GROUNDWATER QUALITY - AN IMPORTANT FACTOR FOR SELECTING HANDPUMPS

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ABSTRACT

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Handpumps are considered to be the most economical means for utilizing groundwater for millions of people in rural and urban fringe areas in many developing countries. Large numbers of handpumps have already been installed and many more are planned to be put into operation during the coming years.

Based on the experience with the World Bank executed UNDP-INT/81/026 Handpumps Project, particularly in the West African Region, the groundwater quality can have a significant impact on the performance of handpumps, and thus, on investment and recurrent costs. This is especially the case where handpumps with non-corrosion resistant below ground components (rising mains, pump rods, cylinder assemblies) are applied under corrosive groundwater conditions resulting in an increase of the frequency of breakdowns. Field experience has shown that up to 2/3 of handpump breakdowns have been directly or indirectly attributable to corrosion (rod breakages).

Therefore, corrosion resistance is an important point with regard to handpump selection in order to minimize maintenance costs. Corrosion resistant material, e.g. stainless steel, however, is generally more expensive than non-corrosion resistant material like galvanized iron, which is still the standard material for many and widely applied handpumps such as the India Mark II and others.

As a consequence, it is essential not only to look at the price, when handpumps are to be selected, but also at the long term maintenance costs, e.g. over 10 years or more. Therefore, in order to avoid any surprises, the groundwater quality should be taken into account so as to verify whether corrosion resistant handpumps, even at higher prices, would offer a more economical solution on a long term basis than the usually cheaper non-corrosion resistant handpumps.

However, corrosion has not only a direct economical impact on handpumps as referred to above, but also an indirect one due to corrosion products affecting the water quality. The result of this are high iron concentrations in the water causing reluctance from the part of the beneficiaries to use such water points for domestic purposes or even abandonment of them with the consequence that the financial means allocated to such water points are badly invested. Field experience suggests that up to 30% of handpump equipped water points are very little or not used mainly due to corrosion related water quality problems.

Furthermore, it becomes more and more evident that the corrosion problem with handpumps is not only restricted to West Africa, where the experience presented in this paper comes from, but occurs all over the world. It is, thus, imperative to take the factor of corrosion into consideration in connection with selecting handpumps and, as a rule of thumb, galvanized iron or mild steel should not be considered as material for rising mains and pump rods where the pH of the groundwater is below 6.5.

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*The views and interpretations in this paper are those of the author and should not be attributed to the World Bank, the UNDP, their affiliated organizations, or any institution, enterprise, etc. referred to in the paper.

1 INTRODUCTION

The main objectives of the World Bank executed UNDP-INT/81/026 Handpumps Project, in short the Handpumps Project, during its first phase (1981-1986) were to test handpumps under laboratory and field conditions, to provide technical assistance to local manufacturers of handpumps, and to promote the technological development of a new generation of handpumps called Village Level Operation and Maintenance (VLOM) pumps. The term VLOM describes the basic element of the new approach, namely handpumps which can easily be operated and maintained on the village level.

Some 2700 handpumps of about 70 different models have been tested in 17 countries distributed over five regions (South East and South Asia, East and West Africa, and Latin America). The results of the Handpumps Project are presented in a number of reports of which the latest one, entitled "Community Water Supply: The Handpump Option", contains a handpump selection guide, a handpump compendium, as well as general recommendations on community water supply systems based on several years of experience gained from the project.

Remarkable achievements have been made with regard to handpump development during the last few years especially with regard to reliability and VLOM approach. Nevertheless, there is no ideal handpump, and there will hardly ever exist a pump which can meet the whole range of conditions and requirements handpumps can be exposed to and are expected to fulfill respectively.

The pump selection guide mentioned above is based on the following parameters: Discharge rate, pumping lift, ease of maintenance, reliability, corrosion resistance, manufacturing needs, and price.

The West African experience of the Handpumps Project has shown that the parameter groundwater quality, through corrosion, is an important factor regarding handpump performance. Aquifers with aggressive groundwater are widespread and common in the West African Region. It is estimated that about 70% of the region has aggressive groundwater (pH<6.5).

