phenomenon of corrosion is governed by such a variety of chemical, physical, biological and metallurgical factors that a universal approach and solution is not possible…[and] no universal index exists for predicting corrosion in all types of water systems and for all water quality condition' (AWWA-DVGW, 1985 quoted in Langenegger, 1994).

BOX 1 A VERY SHORT INTRODUCTION TO TYPES OF CORROSION

There are three types of corrosion, all of which are oxidation-reduction (redox) processes, are as follows:

- **Chemical corrosion**, which occurs when material is in contact with oxidising constituents (e.g. oxygen, hydrogen, carbon dioxide).
- **Electrochemical corrosion**, which is an electrochemical process that occurs in galvanic elements consisting of an anode (metal A) and a cathode (metal B). The classic example is **bimetallic**, or **galvanic corrosion**, which occurs when two different metals are electrically connected and in contact with an electrolyte. As the structure of metal surfaces is never entirely uniform, micro galvanic elements are always present on metal surfaces. The even distribution of these elements results in corrosion that is uniform across the surface.
- **Physico-chemical corrosion**, which is caused by a combination of physical and chemical effects. Corrosion can be greatly influenced by biological processes, especially the microbiological activity of iron bacteria.

Biological processes, especially the microbiological activity of iron bacteria, greatly influence corrosion and are particularly important in tropical areas where the groundwater temperature (around 30°C) favours microbiological activity and chemical reactions. The most common forms of **electrochemical corrosion** are described below:

- **Uniform corrosion** is a relatively even attack on the metal surface. It mainly occurs on rising mains of handpumps, often combined with pitting.
- **Pitting**, or local attack, is the local concentration of corrosion, either in very little spots or over relatively large areas. It occurs when a passive film or another protective surface layer breaks down locally. After this initiation, an anode forms where the film has broken, while the unbroken film (or protective layer) acts as a cathode. This will accelerate localised attack and pits will develop at the anodic spots. The electrolyte inside the growing pit may become very aggressive (acidification), which will further accelerate corrosion.
- **Crevice** and concentration cell corrosion develops in crevices and under rivets and bolts. It is localised corrosion and occurs in a crevice formed between two surfaces, of which at least one is a metal. Crevice corrosion can be considered a particular form of pitting, which occurs between faying surfaces[11] (e.g. in threaded or flanged connections).
- **Galvanic of bimetallic corrosion** can occur between a galvanised iron pump rod with a brass pump cylinder. Galvanic corrosion of mild steel (such as the water tank) or cast iron (such as the cylinder end cap) can be induced by SS, particularly in aqueous environments.
- **Intergranular or intercrystalline corrosion** only occurs at the interfaces of crystals and is observed in SS.
- **Stress corrosion cracking** can develop in any metal under tensile stress in a corrosive environment. It can lead to intercrystalline cracking (along the interface of the crystals) and transcrystalline cracking (through the crystals). Stress corrosion cracking may affect pump rods, particularly those under high tensile stress in deep pump installations. It characteristically results in shapeless cracking, which is typical of rod breakages.

Source: Langenegger, 1994; Baumann, 1998.

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[10] Oxidation occurs when an atom, molecule or ion loses one or more electrons in a chemical reaction. In the case of iron, oxidation occurs when iron combines with oxygen to form iron oxide or rust. The iron is oxidised into rust.

[11] Faying surfaces are the contacting surfaces or faces of two similar or dissimilar materials placed in tight contact to form a joint.

FIGURE 1 NEW AND CORROSION ATTACKED GALVANISED PISTON RODS OF INDIA MARK II HANDPUMPS WITH BRASS PISTON ILLUSTRATING A TYPICAL CASE OF GALVANIC CORROSION IN SOUTHERN GHANA
Source: Langenegger, 1989.[12]

1.2 CAUSES OF CORROSION

PH

When groundwater is aggressive, the protective zinc layer (galvanisation) of handpump rising mains and pumps rods is eaten away by corrosion within a few months (Langenegger, 1989). Once the zinc is no longer intact, the iron concentration in the well increases.

In Ghana, it was found that in completely neutral waters the galvanising layer was still intact after five years of operation, but in aggressive waters GI pipes were corroded or perforated within one year (Wollschied, 1987). Based on research in Côte d'Ivoire, Langenegger (1989) found a much more rapid increase of corrosion rates at pH value ranges of 6 to 6.5 compared to higher values. He defines the aggressivity of water with respect to pH as follows:

- $pH > 7$ – negligible
- $6.5 < pH \leq 7$ – little to medium
- $6 < pH \leq 6.5$ – medium to heavy
- $pH \leq 6$ – heavy

Although low pH is considered a key factor in driving handpump corrosion, there does not seem to be any comprehensive overview of where in SSA low pH levels are likely to be found.[13] Langenegger (1994) states that groundwater originating from acidic or intermediate rock types is generally aggressive, that is with $pH \leq 7$ (see Annex 1 for the dominant rock types in West Africa). Aggressive groundwater is widely spread, particularly in basement formations. Langenegger (1989) compared pH with rock types in southern Ghana and concluded that sand and sandstone were particularly prone to very low levels of pH, but that all rock types examined yielded waters of pH below 6.5 (Figure 2).

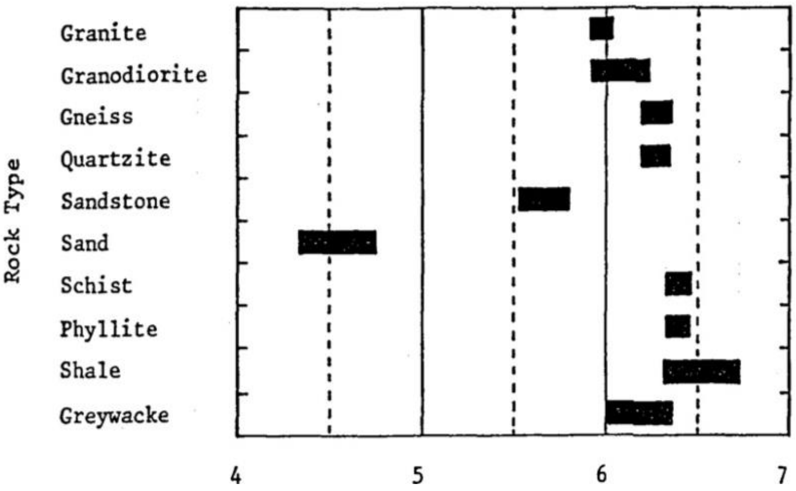

FIGURE 2 RELATIONSHIP BETWEEN PH AND VARIOUS ROCK TYPES OF AQUIFERS IN SOUTHERN GHANA
Source: Langenegger, 1994.
Note: The depicted ranges of pH represent 95% confidence intervals.

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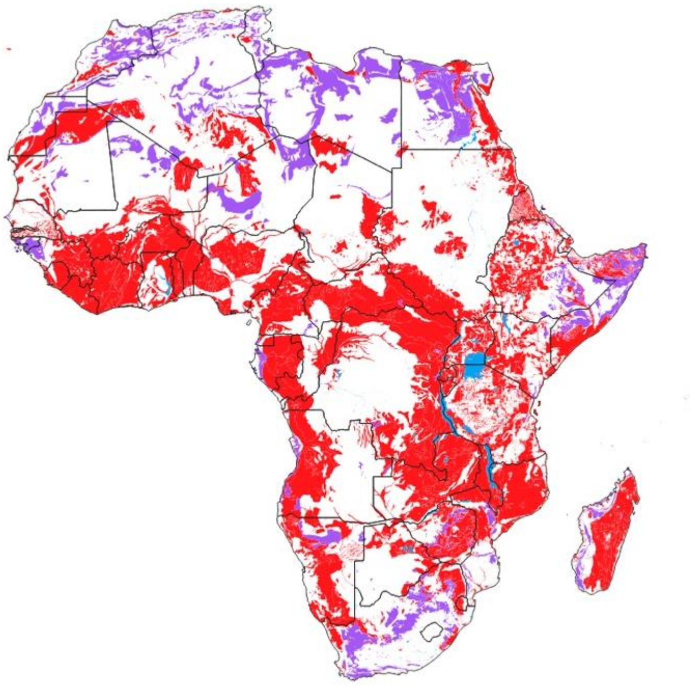
[12] Apologies for the poor resolution image, black and white image but this is the best illustration that could be found.
[13] It has also been observed that wells which tap water from different water-bearing strata with different chemical parameters will yield mixed waters (Wollschied, 1987).

Figure 3 is a first approximation to illustrate the locations that risk having low pH (in red). Mapping areas likely to have low pH could assist in identifying areas that are at risk of corrosive waters and thus could assist with corrosion mitigation efforts. Information on low pH levels in specific locations collated by this study is summarised in Box 2.



Key:

Red – expected acidic, comprising colluvium (if parent rock likely acidic), hydric/organic, alluvium (parent rock likely acidic), alluvium (saline), volcanic (ash, tuff, mudflows, although some lavas are not acidic), metasediments, metaigneous and silicic.

Purple – expected to be alkaline, comprising carbonate, colluvium (if parent rock likely alkaline), alluvium (parent rock likely alkaline), karst, alkaline intrusive volcanic and ultramafic.

White – unclassified.

Figure 3 Map of acidic and alkaline rocks
Source: Prepared for this study by Prof. Martinez-Sanchez.

Box 2 Compilation of data on low levels of pH

- Côte d'Ivoire: Divo Department, Lôh-Djiboua Region – pH 6.3 (Langenegger, 1989).
- Chad: pH 4.5–6.5 throughout Logone Zone in Southern Chad (Furey and Danert, 2022).
- Ghana: pH 3.5–6.0 (Kortatsi, 1994); pH 3.69– 8.88 (Schäfer et al., 2009).
- Niger: there are areas with pH 5.6.
- Nigeria: Owerri (Imo State) – pH 6.1 (Ibe et al., 2002).
- Republic of Congo: within Yaya District, Niari Department – pH of about 4 (Hassan, 2014).
- South Sudan: Northern Bahr el Ghazal, true average of the 10 values was pH 5.68 and only two of the 10 samples had pH exceeding 6.5.
- Sierra Leone: pH levels as low as 4.8 have been recorded (InterAid, 2021).
- The Gambia: widespread low pH (Foster and McSorley, 2016).
- Togo: shale formations in the northwest and southwest are acidic (Dougna et al., 2015).
- Uganda: Amuria and Katakwi districts in the north-east region (Furey, 2014).
- Zambia: pH 5.56–6.89 in 20 boreholes within Luapula, Central, Copperbelt and North-Western provinces (SOMAP3, 2013).
- An estimated 70% of the West African region has aggressive groundwater – pH <6.5 (Langenegger, 1989).

Salinity, chloride, sulphate, hardness and bacteria

While low pH is largely considered as the main factor contributing to the corrosion of the GI and mild steel components of handpumps, there are other reasons for rapid corrosion, including:

- High salt concentration (salinity) in water provides an electrolyte for corrosion to take place. Saline water contains high levels of sodium and chloride ions. Under the right conditions, electrochemical or galvanic corrosion can take place in saline water (Box 1). The electrical conductivity (EC) of water measures dissolved ions and has an impact on its corrosive action. Water is an electrolytic solution and is capable of carrying electric current, so that the zinc in a galvanised pipe will pass into the solution as zinc ions if it is in contact with copper or brass, with the speed of this reaction increasing with the conductivity of the water. Van Beers (2018) notes that combining brass and stainless steel (SS) can cause the SS to corrode.

- High levels of chloride. Based on experiences in Ghana, Wollschied (1987) provides a general guideline for centrifugal pumps, as defined by major pump manufacturers, whereby standard material could only be used for a chloride content of less than 150 parts per million (ppm). He envisages that chloride content of above 500 ppm would be expected to cause a substantial pitting problem in handpumps. In the Bush Pump specifications, the Government of Zimbabwe (2004) notes a chloride risk for corrosion. Baumann (1998) states that pitting and crevice corrosion of SS (see Box 1) is predominantly caused by chloride ions.

