INVESTIGATING THE DIMINISHING BOREHOLE YIELDS IN MALAWI: CASE STUDY OF NANKUMBA IN MANGOCHI DISTRICT

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(BSc. in Mechanical Engineering)

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Master of Science in Water Resources and Supply Management Thesis

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UNIVERSITY OF MALAWI
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DECLARATION

I, **Kondwani Andreah,** hereby declare that this thesis is an output of my own original work. In as far as I am aware, contributions from secondary sources have been acknowledged accordingly. An affirmation is also made on this day by me that this thesis has not been presented for any other academic award at any other institution in the world, but it is being presented for the first time for the award of Master of Science Degree in Water Resources and Supply Management at the University of Malawi.

Signature:…………………………………… Date:……………………………..

CERTIFICATE OF APPROVAL

The undersigned certify that they have read and approve for acceptance by the University of Malawi, The Polytechnic, this thesis entitled ‘Investigating the Diminishing Borehole Yields in Malawi: Case Study of Nankumba in Mangochi District’.

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DEDICATION

This work is dedicated to my wife, Catherine, who through thick and thin offered much encouragement and inspiration throughout. It is also dedicated to my son Zaithwa, whose smile always gives me strength to fight on and win for his sake.

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My sincere thanks should go to my supervisors, Mr Petros Zuzani and Dr Geoffrey Chavula for their invaluable professional assistance and guidance throughout the course of this research work. Without them this work would not have been what it is today.

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Above all, I am grateful to the Almighty God for His strength, wisdom and good health throughout the work.

ABSTRACT

As Malawi joins the whole world to achieve universal access to safe water for all by the year 2030, some boreholes in Traditional Authority Nankumba in Mangochi District in Malawi were said to have diminishing yields as reported in the Final Evaluation Report of the ICEIDA WaSNan Project. The study therefore aimed at investigating these diminishing boreholes yields to understand the extent to which they exist. Pumping tests were conducted and parameters such as static water level, dynamic water level and borehole yield were analysed.

The study revealed that six (6) boreholes (9%) out of seventy (70) studied boreholes had problems to do with yield. One (1) borehole had completely dried up despite having a very good yield of 1.0 litre per second in its initial status while five (5) boreholes had yielded poorly with yields ranging between 0.08 to 0.19 litres per second. The study also revealed that the groundwater level had gone deeper as evidenced by deeper static water levels for almost all the boreholes. It also revealed that all the boreholes that had yield problems also had static water level as well as dynamic water level problems.

The study also analysed construction field data of the studied boreholes in order to understand if any of the construction factors might have had influence on the diminishing borehole yields. It was revealed that four (4) out six (6) boreholes with yield problems had the lowest initial yield of 0.2 litres per second.

The study therefore concludes that the diminishing yields exist but in lesser cases (9%) than what was earlier reported as being at 44%. It also concludes that there were problems of groundwater recharge such that groundwater levels were greatly affected. On the other the study showed that there were more mechanical problems affecting the functionality of boreholes than the yield problems.

Key words: Boreholes, Construction Factors, Diminishing Yield, Discharge, Mechanical Problems, Water Levels.

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ABBREVIATIONS AND ACRONYMS

AM	-	Area Mechanic
AW	-	Available Water
BH	-	Borehole
DWL	-	Dynamic Water Level
FAO	-	Food and Agriculture Organisation
GoM	-	Government of Malawi
HTN	-	Hand pump Technology Network
ICEIDA	-	Icelandic International Development Agency
MDG	-	Millennium Development Goal
MGDS	-	Malawi Growth and Development Strategy
MoAIWD	-	Ministry of Agriculture, Irrigation and Water Development
MP	-	Member of Parliament
MWS	-	Main Water Strike
PD	-	Pump Depth
RWSN	-	Rural Water Supply Network
SKAT	-	Swiss Centre for Development Cooperation in Technology and Management
SWL	-	Static Water Level
UNICEF	-	United Nations Children's Fund
uPVC	-	Unplasticised Polyvinyl Chloride
WaSNan	-	Water and Sanitation Nankumba
WATSAN	-	Water and Sanitation
WHO	-	World Health Organisation
WPC	-	Water Point Committee

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1 INTRODUCTION

1.1 Background

By the time the world was recording a success in meeting the Millennium Development Goals (MDGs), Goal 7, target number 10 for drinking water, which was to halve the proportion of the population without sustainable access to safe drinking water, many countries in sub-Saharan Africa were still lagging behind in progress towards meeting the target. So far, of the 748 million people that still lack ready access to improved water, 43% (325 million) is in sub-Saharan Africa (WHO/UNICEF, 2014). This shows that there are serious problems in some countries in sub-Saharan Africa in terms of access to safe drinking water that need to be addressed as a matter of urgency. Long lasting but cheap solutions need to be found if this population is to be reached so that by the year 2030 we should have achieved a universal and equitable access to safe and affordable drinking water for all, which is Goal 6, target number 1 of the Sustainable Development Goals (United Nations, 2016). As one way to achieve this target, use of groundwater seems to be an economically viable solution (Lutz et al., 2014). Better ways of sustaining the abstraction and use of this groundwater therefore need to be explored further.

Groundwater is the major freshwater store acting in the hydrological cycle (Kløve et al., 2014) and its sources are considered relatively cheaper and easy to install even in remote areas (Lutz et al., 2014; Olabode & Bamgboye, 2013). As such, many countries globally have capitalised on the use of groundwater through drilling of boreholes that are hand pump operated and construction of other groundwater point sources such as protected hand dug wells. As of 2010, there were 1.3 billion borehole users globally, 80% of which were in rural areas (WHO/UNICEF, 2012). Sub-Saharan Africa also has relied much on the use of point water sources such as boreholes and protected shallow wells in the bid to supply safe drinking water unlike in Northern Africa whose safe water is mostly supplied from piped systems (WHO/UNICEF, 2014). This dependency on boreholes is an indication that boreholes are really serving an important function in the provision of safe drinking water and subsequently serving critical social-economic functions in rural communities by reducing health hazards and improving economic and social opportunities (Auckhinleck, 2013).

Similarly, Malawi's safe drinking water provision relies much on groundwater point sources especially in rural areas. The groundwater point sources contribute almost 96% of the total access to safe drinking water supply in rural areas and the major source being boreholes. This groundwater development in Malawi started in the early 1930s (FAO, 2006; GoM, 2012; Kambuku, 2012) and over the years, both government and developmental partners have played a role in the construction of these facilities.

Icelandic International Development Agency (ICEIDA) is one of such development partners and has been implementing various developmental projects in Malawi in the areas of water supply, health, fisheries, community development as well as education. One of the projects that were successfully implemented was the Water and Sanitation Project in T.A Nankumba, in Mangochi District, in the eastern region of Malawi, between 2007 and 2011. This project was commonly known as WaSNan Project. One of the objectives of the project was to increase the number of functioning water points in the project area. As a way of addressing this objective, the project focused on drilling 83 new boreholes, rehabilitating 87 defunct boreholes and also constructing 280 protected shallow wells.

1.2 Problem Statement

In 2013, ICEIDA engaged a consultant to carry out a final evaluation of the project in order to appraise the project's achievements and impacts. One of the findings of the evaluation indicates that 44% of the new boreholes constructed under this project were suffering diminishing yields (Matipwiri, 2013). This percentage is considerably too high considering that it was barely two years after the completion of the project when this study was carried out and that these boreholes were only 4 to 5 years old. As the systems age, the figure is expected to increase and this is very worrisome. This negative development would certainly affect functionality of the water points and eventually defeat the objective of ICEIDA of increasing the number of functioning water points in the project area. This is therefore a big threat to the huge investment made by ICEIDA and also counterproductive bearing in mind that Malawi, having met both Millennium Development Goals (MDG) and Malawi Growth and Development Strategy (MGDS II) targets on the percentage of households with access to safe drinking water (GoM, 2012; WHO/UNICEF, 2014), is also a candidate of the Sustainable Development Goals, Goal 6, Target number 1 which is to achieve a universal and equitable access to safe and affordable drinking water for all by year 2030 (United Nations, 2016).

However, this finding would concur with the assertion of Harvey (2004) that a borehole itself may cease to provide adequate quantities of safe drinking water only a short time after construction.

Further to this, Matipwiri (2013) points out that the diminishing yields were not only attributed to construction problems but also unprotected water catchment areas. This implies that there were either some construction problems and/or that the actual groundwater levels had significantly gone down due to insufficient recharge of the aquifers. However, the methodology of this study in question was questionable because it did not indicate any scientific way of determining the yield of a borehole as it mainly measured the number of strokes to fill a 20 litre pail, which is more linked to discharge test of the hand pumps other than borehole yield test. It is to be noted that confusing pump discharge problems for borehole yield problems is very easy since both are related with decreased flow of water. It is therefore necessary to use the right method of testing. In addition, the report also indicated that there were some construction problems that were contributing to the diminishing of yields but no details on the construction factors were given and also the methodology used in drawing this conclusion was also not clear. As such, it is difficult for the stakeholders to make proper decisions on what to do next with these boreholes in relation to the findings. It was therefore imperative to conduct a study that uses standard analytical methods to understand better the yield situation of the boreholes and the construction factors, which might have contributed to the situation.

As the Ministry of Agriculture, Irrigation and Water Development (MoAIWD) calls for further exploration of the issues affecting functionality of rural water points (GoM, 2012), this study was to further investigate the existence and degree of diminishing borehole yields and also to understand which factors might have been influenced this.

1.3 Justification

In 2014, the Malawi Government sought to borrow money from development partners to finance the drilling of 450 boreholes and construction of 166 toilets in order to improve rural water supply and sanitation services. Opposition legislators in the National Assembly vehemently rejected this proposal considering that there was a 30% non-functionality rate of already existing boreholes, even after 50 years of Malawi's independence. From another perspective, this may seem to make sense. With this high non-functionality rate, boreholes would be considered unsustainable with the potential of scaring away possible donors for future similar projects. Similarly, the issue of diminishing yield could eventually lead into complete non-functionality of these boreholes and therefore needs to be investigated further. Misstear, Banks, and Clark (2006) say that "a water well does deteriorate over the years and it does need periodic maintenance. In order for maintenance to be effective, the causes of the deterioration in well performance must be established through monitoring and diagnosis". Similarly, in the absence of knowledge about the diminishing yields of the boreholes, stakeholders can fail to make the necessary effective decisions on the matter. The research work was therefore conducted so that the findings would aid stakeholders into the drafting of proper response and mitigation measures to the scenario if indeed it existed. In addition, the findings would form a platform for planning for future groundwater developments for the study area, and also district and national developments in the case of findings that are not area specific.

1.4 Objectives

1.4.1 Main Objective

The main objective of the study was to investigate the diminishing borehole yields in Malawi, with Traditional Authority Nankumba in Mangochi District as a case study.

1.4.2 Specific Objectives

Specific objectives of the study were:

- To compare current with initial borehole statuses in terms of yield, static water level and dynamic water level in the research area;
- To assess the physical conditions of the borehole hand pump system; and
- To analyse routine borehole construction field data in relation to construction processes.

1.5 Constraints and Limitations

As the study was going on, there were some constraints and limitations that were encountered. Some of these are detailed below.