The results and experience with regard to handpump corrosion originates mainly from field trials within the Handpumps Project executed in Burkina Faso, Côte d'Ivoire, Ghana, Mali, and Niger.

2 RESULTS

2.1 General

The primary negative aspect of groundwater quality in handpumps is corrosion. Thousands of handpumps in the West African Region are equipped with galvanized iron (GI) rising mains and pump rods which are, as shown in the following chapters, not resistant to corrosion under the generally occuring groundwater conditions.

Corrosion is a complex multi-disciplinary phenomenon. In the AWWA/DVGW * co-operative research Report entitled "Internal Corrosion of Water Distribution Systems" it is stated: "... 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. Equally evident is the well-recognized fact that no universal index exists for predicting corrosion in all types of water systems and for all water quality conditions".

With regard to handpump equipped water points, corrosion has two major effects: (1) increase of mechanical failures of handpumps, and (2) deterioration of the water quality.

2.2 Groundwater quality

As pointed out under 2.1 corrosion depends upon several factors. Some of them, e.g., the pH, is a useful corrosion indicator which can easily be measured in the field as well as the electrical conductivity EC. The EC is a direct measure of the conductivity of the water acting as an electrolyte. This is of importance particularly where galvanic corrosion occurs, that is where different materials are electrically connected.

Groundwater quality in terms of corrosivity, that is on the basis of the two parameters pH and EC of an area in West Africa where corrosion is not considered to be an issue, although not negligible, and an area where corrosion is a serious problem, is presented in Fig. 1.

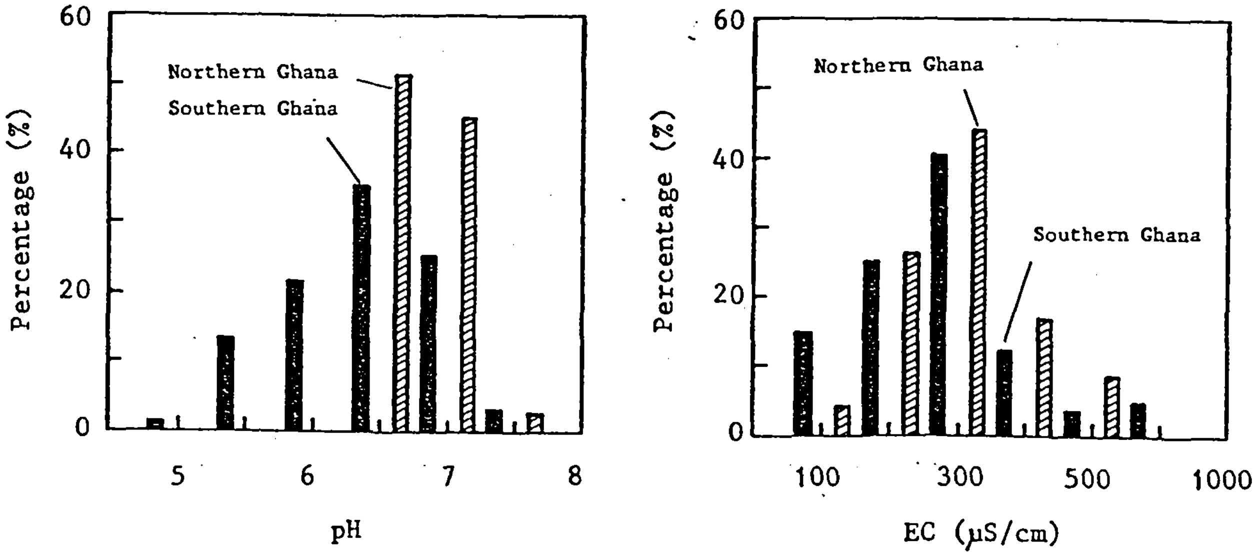

Fig. 1. Frequency distribution of the pH and the electrical conductivity EC in Northern and Southern Ghana.