- Sulphate affects the corrosivity of water, as does carbon dioxide (Arlosoroff et al., 1987). Galvanic corrosion is favoured by a chloride-to-sulphide ratio higher than 0.58 (Nguyen et al., 2011; Triantafyllidou and Edwards, 2011).

- For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) affect corrosion rates. Parameters related to the status of calcium carbonate saturation are, strictly speaking, indicators of the tendency to deposit or dissolve calcium carbonate (calcite) scale, rather than indicators of the 'corrosivity' of a water (WHO, 2017).

- Iron bacteria are small living organisms that occur naturally in soil, shallow groundwater and surface waters and which use iron (or manganese) as an energy source. By combining iron (or manganese) and oxygen, the bacteria form deposits of rust bacterial cells and a slimy material. Iron bacteria thus speed up the corrosion process by utilising inorganic iron in their metabolic processes (Misstear et al., 2006). The bacteria produce an orange slime on iron surfaces, which causes bio-fouling of well screens and other components (Fader, 2011). Wells containing iron bacteria can also produce water with an oily sheen on its surface (Tyrrel and Howsam, 1997). If there is black slime and a rotten egg smell (hydrogen sulphide) it suggests the presence of sulphate reducing bacteria, which are most often associated with corrosion induced by microbes (Cullimore, 1993).

The WHO (2017) and Langenegger (1994) provide further details on the complexity of characterising corrosivity. Water sector practitioners have noted salinity (in parts of Malawi, Côte d'Ivoire and the Democratic Republic of the Congo) and chloride (in the Central Region of Ghana) resulting in rapid handpump corrosion (see Section 5).

1.3 NATURALLY OCCURRING IRON VS CORROSION

In some cases, the discolouration and poor taste of groundwater is caused by naturally occurring iron in the groundwater (Bonsor et al., 2015; Casey et al., 2016). Box 3 explains the chemistry of these two sources of iron. As an example, naturally occurring iron from within Zambia can be found where the underlying rock is mudstone and/or shale of the Kundelungu Formation (pre-Cambrian, in the copper belt within the Katanga supergroup). High iron levels (up to 26 mg/l[3]) have been recorded during drilling, development and yield tests in these areas. It has been observed that iron levels are often high where there is surface laterite (often with a pan or depression nearby), where yield is low and where users pump the borehole water level down to the level of the pump intake (Furey, 2014).

Simple tests have been developed to help distinguish the source of the iron, which involve testing for iron after the water in the well has been stationary for some time, and subsequently testing after pumping for an extended duration (Casey et al., 2016). Initially high levels of iron, which fall significantly after continuous pumping, are indicative of corrosion as the main source. Wollschied (1987) found that, in Ghana, extremely high levels of iron concentrations of up to about 60 ppm were only found if the pump had very little use or was not used at all, and that an average used well would rarely have an iron concentration of more than 4–6 ppm. An alternative method for determining the origin of the iron problem is to replace non-corrosion-resistant handpumps with those that are corrosion-resistant and measure changes in iron concentrations (Arlosoroff, 1987).

There are cases in which both naturally occurring iron and corrosion occur, and cases where results have changed over time, such as the example from Kenya in Box 4. Lane (2021) has also observed similar changes in groundwater chemistry, indicating that corrosion of the casing/screen can be another source of iron.

BOX 3 THE CHEMISTRY OF NATURALLY OCCURRING IRON VS CORROSION

Anaerobic groundwater may contain ferrous iron at concentrations up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidises to ferric iron, giving an objectionable reddish-brown colour to the water. Iron also promotes the growth of iron bacteria, which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping.

Natural occurring iron is present in soils and rock formations in either its reduced soluble form (Fe2+) or as oxidised insoluble ferric iron (Fe3+). The nature of the soluble, colourless form is such that it can be in the groundwater but appear colourless, yet when pumped out of the ground and exposed to the atmosphere will convert to ferric iron, which subsequently reacts to form insoluble iron hydroxides. As they precipitate out, a red/brown cloudiness is observable in the water, which stains.

Pumped groundwater can also contain high iron concentrations due to corrosion of pump components in aggressive groundwater. Corrosion is complex, depends on a number of factors and there is no universal index for predicting corrosion in all water quality conditions. What is clear is that galvanisation does not protect the handpump riser pipe if the pH is less than 6.5 and galvanisation only provides limited protection for pH 6.5–7. Pump rods made of SS have corrosion rates an order of magnitude lower than galvanised iron (Langenegger, 1994).

High levels of geogenic iron in groundwater have been documented in the following areas:

- Ghana – in some wells in Northern and Southern Ashanti regions (Wollschied, 1987)
- Kenya – significant concentrations of soluble iron are found in deep groundwater across Kenya, including within the southern coastal areas and West (MWSI and WSA, 2019)
- Uganda – parts of the north and west, including in Hoima District
- Zambia – Kundulungu (pre-Cambrian) formation (mudstone and/or shale), within Luapula, Western and North-Western provinces (Furey, 2014; Anscombe, 2021a).

Ibe et al. (2002) state that high concentrations of iron in groundwater can also be a result of the leaching of iron from iron scrapes, in wastes at a landfill site, as found in Avu-Owerri, south-east Nigeria. Removal of iron with iron removal plants, as undertaken in Zambia (JICA, 2017) and Kenya (Weir et al., 2009), is beyond the scope of this study.

BOX 4 MYSTERY IRON IN KENYA

In Kenya, an 84 m borehole was drilled and installed with an Afridev handpump with about 29 m of polyvinyl chloride (PVC) rising main and mild steel pump rods. It was commissioned in January 2010. The pump test showed a yield ~3.5 m^3/hour and the water quality showed moderately high pH, low iron, low manganese and moderate alkalinity. By mid-2010, users reported an 'oily sheen' and precipitate formation after exposure to air. During a site visit in July 2011, it was observed that the pumped water was initially clear and then brown precipitation occurred after exposure to air. Users complained of poor taste, stained laundry and spoiled food and tea. Subsequent off-site testing confirmed high iron levels in the 3–7 mg/l range. The pH had changed and was now low, around 6 or so. The water quality was very different than indicated by the initial November 2009 testing. Water users speculated that the cause of the corrosion was the steel borehole casing and pump rods, which was plausible. In January 2012 further testing confirmed very high iron levels, with some initial levels as high as 30 mg/l, but never decreasing below 4–10 mg/l.

Source: Furey, 2014: 7–8.

2. IMPACTS AND EFFECTS OF HANDPUMP CORROSION

2.1 DRINKING WATER QUALITY

Iron is one of the most abundant metals in the Earth's crust and is found in natural fresh waters at levels ranging from <0.5 to 50 mg/l. Iron may also be present in drinking water as a result of the use of iron coagulants or due to the corrosion of steel and cast iron pipes during water distribution. There is usually no noticeable taste when iron concentrations are below 0.3 mg/l, although turbidity and colour may develop (WHO, 2017). Levels above 0.3 mg/l cause discolouration as well as staining of laundry and plumbing fixtures. The WHO does not propose a health-based guideline value for iron in drinking water but do note that there is a provisional maximum tolerable daily intake.

Based on research in Ghana, it was found that the limits of iron concentration levels for consumption were very difficult to indicate 'since taste is a very personal habit and may be subject to change', but 5 mg/l was usually acceptable (Wollschied, 1987: 2). Langenegger (1989) found that handpumps that delivered water of more than 5mg/l were generally little used.

Handpump corrosion causes a deterioration of water quality (Figure 4) and a reduction in performance and increased likelihood of mechanical failures. As GI components corrode, the water initially contains high levels of zinc, with the iron appearing as soon as the protective galvanising has been removed (Langenegger, 1994).

While high levels of iron in drinking water are not considered as presenting a danger to health by the WHO (2017), users often reject 'improved' water supplies containing iron due to its taste, colour and staining effects (Langenegger, 1989). While there is no direct danger to health of handpump corrosion, there is nonetheless an indirect danger as people return to unsafe surface water supplies. Currently, this reality has not been explicitly recognised by the WHO, which does not propose a health-based guideline value for iron in drinking water, nor mention the need for mitigation measures for groundwater point sources. The WHO (2017) guidelines do note that the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a provisional maximum tolerable daily intake (PMTDI) of 0.8 mg/kg body weight. It states that an allocation of 10% of the PMTDI through drinking water equates to about 2 mg/l, which is not considered as presenting a hazard to health. However, as noted above, the taste and appearance of drinking water are already affected below this level.

FIGURE 4 RED, IRON-RICH WATER BEING PUMPED
Source: Nekesa et al., 2015.

When a handpumps fails, breaks down for a short duration, or is rejected by the community for poor performance or unacceptable water quality, users need to seek alternatives. They return to using distant or unsafe contaminated water sources (Anscombe, 2011; Thibert, 2016). Handpump breakdowns can also lead to overcrowding at neighbouring improved sources and even to conflict (MacDonald et al., 2019). Water service failure impacts on health and can inhibit other human development gains (Hunter et al., 2009; 2010; Baguma et al., 2017).

The high turbidity of the water from a corroding handpump that has not been used for some time (e.g. overnight) can be caused by the accumulation of corrosion products. Discolouration of the water to red/brown a few minutes or hours after pumping is due to the transformation of ferrous iron to iron hydroxides and iron oxides when exposed to oxygen in the air. User perceptions of taste, smell and appearance (especially if the water is red after the handpump has not been operated for some time, or if the colour of the water clears after minutes or hours of pumping), changes in turbidity over time (i.e. deterioration over weeks and months), and pumped clear water that turns red after some time are all indicators of handpump corrosion.

Seguin and Lacour-Gayat (2014) cite an example of a handpump in southern Chad with GI riser pipes installed in water with low pH that worked well for three months before providing poor-quality water for six years and then failing completely. Fader (2011) reports users in Uganda finding water more and more unpalatable as the water quality deteriorated as a result of corrosion.

2.2 Handpump performance

Once corrosion causes holes in the pipe such as pitting (Figure 5a, 5b and 6a), gaping holes (Figure 6c) or damaged threads (Figure 6d), the pipes start to leak. As a result, water flow is reduced (or completely eliminated) and handpump performance reduces. More effort is required in terms of pumping to draw up water from underground. Leakage from the riser pipes also means that it takes longer to prime the pump for use after it has not been used for some time (WaterAid, 2021). Corrosion of riser pipes and pump rods can also lead to outright failure, including riser pipes dropping into the borehole due to damaged threads (Figure 6d).

(a) Riser pipe corrosion in Zambia
Source: SOMAP3, 2013.

(b) Riser pipe corrosion in Nigeria
Source: Olajide Oyetunde.

Figure 5 Pitted riser pipes from corrosion in Zambia and Nigeria

(a) Removal of pitted pipes within, Hoima District, Uganda, 2012
Source: Larry Bentley.

(b) Removal of corroded pump rods and riser pipes in Hoima District, Uganda, 2012
Source: Larry Bentley.

(c) Removal of corroded pipes
Source: Richard Carter.

(d) Corroded pipe thread
Source: Richard Carter.

Figure 6 Examples of handpump corrosion

Pump rod and riser pipe threads are particularly vulnerable to corrosion because the protective coating applied is removed when the threads are cut and are easily damaged during installation and maintenance (Figure 6d). In addition, the wall thickness of the threaded sections is reduced.

The rising corroding mains and pump rods that are in contact with water tend to be covered with a red/brown biofilm resembling mud (Figure 7 and 8). When spare parts are not available or are too costly, some communities will improvise by covering holes with locally available materials such as bicycle inner tubes to keep the pump operational (Figure 8). There is also limited literature pointing to the corrosion of the cast iron cylinder (Beers et al., 2013) as illustrated in Figure

9. Baumann (1998) notes that encrustation build-up as a result of biofilm can become so thick that the centralisers can no longer be removed, thus hampering maintenance.