- There was no accessibility to certain research sites due to poor roads. These particular sites had roads that were made accessible during the construction works of these boreholes, after which they were just abandoned by the communities, leaving just footpaths. This made it impossible for studies to be carried out on those sites since equipment, such as that for pumping test, could not be ferried there without the use of a vehicle; and the researcher could not do anything else to solve this situation other than just leaving out these sites due to time[1] and financial[2] factors.

- Some communities refused to grant access to their boreholes because they suspected the study to be some fraudulent act. Two of these communities refused right at the time of sensitisations, and to these the team did not go to conduct the study. However, there was one community that had initially granted permission to the team, during sensitisations, to conduct the study, but when the team went to conduct the study as agreed, they were chased away while being shouted at as thieves. The team tried to seek audience with the village head but it was discovered that the he was not present and the gang leaders took advantage of the chief's absence at that time. All in all, this led to the study being limited to only those sites whose access had been granted and not all the sites as initially planned.

- Mechanical failure of the submersible pump during the pumping tests on some days affected the work progress. It also affected the yield results of some three boreholes that were thought to have very good yield but the pump could regulate itself to a discharge of between 0.61 l/s to 0.87 l/s when the minimum required yield to be set for the pumping was 1 l/s which was the initial yield of the boreholes. This did not provide a true reflection of the yielding of the boreholes; however, this did not affect the yield results as the figures were still way above the benchmark of 0.2 litres per second.

[1] There was limited time
[2] There were limited financial resources

2 LITERATURE REVIEW

2.1 Boreholes and their Sustainability

Just like many countries in the sub-Saharan Africa, Malawi depends more on boreholes fitted with hand pumps as a source of safe drinking water, especially for rural areas (GoM, 2012; WHO/UNICEF, 2014). That is why boreholes continue to be drilled in Malawi. These boreholes are supposed to be constructed in a such a way that each borehole serves a maximum of 250 people within a radius of 500 metres (GoM, 2010). This means that given the population using a single borehole remains at 250 or less, boreholes can be spaced at one (1) kilometre apart so that the furthest users are able to walk a distance not exceeding the maximum recommended distance of 500 metres to draw water as illustrated in Figure 1 below.

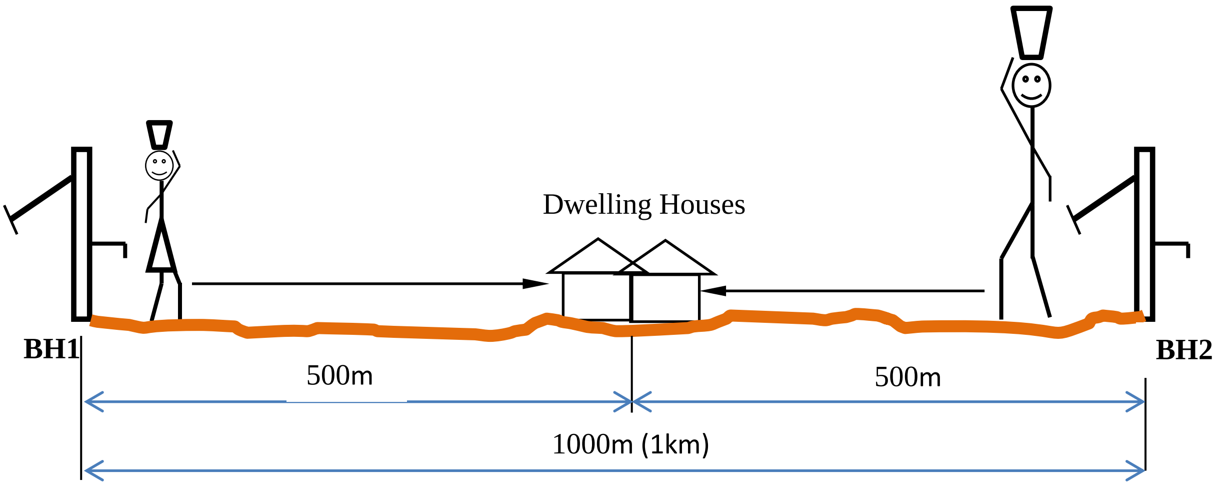

Figure 1: Illustration of Maximum Walking Distance to Safe Water Source (Borehole in Particular)

Although the reliance on hand pump fitted boreholes is very high in rural Malawi and the rest of sub-Saharan Africa, Harvey (2004) says that their sustainability is often low. There are many factors that determine sustainability of these boreholes, and it was suggested by Harvey and Reed (2004) that the borehole's yield is the primary factor. Macdonald, Thompson, and Herbert (1995) further add on the factors by mentioning headwork construction, pump maintenance and water quality. Each one of these factors would fall into one of the five components of sustainability which are financial sustainability, social sustainability, environmental sustainability, technical sustainability and institutional sustainability (Auckhinleck, 2013; Zuzani, Ackim, & Kalulu, 2013).

Considering yield as a primary factor for sustainability of a borehole, it can be seen that it has a direct link with environmental sustainability. Auckhinleck (2013) describes environmental sustainability of boreholes as the one that is more concerned with aquifer recharge and sustenance of groundwater sources. However, the other factors also determine the sustainability of a borehole, and thus the borehole would still fail despite having attained environmental sustainability. That is why Auckhinleck (2013) also describes the other components. For instance, on technical sustainability he mentions factors that are more to do with technical elements in operation and maintenance of the boreholes such as training of water and sanitation (WATSAN) committees and hand pump mechanics (that is water point committees (WPCs) and area mechanics (AMs) in a Malawian setup) in order to impart technical knowhow to them, and availability and affordability of spare parts. Technical sustainability cannot work without financial sustainability which deals with issues of willingness to pay for maintenance and also mobilisation of financial resources. Finally for all this to work, it requires an institution (institutional sustainability); in this regard it would be the formation of water point committee that shall be equipped with leadership skills (social sustainability).

2.2 Borehole Yield

According to Harvey (2004), a borehole yield could be defined as the maximum rate at which a borehole can be pumped without lowering the water level in the borehole below the pump intake. Borehole yield can be represented into two parts namely short-term yield and long-term sustainable yield (Misstear et al., 2006). This review only focused on the latter.

2.2.1 Sustainable Borehole Yield

As discussed in the earlier paragraphs, yield of a borehole is key to its sustainability. The sustainability of the boreholes with regards to yield depends on whether the yield is sustainable or not. Macdonald et al. (1995) define a sustainable yield of a borehole as the one that meets the required volume of water by the population that relies on the borehole and that this volume is available throughout the dry season and over periods when the rainfall is below average. They further highlight that in the worst case scenario, the source (in this case the borehole) may dry up completely if yield is not sustainable. This then means that care must always be taken during new borehole constructions, especially during pumping tests, so that only boreholes drilled with sustainable yields are developed and commissioned.

2.2.2 Causes of Diminishing Borehole Yield

As new boreholes continue to be drilled countrywide as well as worldwide, reports indicate that many boreholes dry up either seasonally or completely. Some also just decrease in their yield. This is counterproductive as investments on these boreholes just go down the drain when these boreholes dry up or cannot be fully utilised due to low yield; and this problem is affecting many countries in the world. As Akudago et al. (2009) mention that the drying of boreholes is a global problem especially in African countries, Van Tonder, Kunstmann, Xu, and Fourie (2000) zoomed in and looked specifically at Southern Africa where Malawi is also located and also made a similar observation that an increasing number of boreholes had dried in the past years.

These problems of reduced yield or drying up of boreholes require a closer look. There may be so many causes of diminishing borehole yield, but the following are some that have already been suggested by other authors.

2.2.2.1 Initial Borehole Yield

After conducting a study on boreholes, aimed at investigating rapid onset borehole failure in Ghana, Harvey (2004) deduced that the initial measured yield of a borehole is the biggest contributor when it comes to subsequent failure of a borehole after it was declared successful at the time of drilling. He found out that boreholes that have low yields at the time of drilling are the ones that usually fail. In his findings, he observed that a higher percentage of the boreholes that failed had initial yields of less than 13l/min. Akudago et al. (2009) also made similar observations that drying boreholes were generally of low yields at the time of drilling. In terms of the actual yield, they observed that the higher percentage of the boreholes they found to have dried up were those whose drill yields were less than 20l/min. Project managers should therefore take heed of the consequences of accepting low yielding boreholes as their sustainability would always be questionable, and the likelihood of these boreholes drying up, either completely or partially, is very high.

2.2.2.2 Season of Drilling

The second cause of diminishing borehole yield that will be discussed is season of drilling. In practice, drilling of boreholes has always been done any time of the year. This is immediately followed by pumping tests in order to establish the yield of the borehole. However, different studies have indicated that most boreholes that dry up are the ones that are drilled during the wet season. In their study in Ghana, Akudago et al. (2009) found that 78% of the dried boreholes were drilled in the wet season, and the findings of Harvey (2004) indicate that drilling in the wet season is approximately six times more likely to lead to borehole failure than dry season drilling.

This is the case because the estimated yields from the pumping tests conducted during the wet season do not normally reflect the true aquifer condition since it might have become saturated (Akudago et al., 2009). That is why drilling projects need to be planned well if they are to be sustainable. There is need to consider the peak of the dry season as the most appropriate period for drilling and yield estimation since water levels are at their deepest (Akudago et al., 2009; Harvey, 2004).

2.2.2.3 Well Penetration

In a number of cases, boreholes have failed to deliver sufficient yield throughout the year despite being declared successful at the time of drilling. This usually happens at the peak of the dry season due to a drop in the water table. This situation is mostly noticeable in boreholes whose drilling did not take into account the seasonal water level fluctuations. Drilling is sometimes stopped at shallower depth due to inability or reluctance by contractors to go deeper and fully penetrate the aquifer (Anscombe, 2011).

How much the borehole penetrates into the aquifer determines its sustainability. Wurzel (2001) suggests that drilling should continue for an additional 10m depth after the required yield is attained in order to allow for these seasonal water level fluctuations and drawdown levels.

2.2.2.4 Relative Influences of Recharge vs. Discharge

Another cause looks at the relative influence of recharge against discharge of the aquifers. Much as the aquifer gets discharged through the pumping and other natural means, it needs constant recharging to counteract the effect of the discharge. Auckhinleck (2013) puts across the fact that boreholes will eventually dry up if the daily rate of discharge, that is rate of water extraction, exceeds the daily rate of recharge. This then means that for boreholes to maintain their yield, the rate of aquifer recharge should always exceed the rate of discharge.

2.2.2.5 Construction Process

Akudago et al. (2009) express how borehole construction errors could also affect the yielding and subsequent drying of boreholes. A good example that they provide is that defective screen and/or plain casings could lead to siltation and thereby blocking the transmission. On the similar note, Olabode and Bamgboye (2013) also attribute high failure rate of boreholes to poor construction.

2.2.2.6 Well Interference

The last cause to be discussed is well[3] interference. The abstractions from the neighbouring wells have got a tendency of influencing the water level in a well in question. This tendency is what is being referred to as *well interference* and is dependent on the spacing of the wells, aquifer parameters and the quantities being abstracted (Macdonald et al., 1995). According to Titus, Beekman, Adams, and Strachan (2009), this interference could lead to a decline in yield. Optimum spacing between boreholes that are sited along the same structure is therefore required in order to minimise the effects of well interference.

[3] Well in this case can also mean a borehole

3 METHODOLOGY

3.1 Study Design

This research was cross-sectional in nature and used a quantitative approach in which scientific methods were used to generate knowledge.