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* AWWA: American Water Works Association
  DVGW: Deutscher Verein des Gas und Wasserfaches

Fig. 2 shows the relationship between the different rock types and the pH of the 3000 Well Drilling Programme area in Southern Ghana.

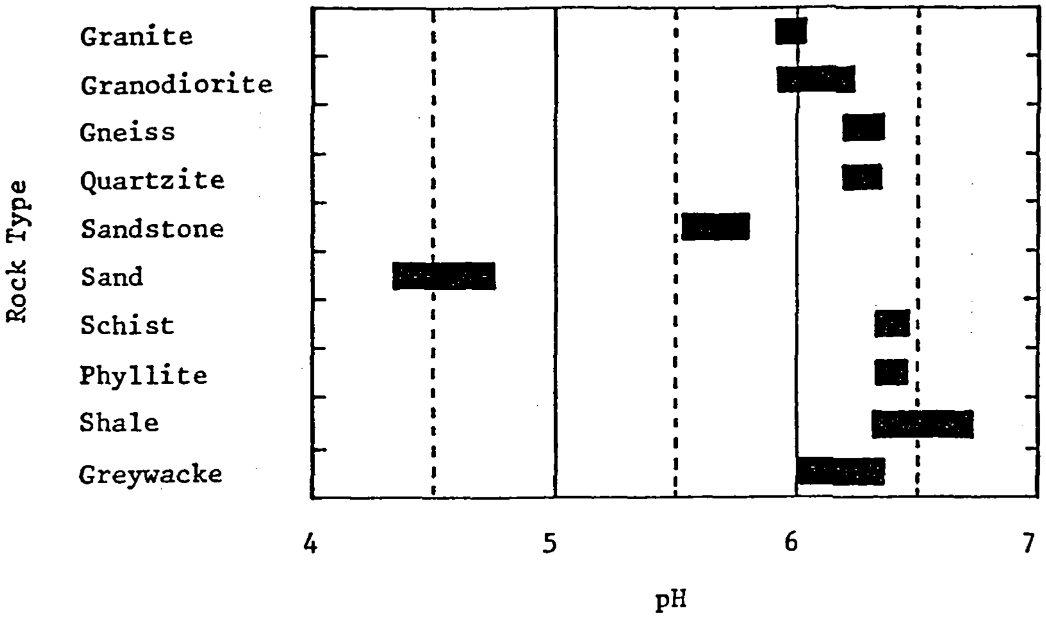

Fig. 2. Relationship between the pH and various rock types of the aquifers in Southern Ghana. The depicted ranges of the pH represent the 95% confidence intervals for the pH (means).

2.3 Effects of corrosion

(i) Mechanical failures. In the following, only corrosion of galvanized and mild steel below ground components of handpumps (rising mains, pump rods) are considered. The corrosion attack of the above ground components (pump stand, pump head) is usually negligible in West Africa apart from areas nearby the coast where high humidity combined with relatively high salt contents create rather highly corrosive environmental conditions. However, in such cases it is a well known problem not only affecting handpumps.

Fig. 3 gives an indication of the physical deterioration of corrosion attacked mild steel rod samples expressed as corrosion rate in terms of diameter reduction in mm/year. The interesting point of this graph is the rapid increase of the corrosion rate in the range between pH 6 and 6.5.

The most vulnerable parts regarding corrosion attack and mechanical failures are pump rods (breakages) and rising mains (perforation, thread damages).

In the field trial within the 3000 Well Drilling Programme in Southern and Central Ghana, it has been found that 2/3 of the handpump breakdowns were directly or indirectly attributable to corrosion (rod breakages). Fig. 4 illustrates the eating of rod material. Without going into detail, it can be shown that galvanic corrosion, which occurs where different materials (metals) are in direct contact, can reach much higher corrosion rates than shown in Fig. 3. This has been observed, e.g., at rods being connected with pistons made of brass (Fig.4).