As well as the aforementioned impacts of corrosion and effects on the pump, water and users, there are also associated costs. The first cost is wasted investments in the form of little used or unused wells. For example, of the 3,000 handpumps installed in Ghana, between 50% and 60% of pumps were out of order mainly due to corrosion after 4–5 years of operations (Langenegger, 1989). The second cost is the increased handpump maintenance expenditures due to component failure.

FIGURE 7 FOOT VALVE COVERED WITH DEBRIS FROM CORROSION
Source: Larry Bentley.

FIGURE 8 CORRODED RISER PIPE WITH BIOFILM AND REPAIRS USING AN INNER TUBE IN AMURIA, UGANDA
Source: Richard Carter.

FIGURE 9 CHANGING RUSTED CYLINDER IN OSUN STATE, NIGERIA
Source: Olajide Oyetunde.

Corrosion-resistant handpumps, or alternative models of the standard, can be more expensive, depending on the materials used. According to Baumann (1998), a U3 handpump with SS down-hole components is 2.5 to 3 times more costly than one with GI components. The higher costs of SS compared to GI means that using the former for riser pipes and pump rods will result in a higher investment cost per handpump, but doing so should reduce wasted investments and maintenance costs. Unplasticised polyvinyl chloride (uPVC) pipes, which are an option for Afridev pumps, also provide a corrosion-resistant alternative. Harvey (2007) emphasises the need to consider the corrosion of GI components installed in groundwater with low pH in determining replacement costs for India Mark II handpumps.

3. OVER THREE DECADES OF HANDPUMP CORROSION

Corrosion of below-ground handpump components has been documented since the late 1980s (Wollschied, 1987; Langenegger, 1989; Nekesa et al., 2015; Danert, 2019; Kebede et al., 2019; Mwathunga et al., 2019; Owor et al., 2019). The incidence and extent of corrosion damage mainly depend on pump component materials, groundwater quality and pumping regime, with light pumping causing greater accumulation of corrosion products (Arlosoroff et al., 1987). Fader (2011) found that the more people that used corroding pumps in Uganda, the longer it took for the pump to be abandoned.

In West Africa in the late 1980s, it was estimated that two-thirds of handpump breakdowns were directly or indirectly attributable to corrosion (Langenegger, 1989). Research concluded that galvanisation of pump riser pipes and pump rods does not prevent corrosion where the pH < 6.5 and only provides limited protection for pH 6.5–7 (Langenegger, 1994). It was found that the galvanisation of rising mains exposed to groundwater with a pH < 6 was eaten away within approximately three to six months (Langenegger, 1994). However, it is worth mentioning that rapid corrosion is not the only reason that handpumps do not reach their end-of-service life. In Malawi, handpumps (Afridev and Malda)[14] only reach an average service life of about five years due to insufficient ongoing maintenance (Baumann, 2009); rehabilitation programmes are required to restore their functionality.

Components that are permanently submerged, or in and out of, water will eventually corrode. However, the lifetime of the pump is significantly reduced if this corrosion is rapid. But what constitutes regular versus rapid corrosion? Participants of a World Bank workshop in 1994 reported that, with regular maintenance of fast-moving parts, the India Mark II and Afridev pumps have a lifespan of 10 years, and with overhaul of other components, the lifespan would increase to 18 to 25 years (World Bank, 1996).[15] With a maintenance programme involving minor as well as major repairs, Baumann (2009) estimates that handpumps should reach a service life of approximately 10 years. Riser pipes and pump rods are not considered as fast-moving parts (Skat and RWSN, 2008), suggesting an expected lifespan of 10 years. However, in contrast, the Installation and Maintenance Manual for the Afridev handpump gives an approximate lifetime of three to five years for the riser pipes and pump rods (Erpf, 2007). Handpump component lifetime is examined in more detail in Report III of this initiative (Danert, 2022b).

This study proposes that corrosion of handpump components in contact with water should be categorised in three broad groups:

- Early-life or rapid corrosion – referring to GI riser pipes and pump rods if they are installed in aggressive groundwater.
- Mid-life corrosion – particularly if galvanising quality is poor or removed, which happens in the case of the threading on riser pipes and pump rods.
- End-of-service-life corrosion – when the components approach the end of their service life, presumed to be 8–10 years.

With regard to early-life or rapid corrosion and to mid-life corrosion, sector professionals have found the following:

- Based on observations in Zambia and Malawi over more than 15 years, Anscombe (2021a) states that 'groundwater with a low pH will hole the pipes within 2-years'. In Zambia, high iron content in boreholes in some parts of the country was a major concern but was not studied in detail or documented prior to 2012 (SOMAP3, 2013).

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[14] The Malda Pump is a direct action pump for low lift wells: https://www.rural-water-supply.net/en/implementation/public-domain-handpumps/malda-pump.

[15] The World Bank (1996) quotes Sarkkinen (1994) on the economic lifespan of the India Mark II (8–10 years) and Afridev (9–12 years) and the working lifespan of the India Mark II (15–20 years) and Afridev (18–25 years). Unfortunately, no hard or soft copy of the Sarkkinen report could be found.

- Aggressive groundwater resulting in rapid corrosion of galvanised iron rising mains and rods was a problem in some areas of Ghana and Zambia. In some cases, handpumps functioned for less than two years before suffering breakdown due to corrosion problems (Harvey, Skinner and Reed, 2002).
- Bentley (2021) describes India Mark II pumps in Hoima District, Uganda, whereby new GI pipes were installed and the pumped water became stained by 'rust almost to the colour of tomato soup' within about six months.
- In Sudan, corrosion of GI pipes in some parts of the country necessitated their replacement by local as much as two or three time a year (Sabeel, 2021). The high turnover of spares in certain areas was one of the indicators that led to the selection of the locations for research by Sabeel (2006).
- Water with low pH led to corrosion of GI handpump components within three months in the Logone Oriental Region, south-west Chad (Seguin and Lacour-Gayat, 2014).
- In the village of Kanyawawa, western Uganda, users had to replace the riser pipes six times in the eight years since the well's installation because they were consistently rupturing due to corrosion (Fader, 2011).
- Poor handpump component quality is another key issue in mid-life corrosion, leading not only to more corrosion but also to a number of other failures. This is discussed further in Report III of this study (Danert, 2022b). The quality of the galvanising impacts on how quickly GI will corrode, and the standard for galvanised coating on rising mains and pump rods comprises a 60–70 µm thick layer of zinc. However, when groundwater is moderately to highly corrosive (pH < 6.5), the quality of galvanising does not have a significant impact on corrosion resistance (Langenegger, 1994). This results in early-life or rapid corrosion, as described above.

Field measurements found that the external surfaces of GI pipes exposed to aggressive water were generally more heavily corroded than internal surfaces, and that corrosion rates decreased over time due to the protective effects of biofilms, scales and corrosion products deposited on the corroded surfaces (Langenegger, 1994). While biofilms have a protective effect against corrosion, the debris negatively affects the taste, smell and appearance of the water.

4. CORROSION OF CASINGS AND SCREENS

The topic of corrosion of borehole casings and screens is beyond the scope of the study but warrants briefly addressing.

Steel casing is rarely installed in boreholes in handpump-equipped water points in West Africa, but where steel cased wells exist, corrosion of the well casing contributes to the iron problem (Chilton and Lewis, 1989). Anscombe (2021b) also observed the corrosion of casings in Malawi.

Examples of the corrosion of mild steel borehole casings and screens have also been observed along the southern Kenyan coast. The Swedish International Development Agency (SIDA) handpump project of the 1980s and 1990s accepted uPVC casing as standard in response to the corrosion of mild steel or mild steel welded SS in the region. More recent examples include wells drilled for mines in the Mazeras sandstone, where the wells failed at the welds between mild steel and SS. Subsequent boreholes were cased/screened with dielectric joints and mild steel casing or by using very high grade SS casing and Munipak screens, and Johnson couplings (Lane, 2021).

5. THE EXTENT OF RAPID HANDPUMP CORROSION

Report I of the Stop the Rot initiative concluded that handpump technical quality is largely taken for granted and found that the topic of handpump corrosion is not only relatively absent in the literature but also falls outside the scope of current monitoring and evaluations or assessment tools (Danert, 2022a). Some notable exceptions include a study by WaterAid; a recent research project on handpump failure in the Ethiopian Highlands, Malawi and Uganda led by the British Geological Survey (BGS) with FCDO funding; and some UNICEF-financed assessments in Malawi and Zambia. These provide detailed information on handpump corrosion as well as component quality issues (summarised in Danert, 2022a).

Section 3 of this report emphasises that while components that are submerged in, or in and out of, water will eventually corrode, the lifetime of the pump is significantly reduced when the rate of corrosion is rapid, which will happen if GI riser pipes or pump rods are installed in water with pH < 6.5 or if the quality of the galvanising is poor.

This study has collated information about handpump corrosion in specific countries by collating:

- Observations by professionals – shared via the RWSN Groundwater group through personal communication with the author, and from two RWSN surveys (2013; 2021) on handpumps.
- Reports – technical audits, evaluations and consultancy reports.
- Academic research – such as has been undertaken by the BGS and WaterAid.

Of the 130 respondents to the 2021 RWSN Handpump Survey, 69% stated that rapid corrosion was either a widespread or a location-specific problem (Furey and Danert, 2022). This study finds that there are 22 countries in SSA for which there is anecdotal evidence (from observations by sector practitioners), reports and/or academic studies of rapid handpump corrosion (Figure 10).

Table 1 sets out the specific locations within each country where corrosion has been documented, provided this information is available. In some countries, such as the Democratic Republic of the Congo, Cameroon and Sierra Leone, evidence relates to very few specific cases in one or more geographical areas. This does not mean that rapid corrosion does not occur elsewhere in the country, but rather that, if it does occur, it has not been documented or that documentation has not been found by this study. In some countries, such as Uganda and Zambia, there is evidence of widespread rapid handpump corrosion.

The fact that all components submerged in, or in and out of, water will eventually corrode presents some challenges in verifying anecdotal evidence of rapid handpump corrosion. In order to address this, the literature has been scrutinised to try and distinguish between rapid and end-of-service-life corrosion; end-of-service-life corrosion concerns are excluded from Table 1 and Figure 10 but discussed below or included in the descriptions within the country descriptions in Annex 2.

Countries where reports have indicated that rapid handpump corrosion is not an issue include Angola, in which Mudgal (2001) found no reports suggesting failure of handpumps due to corrosion of riser pipes, pump rods or cylinders. Interaction between the author of this study and with professionals engaged in the water, sanitation and hygiene sector in Angola in the preparation of this report supports this finding.