3.2 Study Area

The study was conducted in Traditional Authority Nankumba in Mangochi District in Malawi. Nankumba is situated on the north western part of Mangochi District and is located between latitudes $13^0$57’58”S and $14^0$31’24”S and between longitudes $34^0$43’19”E and $35^0$06’39”E. Nankumba topographically varies, with some areas, mostly those closest to the Lake Malawi being low and other areas especially those furthest from the lake being on high lands. The minimum elevation for Traditional Authority Nankumba is estimated at around 470m while the maximum elevation is estimated to be at 1976m above sea level (Maphill, n.d.). Figure 2 below shows the study area with a full view of the boreholes that were under study.

3.3 Time of Study

The study was conducted from November to December, 2014, for a period of six weeks. The study was conducted in these months because it is almost at the peak of the dry season in Malawi which was suitable for conducting pumping tests.

3.4 Study Site

The study sites were the 83 boreholes drilled by ICEIDA under the Water and Sanitation Project that was dubbed WaSNan in T.A. Nankumba in Mangochi District.

3.5 Sampling

Since the total number of boreholes was small, sampling was not done. Instead, all the 83 boreholes were put up for the study as it is argued that if the number of boreholes is less than

100, it is better to use all the boreholes as suggested by Brock, (n.d.) and Jacobs, (n.d.) for population studies. The idea was to truly have representative results of the real situation on the ground.

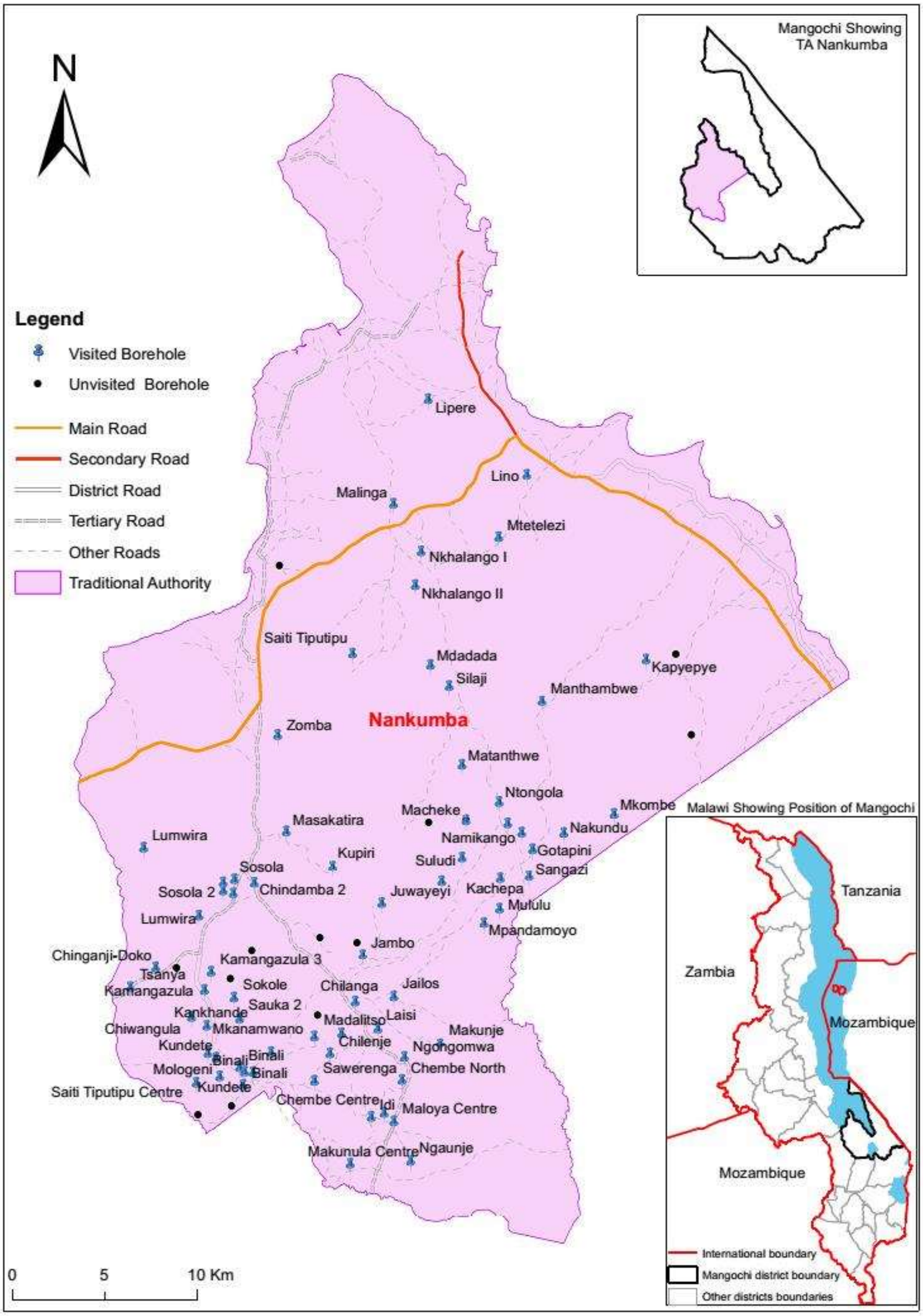

Figure 2: Map of T.A. Nankumba Showing the Studied Boreholes

3.6 Identification and Orientation of Research Assistants

Three research assistants were identified from the Mangochi District Water Development Office because of their technical expertise in the fields of pumping test and hand pump assessment and maintenance. They went through a one day briefing on the background and aim of the study, what was expected of them during the study, as well as the methodology to be used.

3.7 Ethical Consideration

Prior to the start of the study, permission was sought from the local leaders including the water point committees in order to carry out the study at their respective water points. This was done through the resident Water Monitoring Assistant who visited all the respective villages. However, where permission was never granted, the research team did not go.

3.8 Data Collection Methods

3.8.1 Current vs. Initial Borehole Statuses

3.8.1.1 Desk Review

The initial construction data for the boreholes that were studied was collected through a desk review of the borehole construction reports. From the reports, initial borehole parameters such as yield, static water level, dynamic water level and dates of drilling and pumping test were extracted. These reports were mainly sourced from two organisations namely the Ministry of Agriculture, Irrigation and Water Development through the Mangochi District Water Development Office, and also Rural Water Supply (Pty) Ltd who were the Consulting Firm for the Water and Sanitation (WaSNan) Project in T.A. Nankumba in Mangochi District.

3.8.1.2 Pumping tests

Pumping tests for all the 70 boreholes were conducted in order to establish current status of these boreholes in terms of yield, static water level and dynamic water level. These current parameters were compared with the initial parameters as extracted from the construction reports in order to assess the changes that had occurred over the years and establish whether or not the borehole yields had diminished. The starting pumping rates during the pumping tests were based on the initial borehole yields, and where the yields could not hold, adjustments were made accordingly. For instance, upon noticing a rapid drawdown, it was a sign that the yield was not holding and therefore the flow regulating valve was adjusted downwards to allow less discharge. Figure 3 below shows technicians at work during the pumping tests.

Figure 3: Technicians Taking a Reading for Water Level during Pumping Test

3.8.2 Physical Conditions of the Borehole Hand Pump System

In order to know how many boreholes might have other problems other than actual yield problems, the physical conditions of the borehole hand pump system were assessed. Firstly, leakage and discharge tests for the hand pump were conducted. Physical examination of the pump parts was then conducted especially for those boreholes whose hand pumps failed either of or both tests.

3.8.2.1 Leakage and Discharge Tests

Firstly, a leakage test was conducted in order to check if the flow of water from the spout of the hand pump was not delayed due to leakage in the system as a result of worn bobbin or O-ring of the footvalve, disconnected rising main joints or perforated or cracked riser pipes. The following standard procedure was followed in accordance with the Maintenance Card for Afridev Hand pump (SKAT-RWSN, 2009):

a) Operate pump handle until water is flowing from the spout;
b) Stop operating the pump handle for approximately 30minutes;
c) Then operate the handle and count exactly how many strokes are required until the water is starting to flow again. If more than 5 handle strokes are required to make the water flow again, there must be a leakage in the rising main or the footvalve. (Also refer to Appendices D&E).

The leakage test was then followed by a discharge test which assisted in determining if the pump was discharging the required amount of water within a specified number of pumping strokes. The following standard procedure was followed in accordance with the Maintenance Card for Afridev Hand pump (SKAT-RWSN, 2009):

a) Operate pump handle until a constant water flow is achieved (pump ratio approximately 40 full handle strokes per minute);
b) Place a bucket in the continuous water flow for exactly one minute;
c) Take the bucket off the water flow and check the amount of water. If the discharge is less than15 litres, there might be a problem with the bobbins or the cup seal. (Also refer to Appendices D&E)

As discussed earlier, it is very easy to confuse pump discharge problems for borehole yield problems since both are related with less water flowing. So the aim was to make sure that if there were problems with the amount of water flowing out from the pump, i.e. less water flowing, then the exact reason for such reduced discharge should be identified as it can mainly be mechanical problems other than yield problems.

3.8.2.2 Physical Assessment of Hand Pump Parts

This was a follow up action to the results of leakage and discharge tests. For the boreholes whose hand pumps failed the leakage test or the discharge test or both, a thorough examination of the pumping system was conducted. The parts were examined for such factors as cracks, wear, clogging, depth setting and plunger timing in accordance with the Troubleshooting Chart for Afridev hand pumps (Erpf, 2007). The results were used to determine what was causing the reduced capacity of the hand pump.

3.8.3 Analysis of Routine Borehole Construction Field Data

Final construction reports for the boreholes were also reviewed in order to extract initial borehole construction field data for analysis. This analysis was done only for the boreholes that indicated some yielding problems after the pumping tests. This was meant to understand whether some construction factors had an influence on the problematic yielding of these boreholes. This analysis was based on the following variables as adopted from Harvey (2004):

- Initial recorded yield
- Season during which drilling took place
- Well penetration

3.9 Data Management and Analysis

The acquired data was entered and analysed in Microsoft Excel in a tabulated format. Charts and graphs were used for emphasis and clarity on certain variables such as changes in yield, static water level and dynamic water level.

4 RESULTS AND DISCUSSION

4.1 Success Rate: Planned vs. Actual

Out of the 83 boreholes that were planned for this study, 70 boreholes were actually studied while 13 were left out, representing a success rate[4] of about 84%. Out of the 13 boreholes that were not studied, eight (8) boreholes had no accessibility due to very poor roads; two (2) boreholes at health centres had been installed with solar pumps and therefore could not be dismantled to avoid disturbing the systems; and finally three (3) boreholes were left out because the communities owning those boreholes denied the research team access because they did not fully understand the reasons behind the study and they suspected that there could be some foul play which could in the end lead to theft of their hand pump parts.