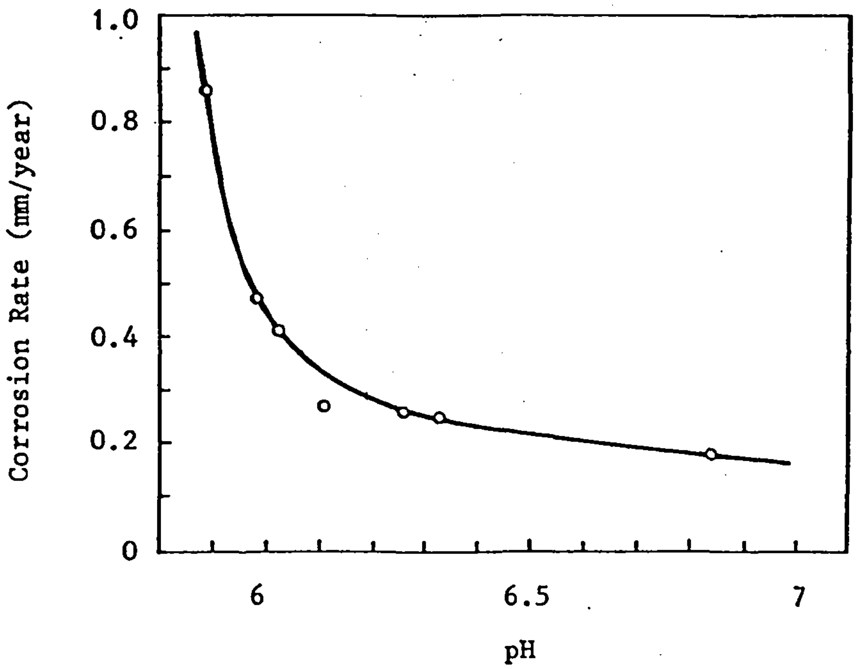

Fig. 3. Corrosion rate of mild steel rod samples expressed as reduction of the sample diameter in mm/year (Côte d'Ivoire).

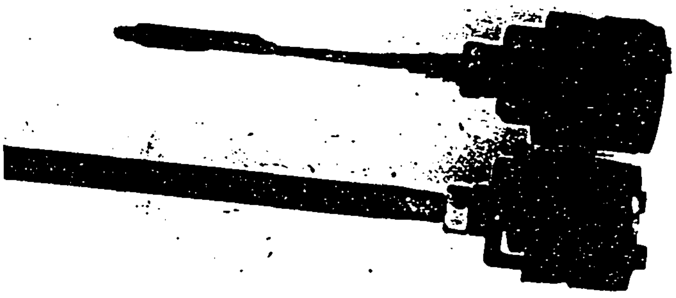

Fig. 4. New and corrosion attacked galvanized piston rods of India Mark II handpumps with piston assemblies made of brass illustrating a typical case of galvanic corrosion (Southern Ghana).

(ii) Deterioration of water quality. The major problem with regard to water quality are the corrosion products causing high iron concentrations, turbidity (red water), and bad taste. These conditions can have side effects such as staining laundry when washed with such water, discoloring food stuff, e.g. cassava, plantains, etc., when cooked with water of high iron content, and unacceptable taste.

Fig. 5 gives an illustration of the mechanism of the red water problem with handpumps which is well known by many villagers early in the morning after the pumps had not been used during the night.