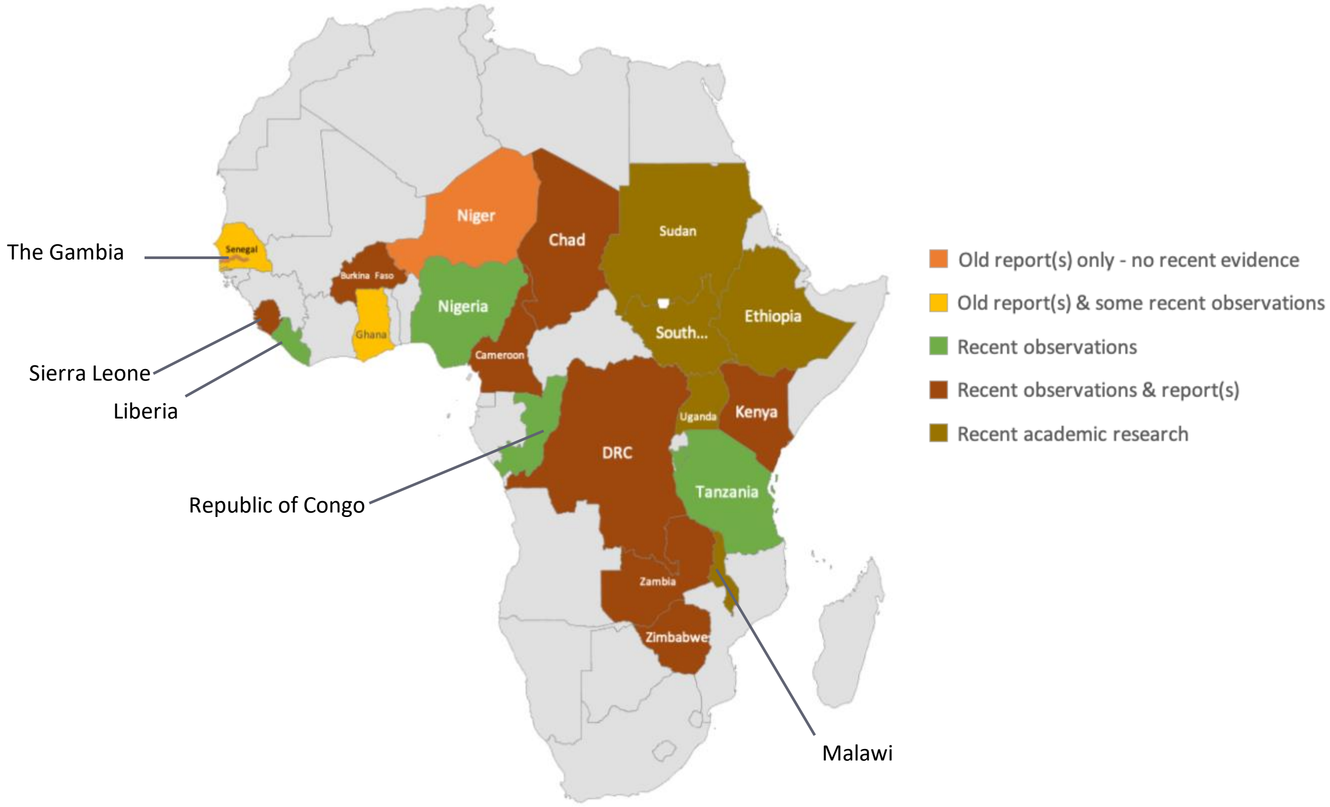

Figure 10 Countries with evidence of handpump corrosion
Source: Data taken from Table 1 and Annex 2.

Table 1 Overview of location(s) of rapid handpump corrosion within countries

Country	Location(s) where handpump corrosion has been observed, reported or studied	References
Burkina Faso	▪ Worst affected regions – Hauts-Bassins, Nord and Sud-Ouest (in 2013/14) ▪ Within the six regions affected by humanitarian crisis (in 2021) – Boucle du Mouhoun, Centre-Est, Centre-Nord, Est, Nord and Sahel	CABINET NTU INTERNATIONAL A/S (2013; 2014); Furey and Danert (2022). Six regions extracted from Cluster Santé (2019)
Burundi	▪ Kirundo and other regions	Furey (2019); Furey and Danert (2022)
Cameroon	▪ Modeka, in South-West Province ▪ Foumbot (West)	Furey (2014); Aziz (2022)
Chad	▪ Bokoro District, northern Chad ▪ Southern Chad, including Logone Oriental and Logone Occidental Provinces	Thibert (2016), Seguin and Lacour-Gayat (2014), Furey and Danert (2022)
Congo, Dem. Rep. of	▪ Mahagi, Ituri Province ▪ Widespread – the problem of corrosion is due to the quality of the water, which is often saline	Koestler et al. (2014); Furey and Danert (2022)
Congo, Rep. of	▪ Kibangou District, Niari Department	Furey and Danert (2022)
Ethiopia	▪ Sodo – Wolaita Zone and Abeshege – Gurage Zone, Southern Nations, Nationalities, and Peoples Region; Mecha – Mirab Gojjam Zone, Amhara Region; Ejere – West Shewa Zone, Oromia Region; other parts of the country (not specified) ▪ Ethiopian Highlands ▪ Eastern Ethiopia ▪ Widespread ▪ In more saline areas	Kebede et al. (2019); specific locations from: Lapworth et al. (2020); McAllister (2021); Furey and Danert (2022)

Country	Location(s) where handpump corrosion has been observed, reported or studied	References
Ghana	▪ In the past ▪ Northern Region, Central Region.	Nampusuor and Mathisen (2000); Harvey, Skinner and Reed (2002); Furey (2014); Furey and Danert (2022)
Kenya	▪ South Kenyan Coast and Western Kenya provinces ▪ Widespread	Reynolds (1992); DHV Consultants (1988); Lane (2021); Furey and Danert (2022)
Liberia	▪ In areas that contain iron in ground water and around the coastal areas	Furey and Danert (2022)
Malawi	▪ Balaka – Balaka District and Machinga District, Southern Region; Lilongwe District and Nkhotakota District, Central Region[16] ▪ Areas with salty/saline water	Anscombe (2011; 2013); Mwathunga et al. (2019); specific locations from: Lapworth et al. (2020); McAllister (2021); Furey and Danert (2022)
Niger	▪ In the past	Langenegger (1989)
Nigeria	▪ Kebbi, Katsina and Jigwa States ▪ North ▪ Benue State ▪ Niger Delta area ▪ Widespread	Olajide Oyetunde (see Figure A2.3); Khan et al. (2009); Andres (2018b); Daw (2021); Furey and Danert (2022)
Senegal	▪ In Matam region (north-east), with the presence of iron. ▪ In the past: Ziguinchor, southern Senegal	Furey and Danert (2022)
Sierra Leone	▪ Bombali District ▪ Western area	Inter Aide (2021); Furey and Danert (2022)
South Sudan	▪ Central Equatorial state, including Kaji Keji ▪ Northern Bahr el Ghazal, Yei and Morobo states	Sabeel (2006); Carter and Guo (2021); Furey and Danert (2022)
Sudan	▪ North Kordofan, North Darfur and River Nile states	Sabeel (2006)
Tanzania	▪ Morogoro, Moshi and Kigoma regions ▪ Simiyu, Tabora, Kagera, Shinyanga and Mtwara Regions ▪ In areas with salty water ▪ Iringa and Dodoma regions	Mubarak (2021); Furey and Danert (2022)
Uganda	▪ Hoima District and other parts of western Uganda ▪ Eastern Uganda ▪ West Nile and other parts of northern Uganda ▪ Isingiro, Mpigi and Buyende Districts	Baumann (1998); Fader (2011); Furey (2014); Casey et al. (2016); Nekesa et al. (2016); Liddle and Fenner (2018); Owor et al. (2019); Lapworth et al. (2020); Bentley (2021); Furey and Danert (2022)
Zambia	▪ Northern Zambia, including Luapula Province ▪ Western Province	Harvey, Skinner and Reed (2002); Anscombe (2011); Furey (2014); Anscombe (2019)
Zimbabwe	▪ In 17 out of 60 districts[17] ▪ In Shipinge, Chimanimani, Chiredzi, Tsholotsho, Kariba, Rushinga there is corrosion of pump rods and pipes on threading section	Fred (2021); Furey and Danert (2022)

Investigations of handpump corrosion that were undertaken in West African field trials of the World Bank's Handpumps Project found rapid corrosion of GI riser pipes in the south of Côte d'Ivoire (Divo Department) and attributed this to aggressive groundwater (Langenegger, 1989). With the exception of an article that notes that the salinity (present in groundwater in the villages of Avikam at the Grand-Lahou barrier beach) can destroy steel and thus makes access to drinking water difficult (Prisca, 2021), and another noting the problem of iron and manganese in drilled wells in the

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[16] These may be end-of-service-life rather than rapid corrosion.

[17] These are: Mashonaland West Province – Kariba district; Mashonaland Central Province – Mt. Darwin, Mbire, Muzarabani; Mashonaland East Province ‑ Mudzi, Uzumba Maramba Pfungwe, Hwedza, Mutoko; Manicaland Province ‑ Chipinge, Chimanimani, Buhera, Makoni; Masvingo Province – Chiredzi; Matebeleland South Province – Beitbridge, Gwanda; Matebeleland North Province – Tsholotsho, Lupane. Note that districts affected by this problem in Midlands Province could not be ascertained.

Tiassalé Region, but attributing this to ions from the soil surface (Oga et al., 2009), no more recent documentation of handpump corrosion in Côte d'Ivoire was found.

Langenegger (1987) found that 30% of the handpumps installed by the 3,000 Well Project in Niger were rarely used or were abandoned due to iron. According to Beers et al. (2013), from 2011 World Vision has only installed stainless steel pump rods in Niger. No recent documentation indicating ongoing rapid handpump corrosion in Niger was obtained for this study.

The 2021 RWSN survey also drew out concerns with respect to Mali (Western Sahel) where there are many 'dilapidated' and broken-down pumps (Furey and Danert, 2022). Unfortunately, the responses to this survey are phrased in such a way that it is unclear whether the breakdowns are due to rapid corrosion. Likewise, a statement with respect to Rwanda that 'in about 3 districts, pumps don't last long and cost the most for maintenance' is inconclusive without further investigation.

In some countries solutions to former problems of corrosion seem to have been found, such as in The Gambia. Highly aggressive groundwaters are found across The Gambia (Foster and McSorley, 2016), but in the 1990s there was a shift to a more corrosion-resistant India Mark II – the Pumpenbose (PB) India Mark II, named after the German Company Pumpenbose[18] (Foster, McSorley and Willetts, 2019). This pump, and another version of the India Mark II with stainless steel riser pipes and rods are used in The Gambia. No documentation of an ongoing problem of rapid handpump corrosion in the country was found.

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[18] Pumpenbose subsequently became the German Water and Energy Group.

6. Preventing rapid corrosion

6.1 Current advice

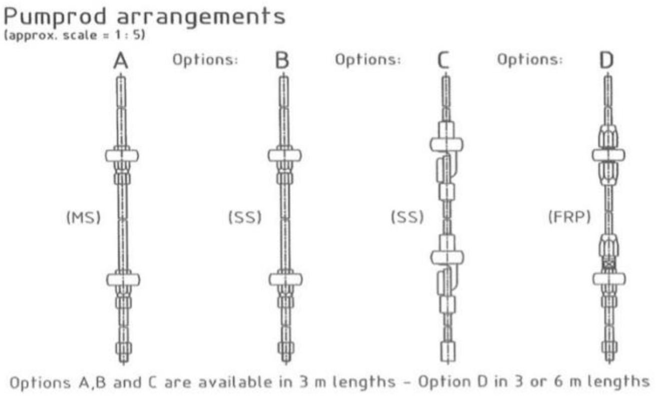
Advice to avoid the use of GI materials in water with pH < 6.5 has been published (e.g. Arlosoroff et al., 1987; Skinner, 1996; Harvey and Reed, 2004). The riser pipes and pump rods of the India Mark II pump can be specified SS instead of GI, and variants using uPVC pipes have also been introduced. From the outset, the Afridev pump was designed to include options that would not rapidly corrode (Box 5).

In light of the corrosion problem, some donor-funded programmes (including in Senegal, Sierra Leone, Uganda and Zambia) switched the GI riser pipes and (in some cases) pump rods to SS and/or uPVC (Baumann, 1998; Harvey and Skinner, 2002; Fader, 2011; Furey, 2014). Studies in Uganda (Fader, 2011) and Zambia (SOMAP3, 2013) have demonstrated that, in areas where pH levels are low and rapid handpump corrosion takes place with a resultant high iron content, replacing GI with SS components significantly reduces the level of iron in the water. Fader (2011) notes that iron concentrations in the wells were less than 1 mg/l when they were drilled, down from ranges between 2.5 to 40 mg/l prior to the remedy.

Other countries (including Ghana, Mozambique and Ethiopia) introduced the Afridev pump with variants using uPVC riser pipes and SS or fibre glass pump rods as described in Box 5 (Harvey, Jawara and Reed, 2002; Baumann and Furey, 2013; RWSN, 2020). In Sudan, in certain locations with rapid handpump corrosion, the India Mark II pumps (with GI riser pipes) were replaced with Afridev and India Mark III pumps (with PVC riser pipes). However, there have been problems of breakage of the pipes (attributed to vibrations when the pumps were in use), and so the new pumps were rejected by community users, who returned to using the rapidly corroding India Mark II (Sabeel, 2021). World Vision Niger switched to using SS pump rods in 2011 (Beers et al., 2013). Given the corrosion issues with GI riser pipes and rods, UNICEF no longer lists them in their supply catalogue. In Sri Lanka, there are cases of India Mark III pumps with SS connecting rods, high-density polyethylene riser pipes and rubber centralisers being installed (Anon, 2021b).