4.2 Comparison of Current and Initial Statuses of the Boreholes

4.2.1 Static Water Level (SWL)[5]

One of the parameters that were considered during the pumping tests was static water level. It was revealed that out of the 70 boreholes tested, one borehole (1.4%) had gained[6] in static water level by 2.53m, while 69 (98.6%) had dropped in static water level and Figure 4 below provides details of how these boreholes were localised. The dropping ranged between 0.04m as the minimum drop[7] and 13.04m as the maximum drop. This could indicate some serious deficiencies in groundwater recharge in the study area as argued by Ayotte et al. (2010) who state that the amount of groundwater recharge affects static water levels. These changes in static water levels are as a result of changes in groundwater storage (ΔS) and can be illustrated by the groundwater balance formula below as provided by Kumar (2005) as well as Taheri Tizro, Voudouris, and Eini (2007).

$$Q_{in} = Q_{out} \pm \Delta S$$

where,

Q_{in} = Total groundwater inflow

Q_{out} = Total groundwater outflow

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[4] In this case success rate is being defined as a ratio of actual to planned and expressed as a percentage

[5] SWL and DWL measured from ground level

[6] Gain means a rise in water level in reference to initial measurement

[7] Drop means water level has gone deeper in reference to the initial measurement

ΔS = Change in groundwater storage

This could be the case because these boreholes, in T.A. Nankumba in Mangochi District, are not used for irrigation purposes or any other purposes requiring heavy groundwater abstraction, but for normal domestic usages only, and therefore the only factor that could probably bring change in groundwater storage is recharge rather than discharge. As the recharge decreases (with discharge almost constant), the change in groundwater storage will also decrease, thereby increasing the static water level (static water level getting deeper), and vice versa. However, only a separate study on ground water recharge in the area could ascertain this claim.

The lowering groundwater levels reduce well penetration and thereby affecting the resulting yield. This is the case because deep wells such as boreholes often pass through more than one aquifer level in the earth. The total flow rate of the water well is therefore the summation of the individual flow rates from the different aquifer levels. As the water table drops, some of the rock fissures or soil passages that previously fed water into the well may have gone dry thus not able to supply water into the well, thereby reducing the total well inflow-rate. ('Definition & Measurement of Well Yield - Well Flow Rate & Water Quantity Explained', n.d.)

It is worthy to also note that as the static water levels get deeper, the column of available water, which is the difference between pump depth (PD) and the static water level (SWL), diminishes thereby reducing the amount of water that could be drawn in a given time as illustrated in Figure 5 below.

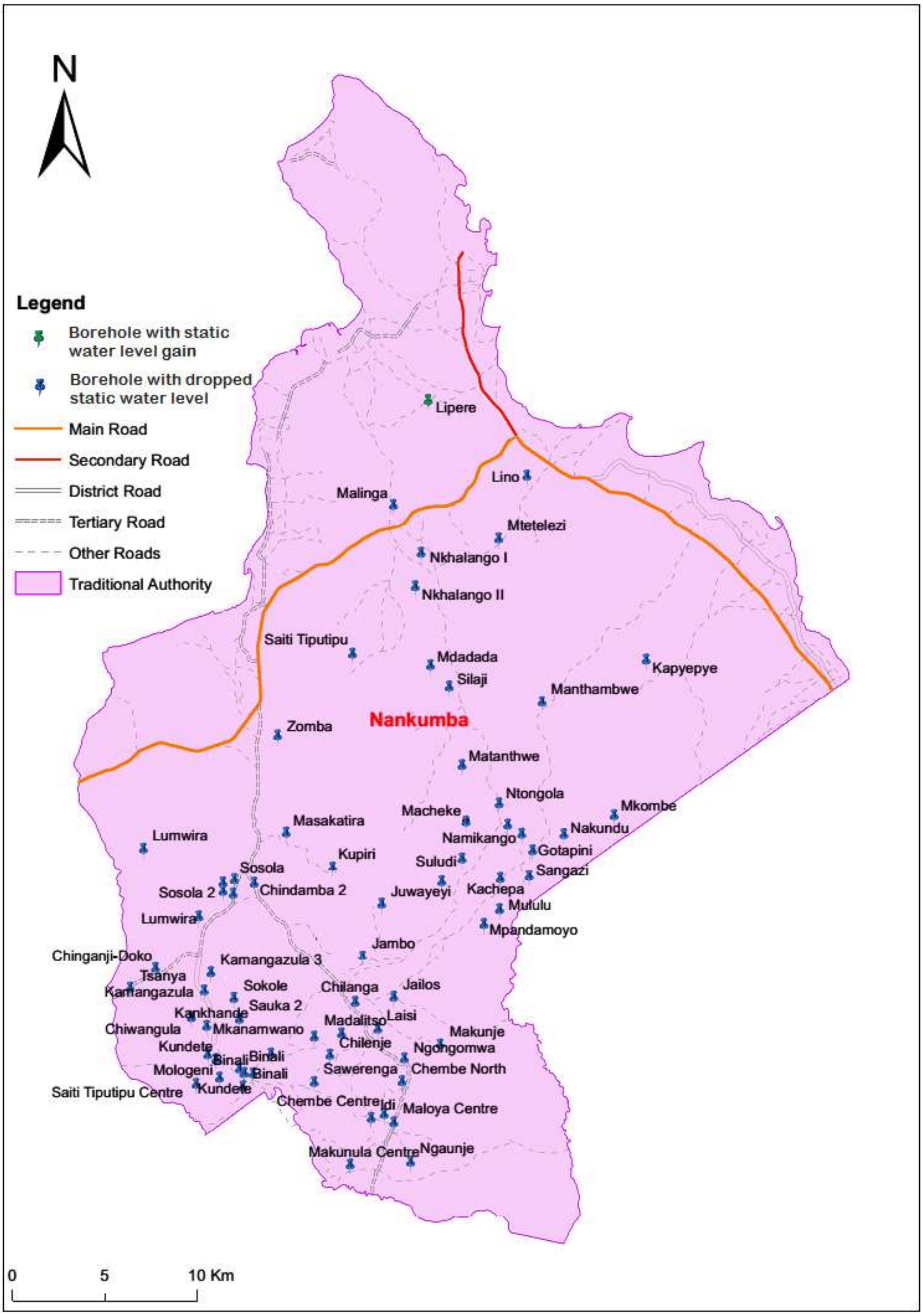


Figure 4: Map of T.A. Nankumba Showing the Localities of the Boreholes with Gain or Drop in Static Water Levels

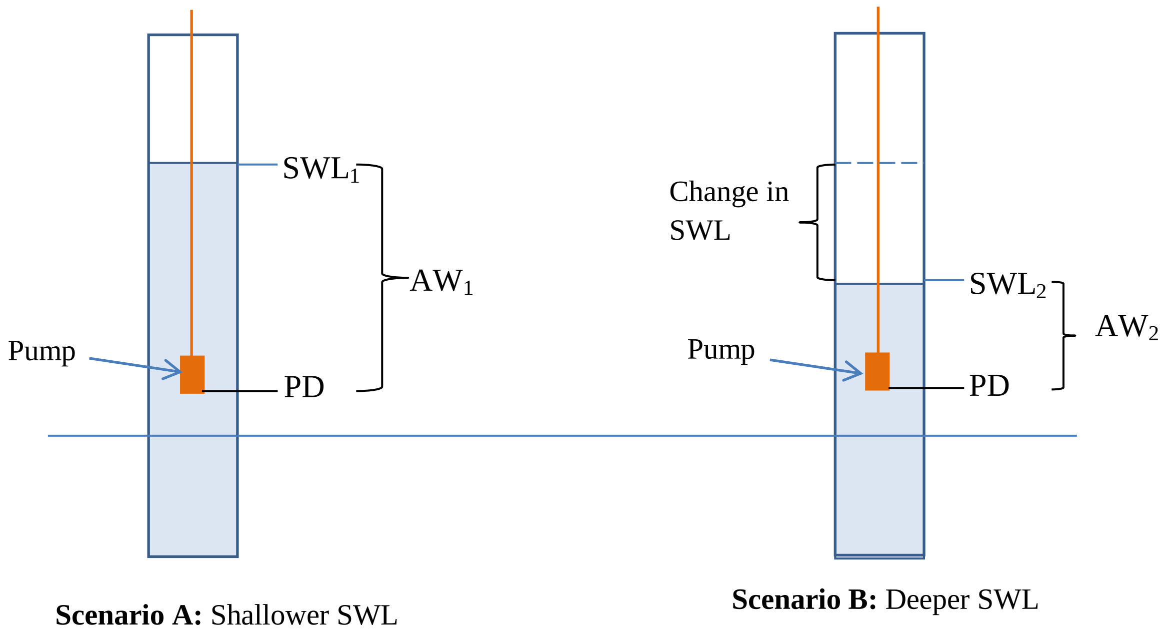


Figure 5: Illustration of Changes in Static Water Levels

4.2.2 Dynamic Water Level (DWL)

In terms of dynamic water level, it was revealed that in general, 49 (70%) of the boreholes had dropped in dynamic water levels. However, six of these 49 boreholes were exposed to a slightly higher pumping rate than the initial pumping rate during the pumping tests and therefore it would be difficult to conclusively declare them to have dropped in dynamic water level in comparison to the initial dynamic water level. As such, the boreholes that should conclusively be said to have dropped in dynamic water level would be those that were tested at a pumping rate equal to or lower than the initial. In this regard, it was conclusively revealed that 43 (62%) boreholes had dropped in dynamic water level as provided in Figure 6 below, and the drop ranged from 0.27m as the minimum drop to 49.96m as the maximum drop.