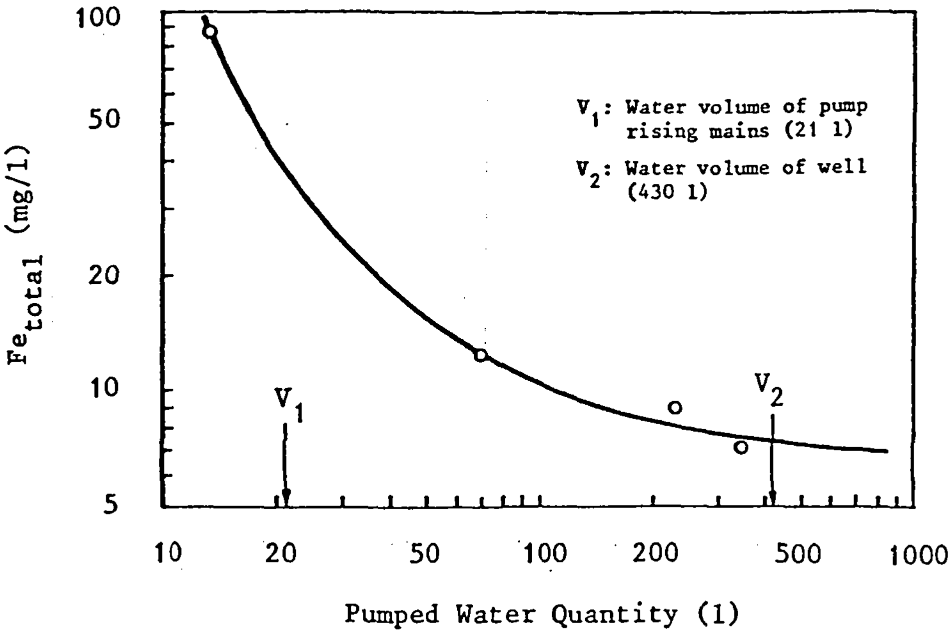

Fig. 5. Total iron content of groundwater from a drilled well equipped with a non-corrosion resistant handpump (Moyno with galvanized rising mains and pump rods) versus pumped water quantity and pump use respectively. This test was started after the pump had been locked for 13.5 hours over night. Before it was locked (evening) the iron content was 3 mg/l. The average daily pumped water quantity of this pump is 3.5 cubic meter.

The water quality problem related to corrosion is probably more serious than the increase of breakdowns due to corrosion, particularly in those areas where traditional water sources can provide water more or less all year round. Furthermore, the iron problem gets worse if corrosion affected handpumps are little used because of the accumulation of corrosion products in the wells.

Field experience suggests that handpump equipped water points having an iron concentration of more than 5 mg/l are generally little used. The iron concentration can be taken as an indicator of handpump use where corrosion is a problem.

Fig. 6 presents the iron concentration of three different areas. This figure indicates that in two cases a high percentage of the handpumps (25-30%) are obviously little used, or even abandoned, mainly due to the corrosion problem.

Of course, there are other possibilities of iron sources besides the handpump corrosion such as the aquifers. The water quality investigations performed within the Handpumps Project in the West African Region have not revealed any indications of other relevant iron sources than corrosion in connection with handpump equipped water points.

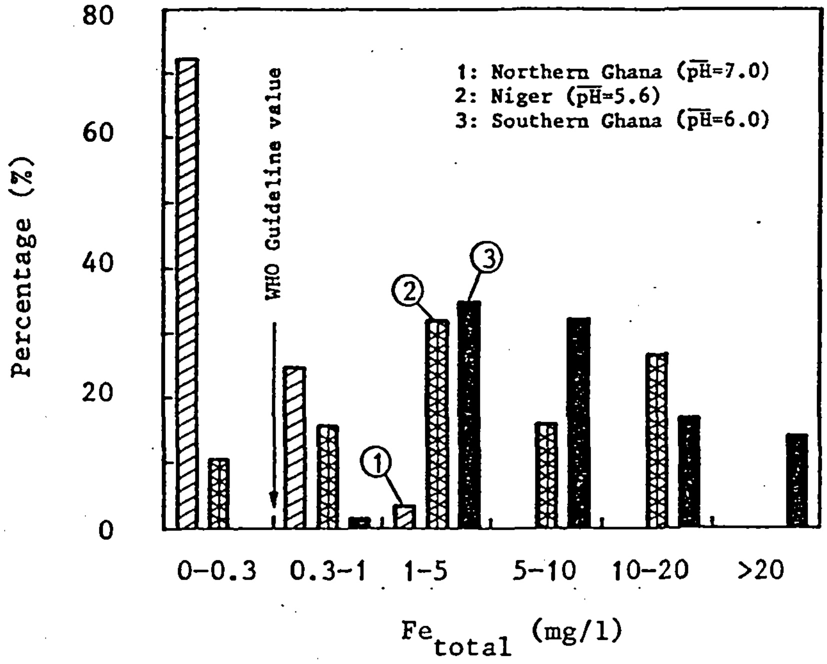

Fig. 6. Frequency distribution of the total iron content of groundwater from wells equipped with non-corrosion resistant handpumps in Niger, Northern, and Southern Ghana.