Box 5 Afridev designs to mitigate corrosion

With the use of stainless steel or fibreglass pump rods, it has been claimed that the Afridev pump was designed to be corrosion resistant. However, the Skat and RWSN (2007a) specification also includes an arrangement with GI (specified as mild steel hot dip galvanised to ISO 1461), which corrodes rapidly in aggressive groundwater (see figure opposite). The specifications state that that hot dip galvanised pump rods can be used in waters with a pH value greater than 6.5 (Skat and RWSN, 2007a: 11). The specifications also state that there are other important factors that can influence corrosion, but provide no further details.



Pump rod arrangements for the Afridev pump
Source: Skat and RWSN, 2007.

However, studies in Uganda the 1990s found that the SS pipes and rods which replaced the GI showed signs of pitting and crevice corrosion, while there was bimetallic and uniform corrosion on the cylinder, with the endcap particularly affected (Baumann, 1998). There was also bimetallic corrosion on the pipe holder in the water tank, primarily on the inside of the thread. In order to prevent this, it was recommended to use a SS pipe holder, as well as to clean all ANSI 316 grade pipe of the green colour markings, which were a starting point for crevice corrosion. In the case of Ghana, where the GI was also replaced by SS, the pump included a SS pipe holder that was isolated from the water tank by a rubber gasket, as well as a fully brass cylinder (Baumann, 1998).

In Zambia, there are examples of GI riser pipes being replaced by PVC, but it has been observed that these sometimes break (close to the water tank). This has been attributed to the weight of the cylinder plus water as being beyond the strength of the threaded material (Gandize, 2021) as well as a lack of pipe centralisers, which allow a lot of movement of the riser pipe (Anon, 2021b). The lack of international standards or guidance for material and dimensioning for PVC riser pipes for India Mark pumps results in uncertainty about what should be used and why. Moreover, the tools that are used to lift the PVC out of the borehole when undertaking maintenance are designed to lift GI and they have at times damaged or even broken the pipes (Gandize, 2021). There are also concerns regarding the right techniques for tightening and loosening both SS and PVC. This has placed a burden on communities and pump mechanics. It is worth noting that these are unlikely to be all of the issues faced but rather what has emerged through this particular study, which is by no means comprehensive.

It is also important to note that if the SS material does not actually adhere to the material specifications, it will also be subject to rapid corrosion, as has been noted in Burkina Faso (Danert, 2019).

In summary, while there are alternatives to GI pipes for the India Mark pumps, these are not without concerns. There is certainly a need to update the specifications, but rigorous verification of the suitability of the solutions should be undertaken so as not to create new problems.

6.2 WHO GUIDELINES

The WHO (2017) Drinking Water Quality Guidelines consider corrosion control as an important aspect of the management of a drinking water system for safety. The emphasis by the WHO is on water distribution systems: corrosion control needs to consider many parameters, with specific requirements depending on water quality and the materials used. The solubility and rate of reaction of most metal species involved in corrosion reactions is controlled by pH values. This is particularly important in relation to the formation of a protective film at the metal surface. The optimum pH in distribution systems is in the 6.5–8.5 range.

Handpumps draw water directly from the ground with no distribution system, so the pH cannot be ‘controlled’. However, it can be mitigated. Given the ongoing use of handpumps in SSA, the prevalence of groundwater with low pH (Box 2) and the indirect impacts of rapid handpump corrosion on human health, this study recommends that the WHO consider expanding or amending its guidance on corrosion control to include mitigation of corrosion in handpumps and for other groundwater pump types. While corrosion does not have a direct impact on human health, it is clearly a safety issue, and corrosion control for piped distribution systems is already considered to be a safety issue.

6.3 HANDPUMP SPECIFICATIONS

Specifications for the India Mark II could be clearer with regard to corrosion resistance. Currently, options for aggressive groundwater (i.e. SS rising pipe and pump rod) are not mentioned in the Bureau of Indian Standards Specifications (BIS, 2004). There is also scope for a stronger emphasis on anti-corrosion measures in any future revision of the Skat and RWSN (2007b) specifications for the India Mark II and III, provided that these are fully field-tested. Improved specifications would help organisations clearly specify their requirements and thus strengthen corrosion control measures. Note that other concerns about current handpump specifications, including sources of lead in drinking water, are presented in Report III of this study (Danert, 2022b).

7. CONCLUSIONS AND RECOMMENDATIONS

Research into corrosion in West Africa within the Handpumps Project of the World Bank in the 1980s concluded that total iron concentration in natural groundwater is rarely greater than 1 mg/l, hence the red water (iron) problem in handpump-equipped wells is usually a result of corrosion. It was also found that at pH levels of less than 6.5 galvanisation does not sufficiently protect riser pipes and pump rods that corrode rapidly (Langenegger, 1994). Furthermore, the less a corrosion-affected handpump is used, the more serious the iron problem becomes. High salinity and chloride also increase the rate of corrosion but, in the case of groundwater lifting, less documentation on these phenomena is available than for pH values.

Rapid corrosion is not only an issue for handpumps, but also for the riser pipes of motorised pumps (e.g. solar, diesel, petrol, electric grid) that feed into reticulated systems. The same principles apply to all GI pipes (or poor-quality SS) that are submerged in, or in and out of, groundwater with low pH levels. Handpump corrosion is not confined to rapid or early-life corrosion, as all components that are submerged in and out of water will eventually corrode.

Although handpump corrosion was acknowledged in the 1980s, this study illustrates that communities in over 20 SSA countries still suffer from its effects more than 35 years later. Yet rapid corrosion is a topic that barely features in global discourse and has remained on the margins of many in-country water supply policies and programmes. This is despite the fact that handpumps provide an estimated 18.5% of the population of SSA with their main drinking water supply and are thus likely to remain important for decades to come.

There seem to be cause for optimism in some countries where, despite aggressive groundwaters, the ‘iron problem’ seems to have been addressed, notably The Gambia and Ghana. In some other countries, such as Chad, Uganda and Zambia, the government has taken action to prevent rapid corrosion by banning or trying to prevent the use of GI pipes in parts of or across the whole country. However, the problem of rapid handpump corrosion continues in many countries (as in Burkina Faso), and a lack of sufficient documentation of the problem prevents a more comprehensive understanding of the status quo in others (as in Niger).

While replacement of GI riser pipes with SS or PVC and replacement of pump rods with SS or fibre glass has the potential to prevent rapid corrosion, these options may pose challenges for the India Mark pumps. It is essential that material specifications for SS are adhered to as ‘fake’ SS will also rapidly corrode. Additionally, SS may introduce galvanic corrosion at the water tank, without an isolating gasket, and PVC pipes have been observed as suffering from breakage. In short, the sector would benefit from more research into these phenomena for a set of ‘water tight’ solutions.

If the rapid corrosion problem continues to be ignored, those living in areas where groundwater has low pH, high salinity or high chloride will simply be left behind with abandoned, poorly functioning or difficult-to-maintain supplies.

The realities of rapid corrosion of groundwater systems need to be better understood and taken into consideration at the planning stage. Given the inevitability of corrosion of submerged materials over the long term, corrosion needs to be considered as part of maintenance and rehabilitation programmes for all systems that rely on groundwater.

In order to take the issues raised by this study forward, it is recommended that:

- **RWSN, other global platforms and international agencies** should use the information in this report, as well as the other two reports from the Stop the Rot initiative, as a basis for raising awareness of:
    - The ongoing reliance on handpumps in SSA, despite growing interest in groundwater systems that use other energy sources, including solar, and in piped supplies.
    - The phenomenon of rapid handpump corrosion, including the causes, effects, impacts and mitigation measures (together with their ongoing challenges).
    - The importance of determining whether rapid handpump corrosion takes place in all SSA countries.
    - The need to consider corrosion as part of the long-term maintenance of all water supplies that rely on groundwater, including handpumps.
- **Donor/funding agencies** should:

  - Ensure that their grantees are aware of rapid corrosion of handpumps, report on it when it is observed or suspected (through monitoring or when undertaking rehabilitation programmes) and support the grantees to understand more about the extent of the problem and actively seek solutions.
  - Support academic organisation(s) to develop a continental map and national maps that illustrate the likelihood of low pH values in SSA, incorporating data on population densities where this is available.
  - Consider funding organisations and/or consultants to:
    - Document what has reduced or mitigated handpump corrosions in those countries where it has been addressed.
    - Investigate the performance of handpumps whereby components have been replaced in order to prevent rapid corrosion and examine whether the new solutions are viable in the short, medium and long term. Studies should include examination of possible galvanic corrosion of tanks and cylinders or failing UPVC.
    - Document what is happening in countries where there is limited evidence of rapid handpump corrosion, which may be currently ignored.
  - In all cases, the information should be made available in the public domain.
- **National governments and their development partners, as well as other implementing organisations** should:
  - Ensure that assessment and post-construction monitoring mechanisms incorporate questions about user perceptions of water quality such as taste, smell and appearance and, if concerns are raised, follow up with studies to identify the cause of the problem (which may include rapid corrosion). Ensure that any studies are placed in the public domain.
  - Consider the options available to prevent rapid corrosion or to mitigate its effects, such as installing a corrosion-resistant option of the Afridev pump (if required pump depth allows), installing another corrosion-resistant pump, use of SS pump rods and riser pipes or use of UPVC riser pipes and SS pump rods for the India Mark pumps, use of a motorised pump with non-corrosive riser pipes. If there is no option but to use GI pipes and rods, these need to be replaced more frequently.
  - It may be necessary to review handpump standardisation policies and standards across the country. In case changes to the components are made that are not in the International Standards, there should be monitoring of pump performance before widescale rollout. Note that any changes in standardisation policy will require investments and support to ensure the availability of spare parts, and to ensure that handpump mechanics, drillers and pump caretakers are trained in the installation and maintenance of variants of existing pumps or new types of pump.
  - In the case of new sources, or for rehabilitation, always undertake water quality testing (including pH, EC and turbidity) prior to installation to determine whether the groundwater source is aggressive and likely to cause rapid corrosion of GI pipes, pump rods and the pump cylinder.
- **Lead international agencies** should form an action group on handpumps (perhaps incorporating other groundwater lifting methods). The action group should comprise not only international agencies, but individuals and organisations that are trying to preventing rapid corrosion of handpumps in-country. The group should:
  - Provide a platform for learning and exchange on handpump issues (including corrosion) and advocate for investments into studies that examine the effectiveness of alternatives to the installation of GI riser pipe and pump rods.
  - Engage in policy dialogue with governments, donor agencies, non-governmental organisations and academics that are working in the countries where rapid corrosion has been identified as a problem.
  - Where appropriate, make policy recommendations.
- **The WHO** should expand its guidance on corrosion control to include corrosion mitigation measures for handpumps (and other groundwater lifting installations) in their next update of the 'Guidelines for drinking-water quality' and incorporate this issue into the next edition of their 'Guidelines for small drinking-water supplies'.

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ANNEX 1 DOMINANT ROCK TYPES IN WEST AFRICA

TABLE A1.1 DOMINANT ROCK TYPES IN WEST AFRICA

Rock Group	Acidic	Intermediate	Basic
Igneous	Granite Granodiorite Migmatite Rhyolite	Diorite Syenite Andesite Monozonite Epidiorite Trachyte	Basalt Dolorite Gabbro
Metamorphic		Gneiss Quartzite Phyllite Schist Metavolcanic	
Sedimentary	Sand Sandstone Arkose Greywacke	Mudstone Shale	Limestone Dolomite

Source: Langenegger, 1994.