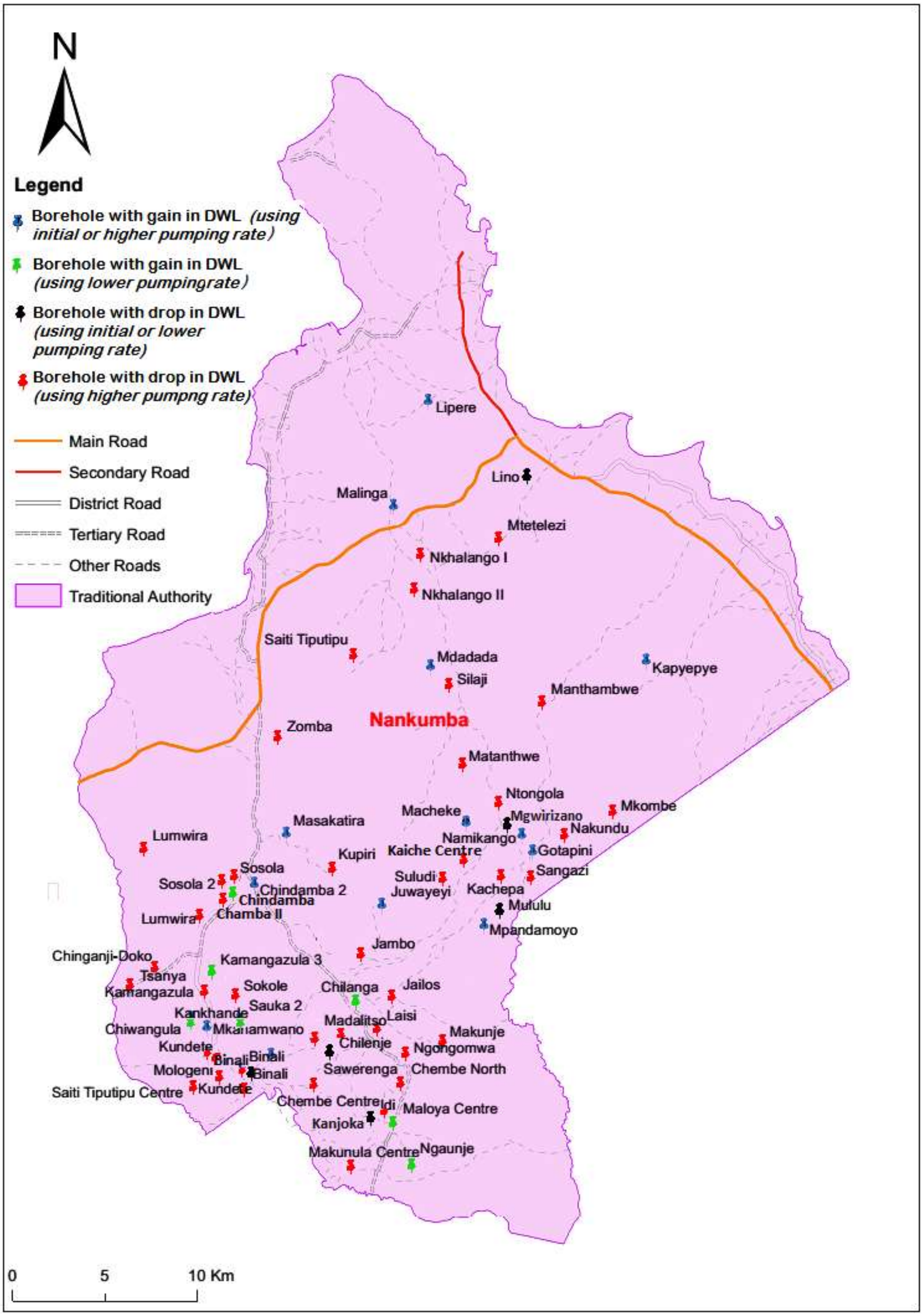
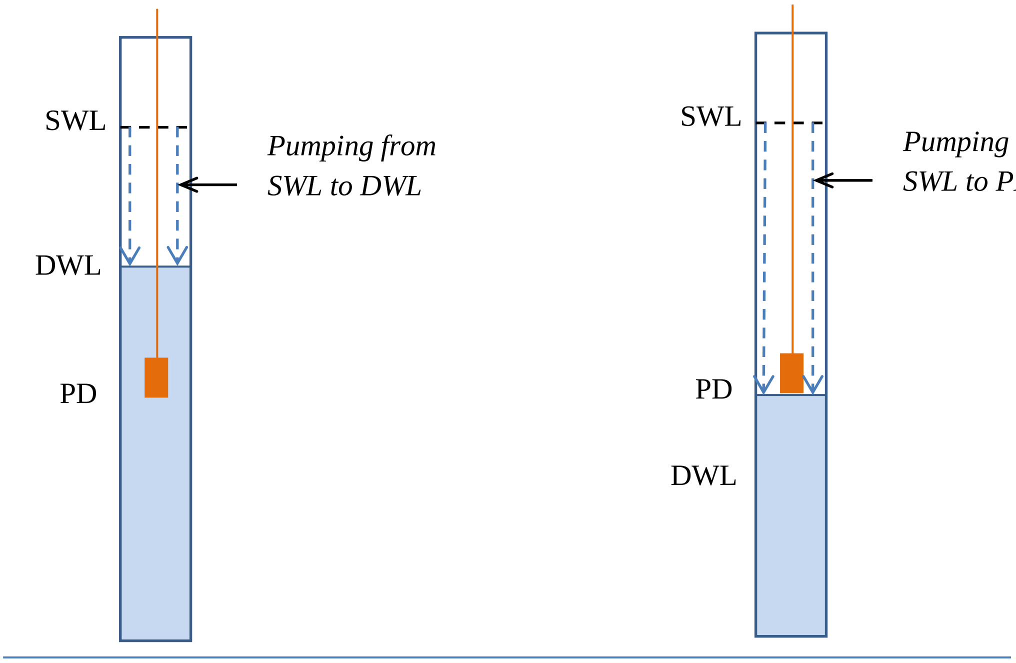


Figure 6: Map of T.A. Nankumba Showing Boreholes with Changes in Dynamic Water Levels

This dropping in dynamic water level could cause the borehole to easily run out of water while pumping if the drop is way below the pump depth. The water would run out because the pump is now above the dynamic water level such that as the water is being pumped, it would reach the pump depth (PD) before it stabilises at the DWL. As a result users would have to wait for water recovery to start pumping again. Figure 7 below illustrates a borehole that has been pumped to a dynamic water level under different scenarios as discussed above.



Scenario A: DWL above PD

Scenario B: DWL below PD

Figure 7: Illustration of Changes in Dynamic Water Level

Looking at the scenario in question above and given other parameters constant, every three metre drop in dynamic water level would mean an additional pump rod being installed in order to compensate for the original pump installation design so as to maintain a consistent flow of water from the boreholes. However, there is also a limit to how deep the pump can go in order to effectively and efficiently pump the water. For the Afridev Hand pump, which is the most commonly adopted and used hand pump in Malawi, including in the WaSNan Project, the maximum depth of installation as per its design is 45 metres (Baumann & Keen, 2007; 'Resources - RWSN', n.d.). Any deeper installation, i.e., beyond 45 metres makes the pumping to physically be difficult and the mechanical stresses and wears on the hand pump parts become greater, resulting in frequent breakdowns due to mechanical failures (Lutz et al., 2014). And this could be the scenario for 11 boreholes, shown in Figure 8 below, whose dynamic water levels dictate that they should be installed to a depth beyond the 45 metre depth, the worst case being a dynamic water level of 62.09 metres followed by 56.76 metres.

On the other hand, it was also revealed that in general, 21 (30%) of the tested boreholes had gained in dynamic water level but just like in the case of the drop discussed above, it would also be difficult to conclusively declare all these as having gained in dynamic water level as 7 out of these 21 boreholes were exposed to a lower pumping rate during the pumping tests. Only those boreholes which were exposed to pumping rate equal to or higher than the initial rate would therefore be conclusively declared as having gained in dynamic water level. In this regard, it was conclusively revealed that 14 (20%) of the boreholes had gained in dynamic water level. Figure 6 above shows the localities of these boreholes with gain in dynamic water level.

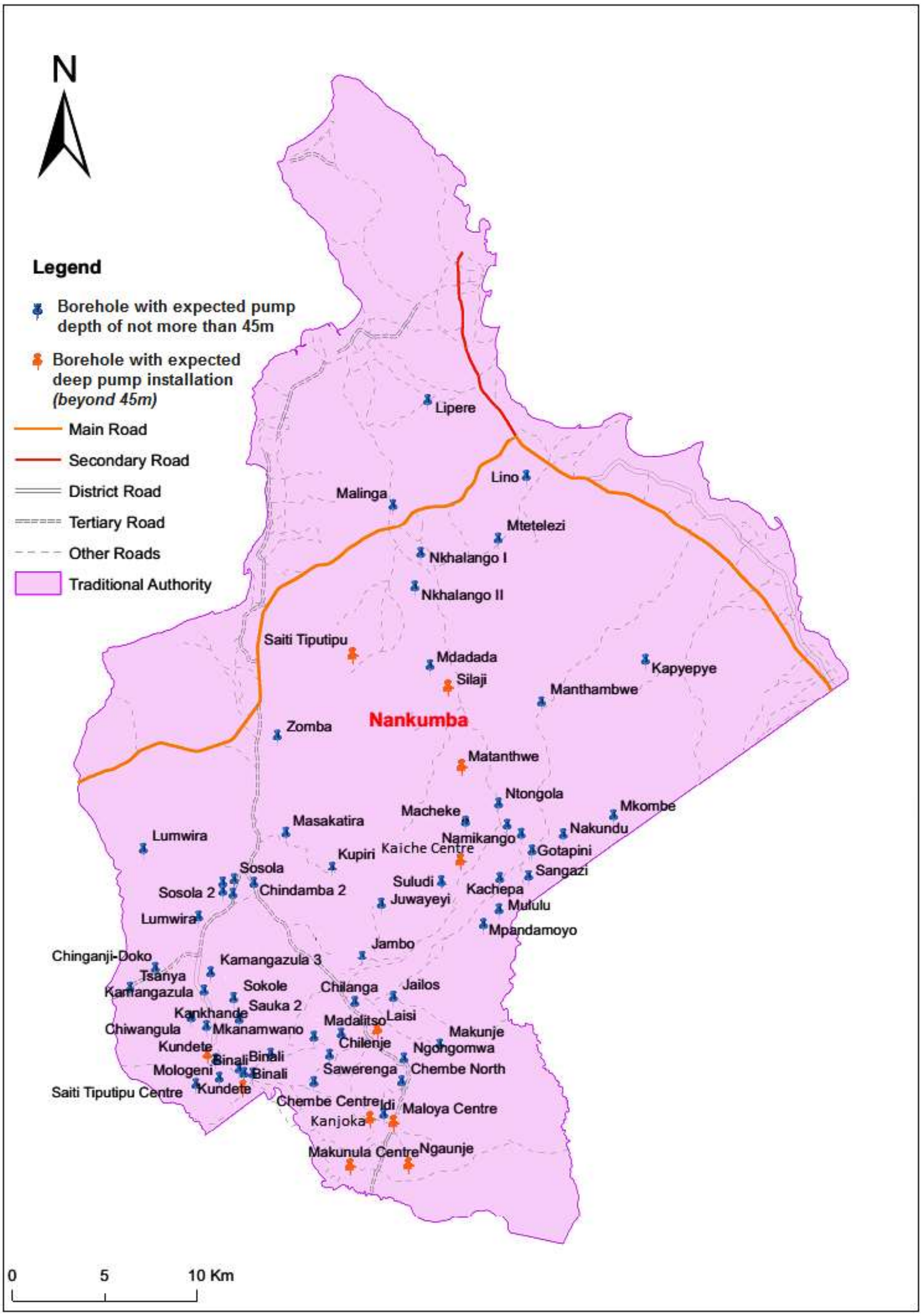


Figure 8: Map of T.A. Nankumba Showing Boreholes with Expected Deep Pump Installations

4.2.3 Borehole Yielding

In terms of yield, it was revealed that six (6) boreholes (9%) namely Matanthwe, Chembe North, Laisi, Silaji, Manthambwe and Kaiche Centre, had problems to do with yield. Among the six boreholes, one (1) borehole namely Chembe North had completely dried up despite having a very good yield of 1.0 litre per second in its initial status. The other five (5) boreholes had yielded poorly, below 0.2l/s which was the WaSNan Project's recommended minimum yield. The yields ranged from 0.08l/s to 0.19l/s. As can be observed from Table 1 below, these six boreholes were also falling in the categories of boreholes that dropped in static water level and dynamic water level, meaning that where there was a failure in yield, there were also problems with both static water levels as well as dynamic water levels. The remaining 64 (91%) boreholes had yields that were deemed acceptable on basis of the project's recommended minimum yield of 0.2l/s and the yields ranged from 0.2l/s to 1.25l/s. Figure 9 below gives a summary of the yielding status of all the 70 boreholes while compares the initial and current yield statuses of the six problematic boreholes.