A simple method to verify whether corrosion is causing the iron problem is to perform a pumping test over several hours in order to clean the well. If corrosion is the major source of iron then the iron content will decrease already after some minutes of continuous pumping and finally approach the vicinity of the iron concentration of the aquifer (Fig. 5). The best method, however, is to replace non-corrosion resistant handpumps by corrosion resistant pumps.

The results of two pump replacements are shown in Fig. 7. This graph also indicates very clearly that other water quality parameters than iron are heavily affected by handpump corrosion. In addition, it points out to microbiological activities (iron bacteria) through the parameters ammonium (NH_4) and nitrite (NO_2).

One point related to handpump corrosion has been omitted so far, namely protection by galvanization. It has become clear that galvanization does give very limited protection against corrosive groundwater as it prevails in the West African Region. Fig. 8 shows that the protecting zinc layer (galvanization) of rising mains and pump rods are eaten away by corrosion within a few months.

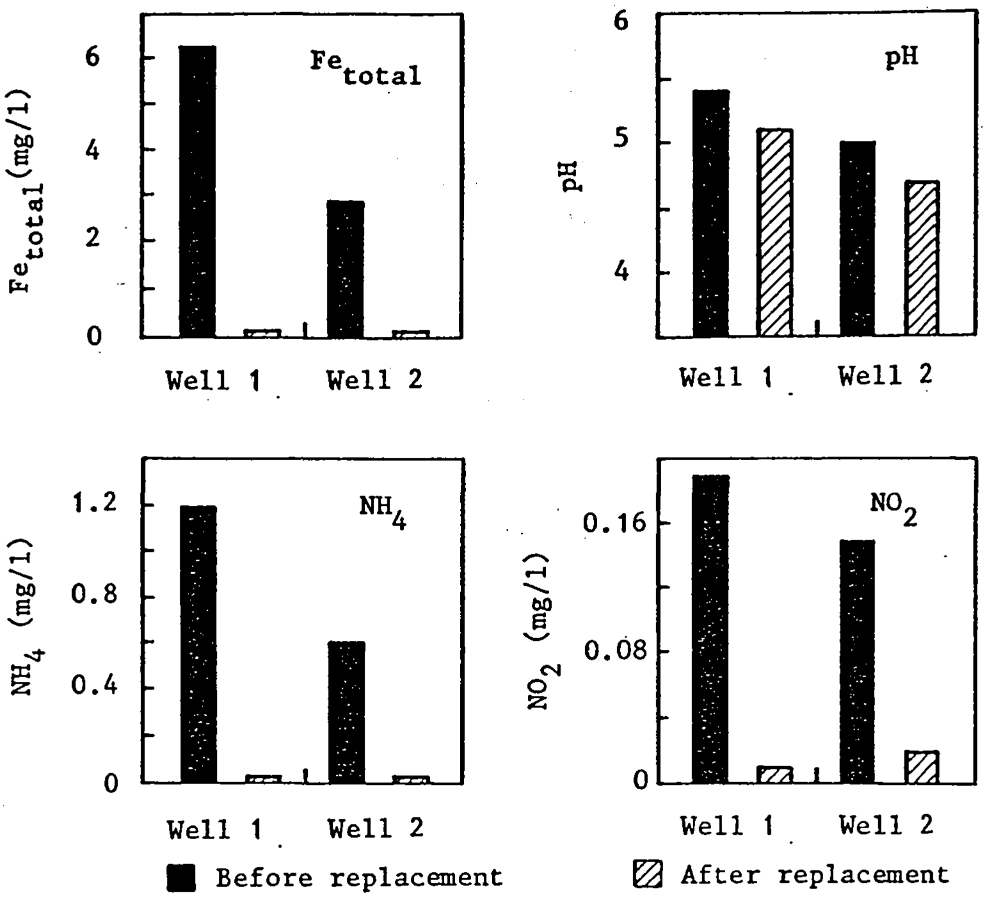

Fig. 7. The concentrations of total iron (Fe$_{total}$), ammonium (NH$_4$), nitrite (NO$_2$), and the pH of groundwater from two wells in Southern Ghana before and two days after the replacement of non-corrosion resistant handpumps (Moyno, India Mark II) with corrosion resistant handpumps (Grundfos).