ANNEX 2 BRIEF COUNTRY DESCRIPTIONS

This annex presents more details of the observations, experiences and research on rapid handpump corrosion for 16 out of the 22 countries shown in Figure 10. In the case of Liberia there is no further information other than responses to the RWSN 2021 survey (Furey and Danert, 2022), thus these countries are not covered below.

Concerns raised regarding end-of-service-life corrosion are included in the descriptions. Note this was not the focus of the research but has emerged as another aspect of handpump performance. It therefore may be more widespread than the descriptions would suggest. Due to variation in the information available, some country descriptions are much more detailed than others.

BURKINA FASO

Six types of handpumps (India Mark II, India Mark III, Vergnet, Diacfa, Volanta and Cardia) are used in the country, with a current preference for the India Mark II and Vergnet (Danert, 2019).

Handpump corrosion in Burkina Faso has been a problem for over 30 years. Governments, aid agencies and others have nonetheless continued to install pumps manufactured with unsuitable materials, leading to high maintenance costs, pump failure and rejection of water sources due to poor water quality (Danert, 2019).

Handpump corrosion has been reported in physical audits (CABINET NTU INTERNATIONAL A/S, 2013; 2014) in which visible corrosion of (below ground) handpump components leading to changes in water quality if the pump is not used for several hours have been noted. In 10% of handpump boreholes (HPBs) sampled by the 2013 physical audit, water quality was deemed dubious by the users due to colour and smell; the worst affected regions were Hauts-Bassins, Nord and Sud-Ouest.

One respondent to the RWSN survey stated that pump corrosion is ‘Very often noted in the 6 regions affected by humanitarian crisis‘ (Furey and Danert, 2022: 20). These regions are Boucle du Mouhoun, Centre-Est, Centre-Nord, Est, Nord and Sahel (Cluster Santé, 2019).

Concerns about non-conformant pumps in 32% and 34% of the HPBs constructed and installed were raised by physical audits (CABINET NTU INTERNATIONAL A/S, 2013; 2014). These problems comprise major defaults that threaten long-term viability of the pump: quality of the cylinder, pipes, rods and external pumping systems. Chemical analysis of 13 pump component samples in 2019 found that five of six sampled riser pipes, and two of four sampled pump rods, did not conform to international standards for the composition of SS of the specified grade. In particular, the low nickel content results in components that are less corrosion resistant than the specified grade (Danert, 2019).

Concerns about component quality are echoed by a respondent to the 2021 RWSN survey who pointed to the need to strengthen control at national level to reduce counterfeits that flood the market and create inconvenience at community level (Furey and Danert, 2022).

The National Water Supply Programme, PN-AEPA, uses turn-key contracts that combine: (i) siting; (ii) drilling; (iii) construction of the superstructure; and (iv) pump supply and installation into one contract, with enterprises paid for successful boreholes only. While this was introduced to overcome budgetary constraints, there are concerns that the company which wins the tender may not actually have the expertise for all components (Danert, 2019).

Danert (2019) estimated that investments of FCFA 0.6–2.9 billion (€0.9–4.5 million) per year were lost due to the installation of poor quality handpumps and other aspects of the construction. It was estimated that in one year, over 130,000 people were provided a water supply service that is likely to break down within a few years.

CAMEROON

A respondent to the 2013 RWSN survey stated that two boreholes with India Mark II pumps (with GI pipes) were installed in a village called Modeka (South-West Province). The water from the pumps turned reddish-brown, while the water from nearby rope-and-bucket wells did not. The boreholes have since been abandoned and the community continue to use rope-and-bucket wells until something is done (Furey, 2013).

Respondents to the 2021 RWSN survey indicated that there is a problem with corrosion as a result of excessive use of handpumps without regular maintenance and a lack of replacements, indicating that handpump corrosion is primarily an end-of-service-life problem, rather than an issue of early-life or rapid corrosion. Aziz (2022) found evidence of handpump corrosion in the Kounoure districts of Foumbot (West, Cameroon).

CHAD

A 1992 evaluation for CARE in Southern Chad found that over 400 wells had been equipped with GI components and that within four years of installation many pumps were breaking, with the riser pipes and pump rods falling to the bottom of the borehole. The *Ministère de l'Hydraulique* (Ministry of Hydraulics) is apparently aware of this; however, it seems that many organisations continue to install pumps with GI components (Furey, 2014).

In Chad, groundwater pH levels are often found to be less than 6.5. Most of the pumps found are India Mark II with galvanised steel pipes and rods. There is a very significant failure rate. Most pumps fail after a year, and the quality of water is almost always poor: it is red in colour, smells foul and has an awful taste. More recent India Mark II installations using SS pipes and rods do not seem to have this water quality problem (Furey, 2014).

Corrosion of riser pipes was also observed in a pump rehabilitation project in Bokoro District, northern Chad (Thiebert, 2016), and rapid corrosion of handpumps has been observed in southern Chad, including Logone Oriental Region, where water has a pH of between 4.5 and 6.5 (Seguine and Lacour-Gayet, 2014). A government directive was apparently issued to ban the use of GI pipes in some southern regions, but is not always adhered to (Anon, 2021a).

DEMOCRATIC REPUBLIC OF THE CONGO

In Mahagi, Ituri Province, corrosion of the riser pipe in the pump cylinder was reported as the usual failure of handpump systems (India Mark II Pumps) (Koestler et al., 2014).

ETHIOPIA

Corrosion and general damage affected handpump components in 50% of the 50 HPBs surveyed in the Ethiopian Highlands, where the main physical factors affecting functionality were depth to groundwater and poor condition of handpump components. Over 55% of the India Mark II handpumps examined had a rising main thickness and/or galvanising coating thickness below the handpump specification (Kebede et al. 2019). The 2021 RWSN survey indicates that handpump corrosion is prevalent in Eastern Ethiopia/Somali region (Furey and Danert, 2022).

GHANA

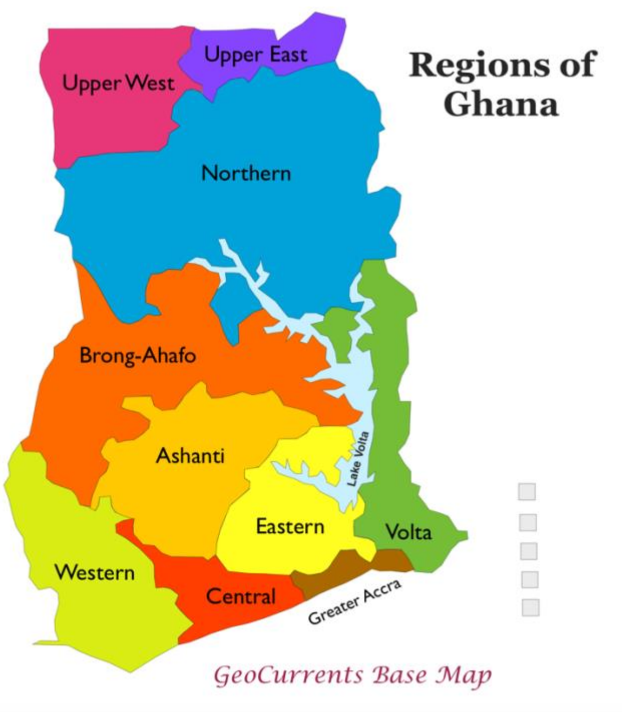
The Ghana Modified India Mark II handpump, which was first introduced in the mid-1990s, has SS riser pipes and pump rods rather than GI. The pump also has a SS pipe holder that was isolated from the water tank by a rubber gasket, as well as a fully brass cylinder (Baumann, 1998). It is one of four pumps (alongside the Afridev, Vergnet and Nira AF-85) approved by the government for installation in communities (MacArthur, 2015).

As one of the countries studied by Langenegger (1989), the earliest information on handpump corrosion in Ghana is almost 35 years old. Wollschied (1987) summarises the aggressiveness of groundwater within seven administrative regions of the country (Table A2.1), indicating that rapid corrosion of GI riser pipes and pump rods would be expected to occur in many parts of the country. Observations of high iron concentrations in the range 1–64 mg/l have been found in boreholes in all geological formations (Kortasi, 1994). However, the percentage of iron derived from the aquifers compared to pump corrosion was unknown (Asare and Boateng, 1992, in Kortasi, 1994).

Table A2.1 Zones in Ghana affected by corrosive waters

Region	Description
Volta	Generally, less aggressive waters of medium hardness, but some pockets with low pH values or high chloride content.
Eastern	Mixed picture ranging from almost neutral to very aggressive waters.
Northern Ashanti	Aggressive waters with low pH values but generally low chloride content. Some wells have elevated iron content from the aquifer.
Southern Ashanti	Generally, very aggressive waters with low pH values; very soft; low chlorine content. Some wells have elevated iron content from the aquifer.
Central	Rather aggressive waters, some with high chloride content (especially along the coast). Some wells abandoned due to high salt content.
Western	Very aggressive waters with very low pH values. Corrosion of pump head due to salty atmosphere along the coast.
Brong Ahafo	Generally, less aggressive with higher pH values, but also some aggressive well waters.

Source: Wollschied, 1987.



Map Source: Geocurrents, 2016.

Langenegger (1989) found that 66% of handpump breakdowns in southern and central Ghana were due to corrosion (rod breakages), and over 30% of handpumps in southern Ghana were rarely used or abandoned due to corrosion. There are examples of rehabilitation projects in the 1990s in which India Mark II GI riser pipes and rods were replaced with SS (Fonseka and Bauman, 1994).

Subsequent research examining biofilm on GI rising mains in Kumasi (Ashanti Region) indicates there was still a handpump corrosion problem in the early 2000s (Ibe et al., 2002). Aggressive groundwater resulting in rapid corrosion of galvanised iron rising mains and rods was also found to be a problem in some areas of Ghana by Harvey, Skinner and Reed (2002): 'in some cases, handpumps functioned for less than two years before suffering breakdown due to corrosion problems'. There has been a lack of documentation on the handpump corrosion situation since the early 2000s.

The RWSN survey indicates rapid corrosion may still be a problem, particularly in areas with high salt and other mineral content, or where there is a lot of chlorine in the water, such as the Norther and Central Region (Furey and Danert, 2022). However, the rapid handpump corrosion problem observed 20 years ago in Ghana may have been largely resolved with extensive use of the Ghana Modified India Mark II or the Afridev. While there has been a shift in technology focus by the Community Water and Sanitation Agency towards piped supplies, an estimated 21% of Ghana's population still rely on handpumps (Danert, 2022a).

One survey respondent stated, 'in Ghana, it is the very old pipes which are over 50 years that experienced corrosion but even now all those old pipes are being replaced with pipes that resistant to corrosion' (Furey and Danert, 2022: 18). This statement is indicative of end-of-service-life corrosion, as outlined in Section 2.

KENYA

The most common handpump in use in Kenya is the Afridev, followed by the India Mark II (MacArthur, 2015). Other pumps that have been installed included the Tara, Tany, Duba and SWN80/81, as well as rope pumps[19] (Lane, 2021). Foster, Furey et al. (2019) state that 24% of handpumps were non-functional in nine out of 47 counties. A Water Infrastructure Audit in Kitui County enumerated 3,126 equipped and un-equipped water sources. Of these, 687 (22%) were handpumps, of which the Afridev comprised 86% and India Mark II's 7%. 32% of handpumps experienced problems and unreliability across the year, with pump rods (32%), foot valves (28%) and rising mains (31%) being the most frequently broken parts in non-operational handpumps (Nyaga, 2019).

The Water Resources Management Authority has a monitoring programme targeting some of the important Kenyan aquifers (Earthwise, 2011Ke). In the case of coastal aquifers, the water quality data collected is limited to pH, colour, EC, total dissolved solids, chloride, salinity, total alkalinity, total hardness, magnesium and calcium (Mumma et al., 2011).

Moderate and high levels of dissolved iron have been found in boreholes throughout Kenya (MWSI and WRA, 2019). Corrosion of GI riser pipe and pump parts has also been observed in both shallow and deep groundwaters of the southern Kenyan coast. In some areas of Kwale (Figure A2.1), low pH has been known to cause rapid corrosion of mild steel pump rods (Reynolds, 1992).