Table 1: Comparison of Initial and Current Statuses for the Six Failed Boreholes

No	Site Name (Village)	Initial SWL (m)	Current SWL (m)	ΔSWL (m)	Initial DWL (m)	Current DWL (m)	ΔDWL (m)	Initial Yield (l/s)	Current Yield (l/s)	ΔY (l/s)
1	Matanthwe	7.55	14.33	6.78	12.13	62.09	49.96	0.20	0.14	- 0.06
2	Chembe North	39.78	52.82	13.04	42.60	N/A	N/A	1.00	0.00	- 1.00
3	Laisi	16.30	25.13	8.83	43.80	56.76	12.96	0.20	0.12	- 0.08
4	Silaji	10.92	12.80	1.88	39.74	41.07	1.33	0.20	0.12	- 0.08
5	Manthambwe	10.72	13.45	2.73	39.40	42.37	2.97	0.50	0.19	- 0.31
6	Kaiche Centre	3.08	3.12	0.04	47.36	56.78	9.42	0.20	0.08	- 0.12

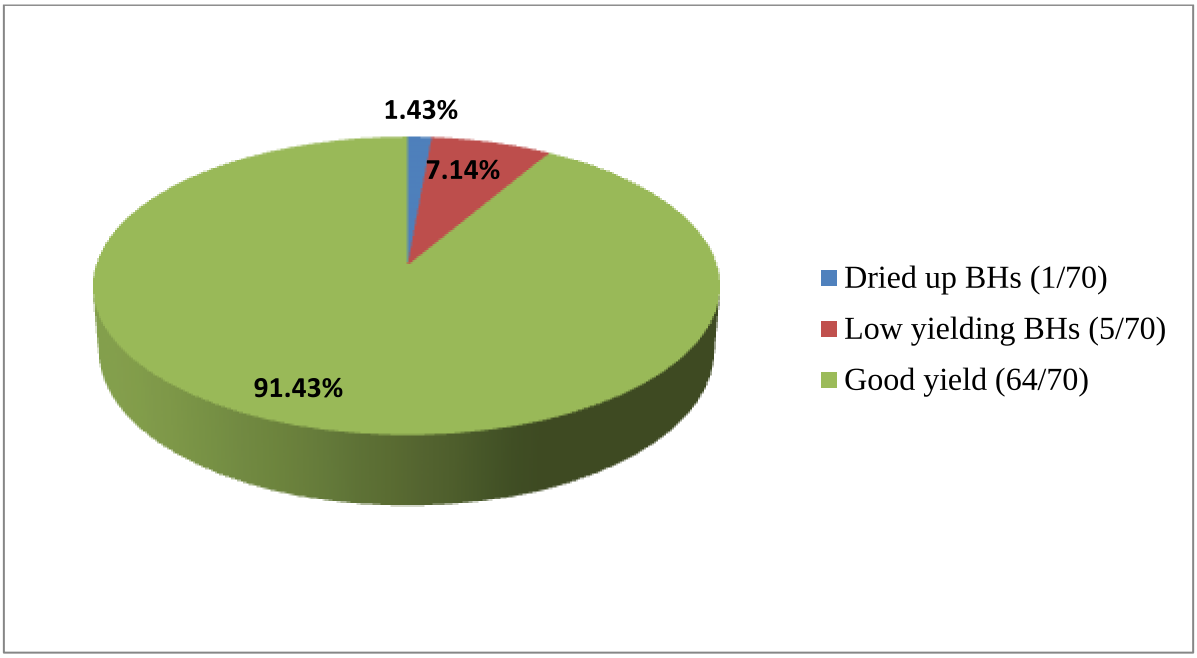


Figure 9: Current Yielding Status of Boreholes

Although the WaSNan Project set 0.2l/s as the recommended minimum yield, the Government of Malawi recognises 0.25l/s as the minimum recommended yield for boreholes in Malawi. Therefore taking into account this government's recommended minimum yield, the number of boreholes with unacceptable yields from the current status would then be 16, as shown in Figure 10 below. The yields of these 16 low yielding boreholes then range from 0.08l/s to 0.23l/s. On the other hand, if the project had adopted the 0.25l/s as the minimum yield during construction, 17 boreholes from the initial status would have been deemed unsuccessful.

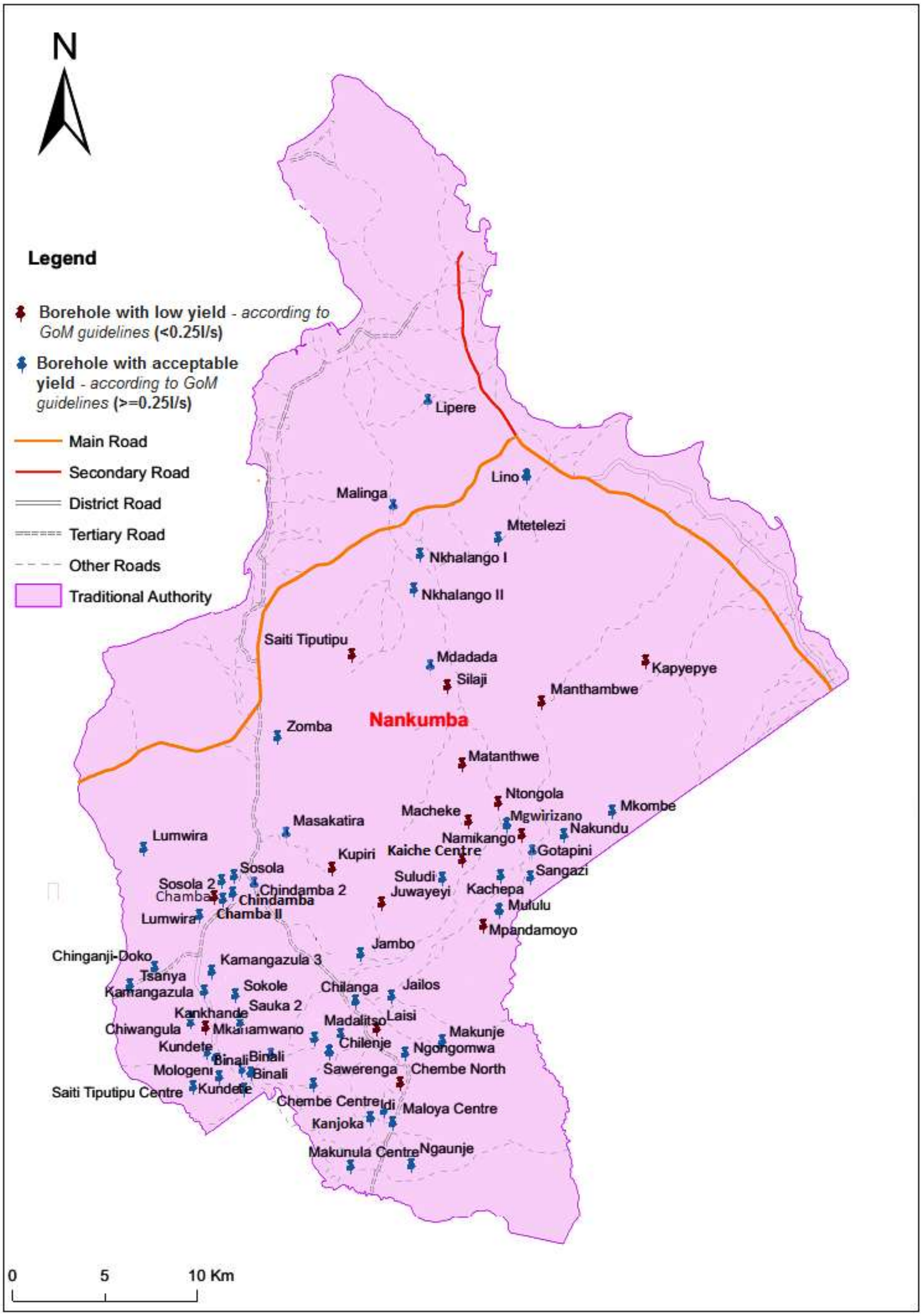


Figure 10: Map of T.A. Nankumba Showing Boreholes with Acceptable and Unacceptable Yields (Using GoM Guidelines)

4.3 Construction Factors

Construction field data was analysed to determine whether construction factors might have played a role on the boreholes that had yielding problems.

4.3.1 Initial Yield

From the analysis of construction data, it was revealed that the boreholes only had three categories of initial yields which are 0.2l/s, 0.5l/s and 1.0l/s. Out of the 70 boreholes, 17 boreholes had yields of 0.2l/s; 13 boreholes had yields of 0.5l/s; and 40 boreholes had yields of 1.0l/s.

As provided in Figure 11 below, out of the 6 boreholes that failed in terms of yield, 4 boreholes (Matanthe, Laisi, Silaji and Kaiche Centre) had the lowest initial recorded yield of 0.2l/s, representing 66.7% of the failed boreholes. One (1) borehole of the failed boreholes (Manthambwe) had 0.5l/s and the last 1 borehole (Chembe North) had 1.0l/s. In terms of categorical proportionality, 23.5% (4/17) of the boreholes that had initial yield of 0.2l/s failed, while for those with 0.5l/s it was only 7.7% (1/13) that failed and only 2.5 % (1/40) of the boreholes which had initial yield of 1.0l/s failed. It was also revealed that the borehole that completely dried up was the one with the highest recorded initial yield of 1.0l/s as at the time of construction.

As it can be observed from the findings, the boreholes with the lowest initial yield at construction are the ones that failed most proportional to their yield category. Further to this, the proportionality failure rate decreases with an increase in yield as seen from the trend as provided in Figure 12 below. This finding agrees with what Harvey (2004) deduced that boreholes that have low yields at the time of drilling are the ones that usually fail. In the findings of his study in Ghana, he observed that a higher percentage of the boreholes that failed had initial yields of less than 13litres per minute, equivalent to 0.22 litres per second which is slightly above the threshold yield of 0.2 litres per second.