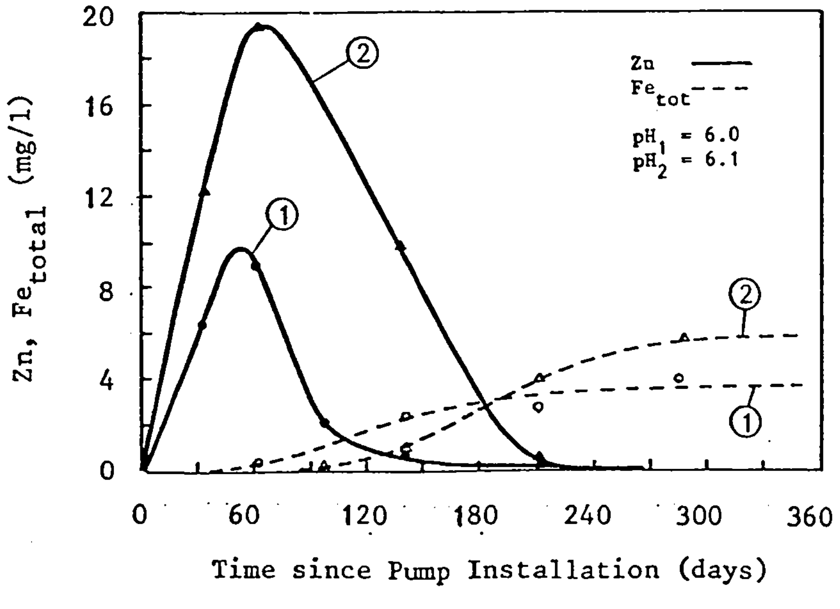

Fig. 8. Zinc (Zn) and iron (Fe$_{total}$) concentrations of groundwater from two wells in the Côte d'Ivoire versus time since installation. The wells were equipped with non-corrosion resistant pumps (Moyno with galvanized rising mains and pump rods). The diagram shows in an illustrative manner how the iron concentration increases after the zinc peaks, that is as soon as the protecting zinc coating (galvanization) is no longer intact.

3 FINANCIAL ASPECTS

The purpose of this chapter is to highlight where handpump corrosion has an effect in terms of cost and to what extent. From what has been shown in the previous chapters, corrosion can have a significant impact on rural water supply investments, namely where handpump equipped wells are not or only very little used due to water quality problems caused by corrosion. In West Africa, the average cost of a drilled well of a depth of 40 m with a handpump is in the sizeable range of 10,000 to 15,000 US$. There is certainly no doubt about it that such "misinvestments" in the form of little or unused wells, which can easily be avoided by selecting appropriate materials or pumps, are not acceptable.

On the other hand, the increase of the frequency of breakdowns of handpumps due to corrosion has a direct impact on handpump maintenance costs. Within the field trials executed in the West African Region the estimated annual maintenance costs per handpump are in the range of about 50 - 300 US$. These costs comprise spare parts, labor, and transport. It is evident, even taking into account a high percentage of pump failures caused by corrosion, that maintenance costs of handpumps are ultimately much less in terms of money than losing the original investment costs where pumps are not used.

Nevertheless, it is not a negligible question whether the yearly handpump maintenance costs per pump could be reduced by up to 100 US$ or even more as indicated in the following. In general, the maintenance costs of handpumps have to be covered by the pump users for which such additional costs can be a financial burden or at least a discouragement for using handpumps. Furthermore, in many developing countries, the parts attacked by corrosion have to be imported and, therefore, require hard currency. This is another reason why handpump corrosion should be avoided.