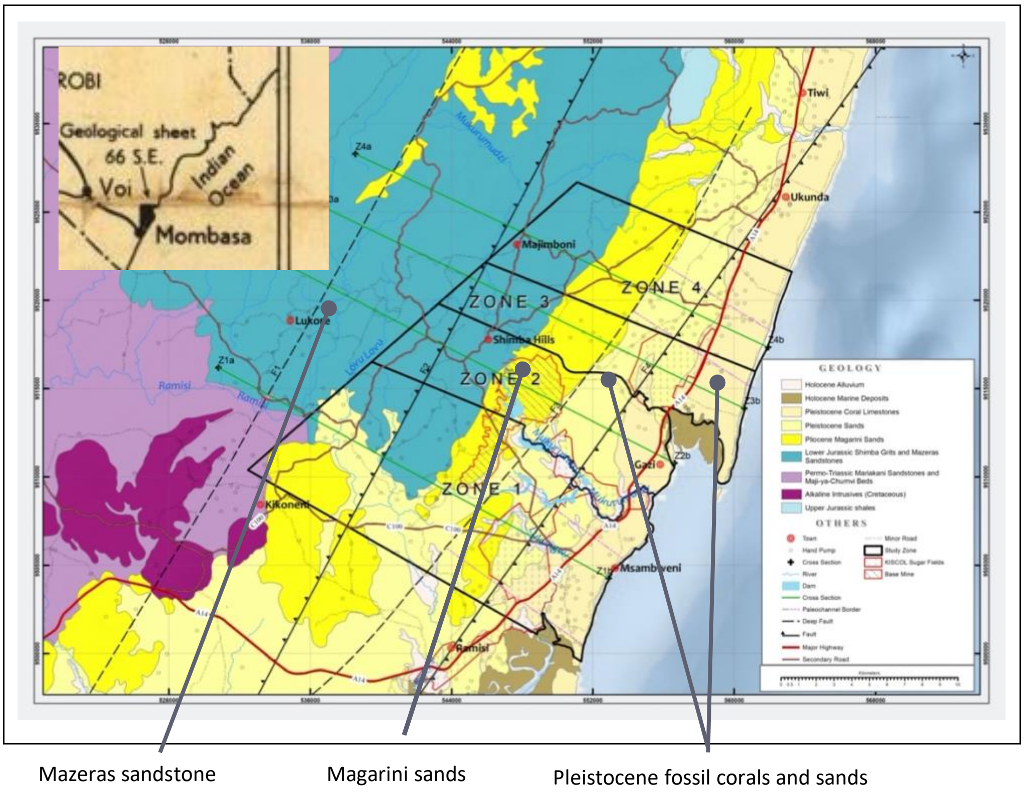


FIGURE A2.1 GEOLOGY OF THE MOMBASA-KWALE AREA WITH IRON-RICH AREAS INDICATED
Source: University of Nairobi, 2019.

Mazeras sandstone (is a naturally iron-rich terrestrial sandstone and forms the Shimba Hills, where observation of rapid corrosion of riser pipes (to paper-thin in 18 months) has been observed (Lane, 2021). Pleistocene fossil corals and Pleistocene sands waters (location shown in Fig A2.1) are sometimes naturally iron-rich, with iron-stained handpump pedestals scattered throughout the area. These waters are typically neutral pH but occasionally less than 7 (Lane, 2021). Magarini Formation is iron-rich, low pH, low EC and low hardness, and thus potentially corrosive water (Lane, 2021).

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[19] There are a few rope and washer pumps used in small areas where specific NGOs have been active (e.g. on shallow wells on the Talek River, Narok County) for drinking water and in wide-diameter shallow wells in the Nairobi Tuffs east of Thika in Thika County (Lane, 2021).

In the 1980s and 1990s, the Kenya-Finnish Cooperation Project (KEFINCO) and the Dutch-supported Rural Domestic Water Supply and Sanitation Programme concentrated on improving rural water supply in Western Kenya (DHV Consultants, 1988). Both relied heavily on boreholes fitted with handpumps but as the projects evolved it became clear that iron was a sufficiently serious contaminant that it led to the abandonment of a 'relatively high percentage (10-12%) of boreholes and wells not used for drinking because of the bitter taste of the water (probably caused by a high manganese and/or iron concentration)' (DHV Consultants, 1988). KEFINCO addressed the issue of aggressive groundwaters by requiring that boreholes be constructed from uPVC rather than steel.

In the archaean greenstone belt of Western Kenya, corrosion was observed in four boreholes completed in 2014 in Kakamega, Kisumu, Siaya and Vihiga counties, whereby significant soluble iron appeared in groundwater within weeks of handpump installation (MWSI and WRA, 2019). The presence of iron rich formations in Western Kenya became apparent in the 1980s (DHV Consultants, 1988).

In addition, boreholes drilled in the southern Kenyan coast that are cased/screened with mild steel, or mid-steel welded to SS, inevitably fail, often in a matter of a few years (Lane, 2021). There are boreholes currently being installed with mild steel casing and screens, even though the lessons of the SIDA handpump programme in the 1980s and 1990s indicated that, along the coast, these corrode and uPVC should be used (Lane, 2021).

In response to the 2021 RWSN survey, one respondent alleged that rapid pump handpump corrosion is a problem in Kenya (Furey and Danert, 2022).

MALAWI

The Afridev handpump became the dominant handpump in Malawi through standardisation in the 1990s (MacArthur, 2015). In terms of history, according to Anscombe (2004), the year 1998 was the onset of a major rural water development drive and a substantial increase in drilling activity. More recently, it has been estimated that 600–1,200 handpump installations (Afridev) were undertaken between 2000 and 2016 (Truslove et al., 2019). As the Afridev riser pipe is uPVC, it is not subject to corrosion, whereas GI pump rods could be corroded if they are installed in aggressive groundwater.

Some cases of high levels of iron and handpump corrosion have been found in Malawi. In the assessment by Anscombe (2011), out of 102 sampled boreholes, three were not used due to bad tasting water (due to high salt and/or iron levels), and chemical precipitate from salt and iron were found in Chimpangu /Chisapo, Lilongwe. Out of 128 sampled boreholes in the 2012 assessment (Anscombe, 2013) there were five incidences that were classified as premature abandonment due to salty, iron-rich or muddy water, with sources rejected by users. Another 12 had complaints from water uses including discolouration (indicating high iron levels). Mwathunga et al. (2019) found that corrosion and general damage affected handpump components in over 75% of the 50 HPBs in Malawi for which forensic surveys were undertaken. Note that the term 'general damage affected' does not relate to corrosion. According to McAllister (2021), 56.4% of rods were corroded. However, this may be end-of-service-life rather than rapid corrosion. Lapworth et al. (2020) found high concentrations of zinc in water from handpumps that use galvanised components in Malawi, Uganda and the Ethiopian highlands, indicating corrosion.

High levels of salinity have been recorded in parts of southern Malawi (Rivett et al., 2019), which can also result in rapid handpump corrosion (see Section 1).

NIGERIA

Daw (2021) has observed what he considers to be rapid handpump corrosion in Kebbi, Katsina and Jigwa states (in the north) and Benue State (in the south-east). Rehabilitation of boreholes in Katsina State by UNICEF has found handpump corrosion, including rapid corrosion.

In the case illustrated in Figure A2.3., the handpump was initially installed in 2019 and rehabilitated in 2021. The photos indicate rapid corrosion or point to the installation of second-hand parts in the first place.

Respondents to the RWSN 2021 survey raised concerns about rapid handpump corrosion specifically in the north and the Niger Delta area, with some stating that it is a widespread problem and others who did not think that it was a problem (Furey and Danert, 2022).

FIGURE A2.2 STATES OF NIGERIA
Source: Wikipedia, n.d.(a).

FIGURE A2.3 PHOTOGRAPHIC EVIDENCE OF RAPID HANDPUMP CORROSION IN KATSINA STATE, NIGERIA
Source: Olajide Oyetunde.

SENEGAL

'In southern Senegal (Ziguinchor), the USAID/PEPAM project at first installed India Mark II pumps with galvanised pipes but encountered iron problems, which have been resolved by replacing with PVC pipes and stainless steel pump rods' (Furey, 2014: 12). A respondent to the RWSN 2021 survey observed rapid corrosion of handpumps in Matam Region (Furey and Danert, 2022).

SIERRA LEONE

Handpumps in use in Sierra Leone are India Mark II and III, PB II and III Kardia (including Inkar), Afridev and pulley pumps (Inter Aide, 2021). Inter Aide (2021) recommend the systematic replacement of all galvanised components and the cylinder with SS components in Bombali District.

SOUTH SUDAN

The corrosion of GI components on the India Mark II in South Sudan has been a longstanding problem for both water quality and the cost of the operations and maintenance (Furey, 2014).

In Northern Bahr el Ghazal state, one respondent noted that 'Most of the handpumps have their pipes rusted even some of which were repaired or rehabilitated about 6 months ago have their pipes rusted' (Furey and Danert, 2022: 17). Low pH values were also measured in a small sample of HPBs in the state (Carter and Guo, 2021).

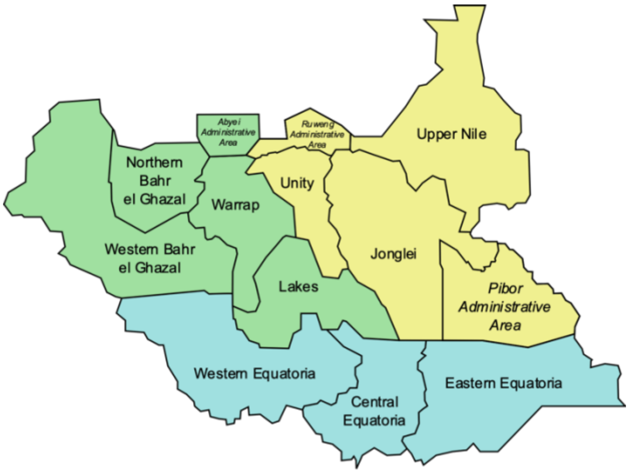

FIGURE A2.4 STATES OF SOUTH SUDAN
Source: Wikipedia, n.d.(b).

SUDAN

Within North Kordofan (Figure A2.5) 'handpumps consumed a lot of connecting rods and rising mains in the El Hamadia and Um Ashira villages' where pH ranges from 6.2 to 7 (Sabeel, 2006: 87). Within El Fashir North, 'connecting rods and rising main pipes are … a problem at Rab Al wail [site] because of corrosion' of GI riser piped and pump rods. The rods break and corrosion affects water quality making is unacceptable due to unpleasant tased and discolouration (Sabeel, 2006: 90). In fact, the high turnover of spares in certain parts of Sudan was one of the indicators that led to the selection of the locations for research by Sabeel (2006).

FIGURE A2.5 STATES OF SUDAN
Source: WorldAtlas, 2021.

In certain locations with rapid handpump corrosion, the India Mark II pumps (with GI riser pipes) were replaced with Afridev and India Mark III pumps (with PVC riser pipes). However, there have been problems of breakage of the pipes (attributed to vibrations when the pumps were in use), and so the new pumps were rejected by the communities, who returned to the rapidly corroding India Mark II (Sabeel, 2021).

UGANDA

In Uganda, the India Mark II and III are referred to as the U2 and U3 having been adopted by the Uganda National Bureau of Standards[20] (UNBS, 2019).

Rapid corrosion of the U3 was observed in the DANIDA-funded RUWASA project in Eastern Uganda in the early 1990s. It was considered a major issue and led to trials whereby GI pipes and rods were switched to SS (American National Standards Institute [ANSI] 304 and later ANSI 316). However, the SS pipes and rods showed signs of pitting and crevice corrosion while there was bi-metallic and uniform corrosion on the cylinder, with the endcap particularly affected (Baumann, 1998). There was also bi-metallic corrosion on the pipe holder in the water tank, primarily on the inside of the thread. It was

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[20] US 403:2000 Standard specification for deep well CBMS handpump (model U3), US 404:2002 Standard specification for Extra deepwell CBMS handpump and US 205:2002 Standard specification for shallow well handpumps (model U2/U3).

recommended to use a SS pipe holder in the water tank to prevent galvanic corrosion and to clean all ANSI 316 from the green colour markings, which were a starting point for crevice corrosion.