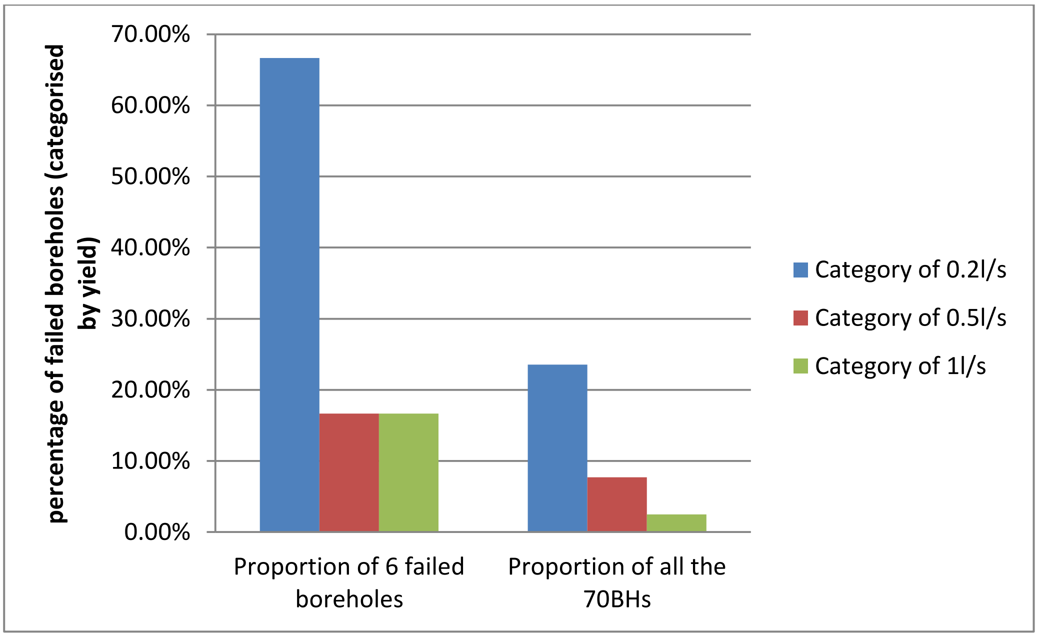


Figure 11: Relationship of the Six (6) Failed Boreholes to Initial Yield

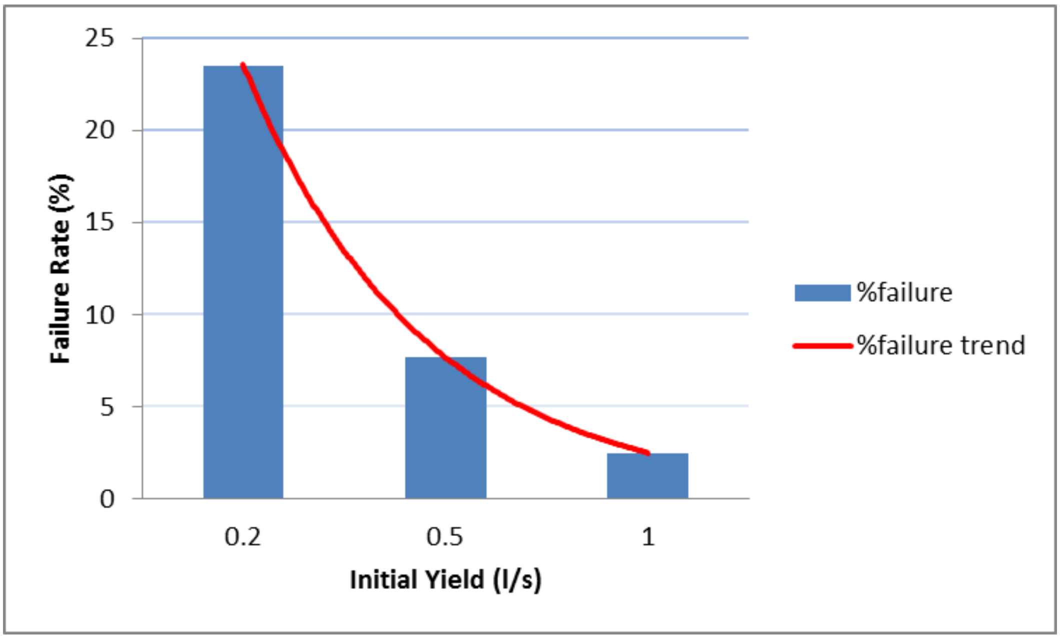
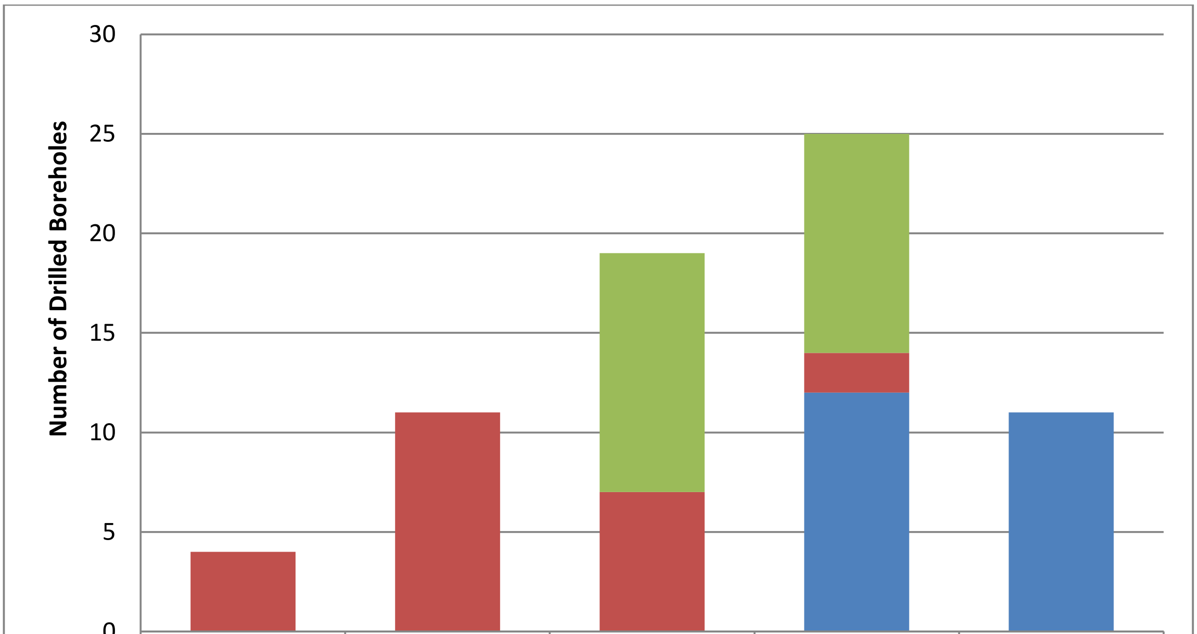


Figure 12: A Trend of Failure Rates Proportional to Initial Yield Category

4.3.2 Season of Drilling

In terms of the season in which drilling for these boreholes under study took place, it was revealed that all the boreholes were drilled and pump tested in the dry season. For boreholes constructed in 2007, drilling and pumping tests took place between the months October and November, whereas for those constructed in 2008, drilling and pumping tests took place between the months of July and September. Finally, drilling and pumping tests took place between the months of August and September for the boreholes constructed in 2009. In general, the drilling and pumping tests of these boreholes were done between the months of July and November and these months fall within the dry season in Malawi, which is the best time for drilling boreholes. Figure 13 below is a summary of how the boreholes were distributed in terms of drilling period as discussed above.



	July	August	September	October	November
2009			12	11	
2008	4	11	7	2	
2007				12	11

Figure 13: Monthly Distribution of the Drilled Boreholes

4.3.3 Well Penetration

Borehole failure in terms of yield can sometimes be due to inadequate well penetration into the aquifer. As suggested by Wurzel (2001), drilling should continue for an additional ten (10) metres after the required yield is attained in order to allow for seasonal water level fluctuations and drawdown levels. In line with this, the study reveals that out of the six boreholes that failed, only three (3) boreholes (Kaiche Centre, Matanthwe and Manthambwe) had reached a minimum of 10 metres beyond the main water supply strike while two (2) namely Chembe North and Silaji had the drilling stopped at 8 metres beyond the main water strike and one (1) borehole (Laisi) had the drilling at 6 metres beyond main water strike. In general, 50% of the failed boreholes had good penetrations while the other 50% did not. Table 2 below provides more details.

Table 2: Well Penetration

No	Borehole Name	Borehole Number	Depth (m)	Yield (l/s) Initial/ current	Main Water Strike (MWS) (m)	Aquifer Penetration (Depth – MWS) (m)
1	Kaiche Centre	WaSNan 96	78	0.2/0.08	24	54
2	Manthambwe	WaSNan 157	56	0.5/0.19	27	29
3	Laisi	WaSNan 72	78	0.2/0.12	72	6
4	Chembe North	WaSNan 84	60	1.0/0.0	52	8
5	Matanthwe	WaSNan 102	69	0.2/0.14	18	51
6	Silaji	WaSNan 224	70	0.2/0.12	62	8

4.4 Physical Conditions of the Borehole Hand pump System

4.4.1 Functionality Status

It was revealed that 64 (91%) boreholes were functional and only 6 (9%) boreholes were non-functional, and it should be noted that these are not necessarily the six (6) boreholes with yield problems. Figure 14 below provides details in terms of functionality status of the boreholes and their locality.

After assessment, it was revealed that five (5) (83%) of the non-functional boreholes were due to mechanical problems, and these are Maloya Centre, Laisi, Kundete, Kaiche Centre and Saiti Tiputipu, while only one (1), Chembe North, was due to yield related problem in which the borehole was found to have dried up. This shows that the non-functionality of the boreholes was mostly caused by mechanical problems rather than yield problems.

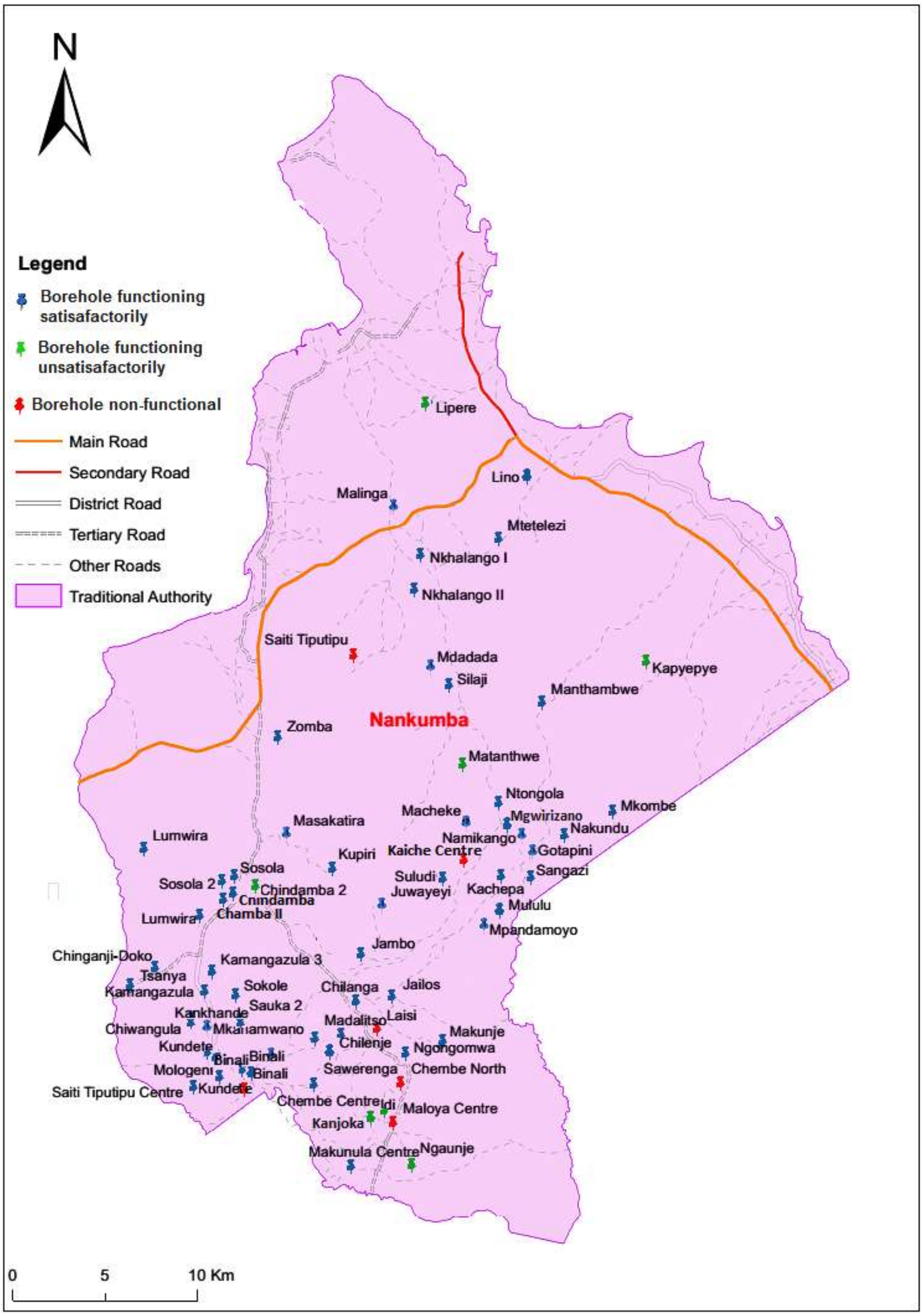


Figure 14: Map of T.A. Nankumba Showing Functionality Status and Locality of the Boreholes

4.4.2 Leakage and Discharge Tests

Having conducted the leakage and discharge tests on the 64 functioning boreholes in accordance with Maintenance Card for Afridev Hand pump (SKAT-RWSN, 2009), it was revealed that four (4) boreholes (Kapyepye, Ngalinje, Kanjoka, and Lipere) had failed both the leakage and discharge tests while three (3) boreholes(Idi, Chindamba2, Matanthwe) had failed discharge test only. The other 57 boreholes passed both tests. In other words, out of the 64 boreholes that were found functional, 57 boreholes, as shown in Figure 14 above, were functioning satisfactorily while seven (7) boreholes were functioning unsatisfactorily due to some mechanical problems.