A classic example of a large scale corrosion-affected project is the 3000 Well Drilling Programme in Southern and Central Ghana where after 4 to 5 years of operation about 50 to 60% of the 3000 handpumps (India Mark II and Moyno equipped with galvanized rods and pipes) have been out of order mainly due to corrosion. It has been suggested to replace all the galvanized pump rods with stainless rods and to replace the original galvanized pipes with stainless (75%) and high quality galvanized pipes (25%) respectively. In 1985, the total cost of the mentioned material has been estimated to be in the range of 3 millions of US$ or about 1000 US$ per pump. The CIF price (1981) per pump including galvanized rising mains and pump rods for an installation depth of 30 m was about 700 US$ (India Mark II) and 1100 US$ (Moyno) which corresponds approximately with the new investments required for the corrosion resistant pipes and rods. There is, of course, no need to emphasize that the mentioned figures comprise only material cost. It is evident that the labor replacement cost of the pipes and rods including transport and equipment is another important factor.

The quoted figures are to be taken as indications not only because the price of stainless steel rising mains and pump rods varies depending on the quality and the market prices of steel, but also because the question of what material shall be used in the 3000 Well Drilling Programme is still open. As a general rule, however, stainless steel rising mains and rods are about 3 - 5 times more expensive than galvanized ones.

The experience of the 3000 Well Drilling Programme clearly indicates the financial and technical impacts of handpump corrosion on a large scale. The lesson which can be learned from this program is applicable to any size of project, namely that the water quality in terms of corrosivity has to be taken into account in connection with handpump selection in order to avoid costly surprises and to render a decent service to the beneficiaries of handpumps in the form of an acceptable water quality.

There are quite a number of corrosion resistant handpumps available on the market supplied with below ground components made of plastic and/or stainless steel. With regard to those pumps whose standard models are not corrosion resistant, it is important to note that their corrosion resistant versions can be much more expensive, depending upon the material used (plastic, stainless steel), than their standard models, e.g. with galvanized below ground components. As an example the India Mark II pump made in Mali (called India Mali pump) costs approximately 700 US$ for the galvanized and 1400 US$ for the stainless steel rising main/pump rod versions respectively with an installation depth of 30 m.

4 CONCLUSIONS AND RECOMMENDATIONS

Groundwater utilization by means of handpumps is the most feasible and cheapest approach to improve the service level of millions of rural and urban fringe dwellers in developing countries. On the other hand, aggressive groundwater is widely spread not only in the West African Region but all over the world, particularly in basement formations. It is therefore imperative to take the water quality, that is corrosivity, into consideration in connection with the selection of handpumps. Galvanized iron rising mains and pump rods, which are used for large numbers of different handpumps, offer no or only very little protection against corrosion and, thus, should not be used where groundwater is corrosive.

As the West African experience has shown, in many cases the major problem of handpump corrosion is not necessarily an increased frequency of breakdowns due to mechanical failures induced by corrosion, e.g. rod breakages and perforated rising mains, but the deterioration of the water quality in terms of high iron concentrations originating from corrosion products. The iron problem (red water) makes the pump users reluctant to accept such water which can lead to abandoning of handpump equipped wells.

Therefore, whenever handpumps have to be selected, it is highly recommended to take water quality parameters into consideration with regard to corrosiveness. Where insufficient data are available, basic data, e.g., pH and electrical conductivity, should be collected. Where even such basic water quality data cannot, or insufficiently, be made available, the relationship between rock type and pH, as presented in Fig. 2, can be taken as a reference for deciding whether corrosion resistant handpumps should be considered or not.With regard to the application of galvanized iron rising mains and pump rods, the following guidelines based on the pH as corrosion index might be useful as a rule of thumb for the majority of groundwater conditions (Table 1).

TABLE 1

Guidelines for the application of galvanized rising mains and pump rods with handpumps under corrosive conditions with the pH as corrosion index.

pH	Aggressivity of water	Application of galvanized material
pH > 7	Negligible	Suitable
6.5 < pH ≤ 7	Little to medium	Limited
6 < pH ≤ 6.5	Medium to heavy	Not recommended
pH ≤ 6	Heavy	Not recommended