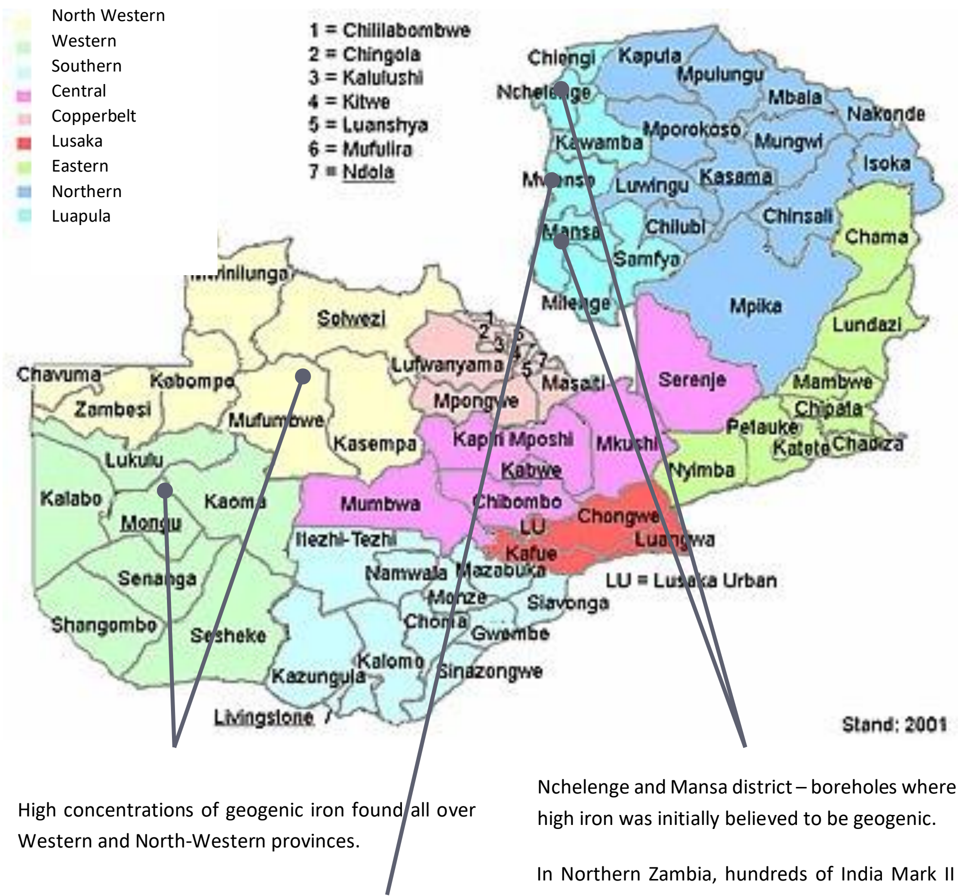
The ongoing corrosion problem observed in eastern Uganda at the time led to piloting PVC down hole components, and ultimately the development of the U3M pump (M for modified). The U3M resembles a U2 or U3 at the surface but uses PVC riser pipes and SS rods and an Afridev cylinder, plunger and foot valve (Erpf, 2001). Retrofitting boreholes with the U3M was demonstrated to be successful in solving the corrosion problem (Fader, 2011). However, writing some 15 years later, Casey et al. (2016: 63) state that 'there appears to be limited awareness and some confusion about the U3M, its purpose and use among many stakeholders in Uganda'. Rapid corrosion of pump rods and riser pipes in Uganda continues to be a widespread problem. Arguably Uganda is the SSA country for which most documentation on the topic exists (e.g. Baumann, 1998; Fader, 2011; Furey, 2014; Nekesa et al., 2015; Casey et al., 2016; Liddle and Fenner, 2018; Owor et al., 2019; Lapworth et al., 2020; Bentley, 2021; Furey and Danert, 2022). The corrosion studies undertaken within the RUWASA programme were also considerable.

The BGS-led study to understand why handpumps fail (Owor et al., 2019) finally led to a change in government policy on handpump materials, which came into effect in November 2016. The Ministry of Water and Environment issued a directive to stop the use of GI materials in handpump, specifying uPVC or SS alternatives must be used for riser pipes in new installations (UPGro, 2020). However, with the price of SS three or four times as much as GI, and uPVC being unsuitable for depths more than about 45 m (due to strength issues), challenges have been observed in the implementation of this directive (Liddle and Fenner, 2018). Given the aforementioned experiences of bi-metallic corrosion with the use of SS in the 1990s, there are also questions of whether this problem will recur.

A WaterAid/Poldaw study in 2019/20 on handpump improvement replaced GI riser pipes and pump rods with uPVC and SS respectively, including a novel riser pipe configuration, at six handpump sites in Masindi, Uganda (WaterAid, 2021). The study also incorporated design and material improvements to rod centralisers and piston bucket seals. The study found that, following the modifications, 92.7% of respondents reported no handpump breakdowns in a year, compared to 0.6% beforehand. Corresponding figures for monthly breakdowns were 5.3 % and 61.2% before and after the modifications. Changes in user perceptions of water quality were also significant, with only 2% of users experiencing no change in water quality over time before the modifications, and 96.7% afterwards.

ZAMBIA

The approved standard handpump in Zambia is the India Mark II, with variations for corrosion protection, including SS riser pipes. Afridev pumps have also been introduced on projects in certain areas (Sansom, 2009); Malda and Access 1.2 pumps are also in use (Furey, 2014). Naturally high levels of iron and corrosive groundwaters are found all over the Western, North-Western, and Copperbelt provinces (Anscombe, 2021a), which may have overshadowed the handpump corrosion problem. Determining the cause of the 'iron problem' for handpump supplies and taking appropriate action has therefore been a challenge. However, progress is being made in some areas. By replacing GI components with SS and PVC in existing handpumps, the two studies by JICA and UNICEF (described below) have helped diagnose the problem in some areas. However, questions still remain in some parts of the country. Dissolved iron is a common problem in Sinazongwe District of the Southern Province (Beers, 2021), but there is no conclusive evidence as to whether it natural or as a result of corrosion.



High concentrations of geogenic iron found all over Western and North-Western provinces.

GI components in boreholes in Luapula Province were replaced with uPVC or Afridev pumps and the iron problem was solved (i.e. no more corrosion).

Nchelenge and Mansa district – boreholes where high iron was initially believed to be geogenic.

In Northern Zambia, hundreds of India Mark II with GI pipes were installed in 2013/14. Complaints about rust and taste reported by users, sometimes within four months of installation. Similar complaints have not been observed with other pumps that are less vulnerable to corrosion.

FIGURE A2.6 PROVINCES OF ZAMBIA ANNOTATED WITH AREAS OF CONCERN FOR CORROSION OR HIGH IRON CONTENT
Source: Adapted from Wikipedia, n.d.(c).

In Northern Zambia, hundreds of India Mark IIs have been installed and there have been varying degrees of complaints about rust and taste, although similar complaints have not been observed with other pumps that are less vulnerable to corrosion (e.g. Afridev, Malda, Access 1.2) (Furey, 2014). Meanwhile, Anscombe (2018) states that in North-Western Province, a project under the Ministry of Local Government and Housing (funded by KfW)[21] involved the installation of India Mark II pumps with fully SS riser pipes and pump cylinders, which were still functional eight years later.

Following observations that, in several areas of Zambia groundwater drawn from handpump water supply facilities contains iron levels that are higher the Zambian guideline standard value of 1.0mg/l, the JICA-funded Sustainable Operation and Maintenance Programme (SOMAP) commenced a study in May 2012. A total of 20 handpump sources with high levels of iron[22] were selected (distributed as shown in Figure A2.7). Water quality tests were undertaken before and after the removal of the India Mark II handpump; boreholes were then re-developed, and a new Afridev handpump (with SS pump rods) was installed and the water quality monitored after four months. Subsequently, the SS rods were

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[21] KfW is a bank committed to improving economic, social and environmental living conditions across the globe on behalf of the Federal Republic of Germany and the federal states.

[22] On all sites except one, measured iron values were greater than 1 mg/l (acceptable drinking limit for Zambia). Most readings were greater than 10mg/l, with a few varying between 1.89–7.5mg/l (SOMAP3, 2013).

replaced with GI, and the water quality was also monitored after four months before being replaced with SS (SOMAP3, 2013).

On all sites except one, measured iron values were greater than 1 mg/l before borehole cleaning and the levels decreased to less than 1 mg/l after borehole re-development. In all but four sites, the water iron content dropped after pump replacement. At one of the sites where iron content remained high, it was speculated as being possibly caused by steel casing (SOMAP3, 2013).

UNICEF undertook a similar study whereby 60 boreholes in Mansa District, Luapula Province, with high levels of iron (> 2 mg/l) and high pH had the India Mark II GI riser pipes and (probably) electroplated mild steel rods replaced with PVC pipes and SS rods. Monitoring of 30 of the handpumps after replacement found that 26 were acceptable to users (Anscombe, 2016).

In light of the findings, JICA developed a flow chart for handpump selection according to water quality. In the construction of new boreholes, those where water has iron content of less than 1.0 mg/l are tested for pH levels. If the pH level is less than 7.0, either the Afridev or India Mark II with PVC or SS rods and riser pipes is to be installed (JICA, 2017). In cases where iron content is greater than 1.0 mg/l, iron removal plants are to be installed. Further analysis of whether this guidance is being followed, and its impacts, is beyond the scope of this study.

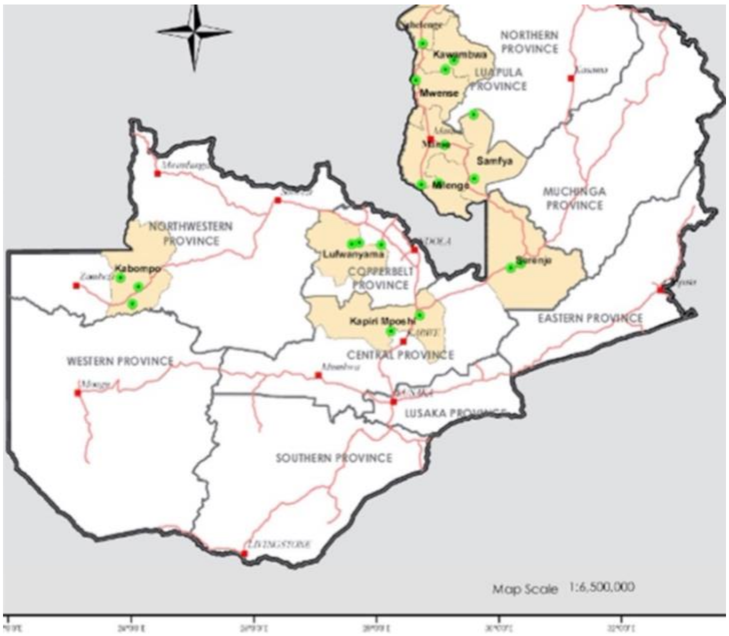

FIGURE A2.7 TARGET AREA (SHADED) AND SITES (IN GREEN) FOR SOMAP STUDY ON HANDPUMP CORROSION
Source: SOMAP3, 2013.

ZIMBABWE

The Zimbabwe Bush pump is the main handpump used in Zimbabwe, which is manufactured in-country. There are pockets within the country where corrosion of handpump components is high, and a set of tele-inquiries undertaken to contribute to this study suggests that it affects some communities within 17 out of 60 districts (Fred, 2021). However, more research is needed to better understand the problem. Two respondents to the 2021 RWSN survey raised concerns about component quality, particularly low-quality GI and SS as contributing to corrosion problems.