4.4.3 Status of Hand Pump Parts

Having done the leakage and discharge tests, the hand pump parts were also assessed to check their conditions. It was revealed that a total of 12 (17%) boreholes had serious mechanical problems that had affected the performance of the boreholes in such a way that five (5) boreholes were completely non-functional and seven (7) boreholes just had reduced discharge and/or delayed flow. The five non-functional boreholes are the ones mentioned in sub-section 4.4.1 above as being non-functional due to mechanical problems. Table 3 below provides details on the mechanical problems of the boreholes. Further detailed explanations are provided in the following sub-sections.

Table 3: Details of Mechanical Problems for Non-functional and Poorly Functioning Boreholes

No	Site Name	Functionality Status	Issues	Cause
1	Matanthwe	Functioning unsatisafactorily	Discharge problems	Worn out plunger bobbin and U-seal
2	Chindamba 2	Functioning unsatisafactorily	Discharge problems	Worn out plunger bobbin and U-seal
3	Idi	Functioning unsatisafactorily	Discharge problems	Worn out plunger bobbin and U-seal
4	Kapyepye	Functioning unsatisafactorily	Leakage and discharge problems	Minor crack on riser, worn out cup seal and bobbins
5	Ngalinje	Functioning unsatisafactorily	Leakage and discharge problems	Minor crack on riser, worn out cup seal
6	Kanjoka	Functioning unsatisafactorily	Leakage and discharge problems	Minor crack on riser, worn out bobbins
7	Lipere	Functioning unsatisafactorily	Leakage and discharge problems	Worn out O-ring, bobbins and cup seal
8	Kundete	Non-functional	Heavy leakage	Cracked riser
9	Laisi	Non-functional	Heavy leakage	1 Cracked and 1 disjointed risers
10	Maloya Centre	Non-functional	Heavy leakage	Disjointed risers
11	Saiti Tiputipu	Non-functional	Heavy leakage	2 big cracks on risers joints
12	Kaiche Centre	Non-functional	Heavy Leakage	Cracked foot valve and cracked riser

4.4.3.1 Wearing out of parts

The assessment revealed that seven (7) boreholes had worn out parts such as bobbins, cup seals and O-rings. Due to this, the hand pumps performed poorly in terms of discharge. Three (3) of these boreholes are the ones that failed discharge test only and the other four (4) are in category of those that failed both leakage and discharge tests.

It was also revealed that three (3) (43%) of these seven (7) boreholes with worn out parts were due to failure of community (Kapyepye, Ngalinje, Lipere) to do routine maintenance as a result of corrosion that led to the metal parts being welded together. This affected the community as they could not be able to dismantle the pump to replace the worn out parts. However, for the metal parts to get corroded to such an extent, it raises some questions on the activeness of the water point committees (WPCs) in carrying out weekly and monthly checks on their pumps, which is the most likely time when they could have easily identified traces of corrosion at an early stage.

4.4.3.2 Cracking and disjointing of rising mains

It was revealed that eight (8) boreholes had problems to do with cracked and/or disjointed uPVC rising mains. Four (4) of these boreholes are the ones that failed the leakage test and the other 4 are from the non-functioning boreholes.

It was also revealed that all these 8 (100%) boreholes had deeper pump installation depths that ranged from 46m to 55m as can be seen in Table 4 below. The cracks, as seen in Figure 15 below were therefore caused by high stresses on the upper rising mains as a result of heaviness as argued by Lutz et al. (2014) that mechanical stresses on hand pump parts are greater for deeper pump installations.

Table 4: Details of the Boreholes that had Cracked Riser Mains

No	Site Name	Installation depth (m)	Comment	Cause
1	Matanthwe	30	<45, normal installation	Worn out plunger bobbin and U-seal
2	Chindamba 2	36	<45, normal installation	Worn out plunger bobbin and U-seal
3	Idi	43	<45, normal installation	Worn out plunger bobbin and U-seal
4	Kapyepye	55	>45m, deep installation	Minor crack on riser, worn out cup seal and bobbins
5	Ngalinje	54	>45m, deep installation	Minor crack on riser, worn out cup seal
6	Kanjoka	46	>45m, deep installation	Minor crack on riser, worn out bobbins
7	Lipere	42	<45, normal installation	Worn out O-ring, bobbins and cup seal
8	Kundete	47	>45m, deep installation	Cracked riser
9	Laisi	51	>45m, deep installation	1 Cracked and 1 disjointed risers
10	Maloya Centre	55	>45m, deep installation	Disjointed risers
11	Saiti Tiputipu	51	>45m, deep installation	2 big cracks on risers joints
12	Kaiche Centre	53	>45m, deep installation	Cracked foot valve and cracked riser

Figure 15: Cracked Rising Main

4.4.3.3 Corroding of metals parts

One other thing that was revealed in this study through the assessment of pump parts was that there were three (3) serious cases of corrosion on metal parts of the hand pumps. This corrosion mainly attacked parts like hunger housing, pedestal, bolts and nuts. This corrosion was solely due to salty water. Figure 16 below is a pictorial view of the severe corrosion that attacked metal parts.

Figure 16: Severe Corrosion Due to Salty Water

4.4.3.4 Clogging

From the same assessment, 2 boreholes were found to be experiencing clogging of the slots and the foot valve. 1 borehole was found to be clogged with small roots from a nearby tree and these roots had gone through the slots, blocking the passage of inflowing water. On the other borehole, it was found that termite mound had developed between the pedestal and the casing as in Figure 17. This led to the clay falling inside the borehole and clogging the pumping system as well as the affecting the quality of water.

Figure 17: Termite Mound Developing in a Borehole (Top Picture) and Muddy Rising Main (Bottom Picture)

Although this clogging did not indicate any significant effect on the yielding of the boreholes at the time of study, in the long run it could have serious impact as the accumulation of the roots and the clay could hamper the pump operation as well as the inflow of water.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the observations made in this study, the following conclusions are made:

- The diminishing borehole yields indeed exist in the study area but in lesser (9%) cases than what were earlier reported as 44%. Despite other factors that might have been there, the low initial yield at construction had much influence on these diminishing yields since almost all the boreholes that diminished in yield had the lowest recorded initial yield. However, although the causes for the one borehole that had a higher yield at construction but eventually dried up could not be readily identified, it is suspected that the causes could be hydrogeological in nature. These hydrogeological factors might also apply to all the other boreholes with low yields both in the initial and current statuses.

- There are more mechanical problems than yield problems affecting the functionality of the boreholes, more especially reduction in pump discharge in the study area. These mechanical problems range from wearing of parts such as O-rings, bobbins and cup seals, and also the disjointing and cracking of the rising mains. The adverse effects of the reduction in pump discharge due to the mechanical problems, on the community water users, are similar to those effects of diminished yield as both would affect the amount of water the community is able to draw per day. That is why there is high likelihood of mistaking one for the other i.e. generalising discharge problems as yield problems.

- There has been insufficient groundwater recharge to balance up with the amount of groundwater discharge in the study area in the recent past years such that groundwater levels have considerably gone deeper than where they were at the time of construction as observed from the lowering of the static water levels of almost all the boreholes. This could eventually have an impact on the yielding of the boreholes, including those that have not yet started showing signs of diminishing yields.

5.2 Recommendations

It is being recommended that:

- Further studies to understand the aquifer characteristics such as permeability, transmissivity, specific storage, storativity as well as hydraulic conductivity be conducted with respect to those boreholes that had low yielding (both initial and current) and dried up statuses in order to determine whether the aquifers are fit for future sustainable groundwater development;

- Good catchment management practices must be followed in the study area in order to maximize on groundwater recharge through infiltration of precipitated water;

- Monitoring of operation and maintenance of these boreholes be intensified by the Mangochi District Water Development Office so that the water point committees as well as area mechanics are followed up to see if they are doing maintenances regularly; and

- A continued monitoring on the water level trends be intensified in order to properly plan for future interventions.

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APPENDICES

Appendix A: Sample Pumping Test Record Form

Village:…………………..………………GVH:………………..…………………
BH No:………………………………….. Date:…….……………………………….

PUMPING				RECOVERY				
Yield (l/s) or Seconds for 20l pail	Minutes since pumping started	Water Level (m)	Draw Down (m)	Minutes since pumping stopped	Water Level (m)	Draw down (m)	Time Ratio	Percentage Recovery
	0			0				
	0.5			0.5				
	1			1				
	1.5			1.5				
	2			2				
	2.5			2.5				
	3			3				
	3.5			3.5				
	4			4				
	4.5			4.5				
	5			5				
	6			6				
	7			7				
	8			8				
	9			9				
	10			10				
	12			12				
	14			14				
	16			16				
	18			18				
	20			20				
	25			25				
	30			30				
	35			35				
	40			40				
	45			45				
	50			50				
	60			60				
	70			70				
	80			80				
	90			90				
	100			100				
	120			120				
	140			140				
	160			160				
	180			180				
	210			210				
	240			240				
	270			270				
	300			300				
	330			330				
	360			360				
	420			420				
	480			480				

Pumping test team

1.………………………………………………………Signed…………………………….….

2.………………………………………………………Signed……………………………......

Appendix B: Sample Filled Pumping Test Record Form

An Assessment of borehole yielding in T.A. Nankumba in Mangochi District

Pumping test results

Village: MATANTHWE GVH: MSELEMA

BH No: WASNAN 102 Date: 04/11/14

Depth 69

ISWL 7.55

IDWL 12.13

I.Y. 0.2

NSWL 14.33

NDWL 62.09

N.Y 0.138

PUMPING				RECOVERY				
Yield (l/s) or Seconds for 201 pail	Minutes since pumping started	Water Level (m)	Draw Down (m)	Minutes since pumping stopped	Water Level (m)	Draw down (m)	Time Ratio	Percentage Recovery
	0	14.33		0	62.09			
	0.5	16.55	2.22	0.5	59.86	2.23		
	1	18.76	2.21	1	57.59	2.27		
	1.5	20.99	2.23	1.5	55.41	2.18		
30/	2	23.15	2.16	2	53.21	2.20		
	2.5	25.24	2.09	2.5	51.07	2.14		
27	3	27.34	2.10	3	49.07	2.09		
	3.5	29.35	2.01	3.5	47.11	1.96		
	4	31.32	1.97	4	45.01	2.01		
	4.5	33.22	1.90	4.5	43.06	1.96		
	5	35.08	1.86	5	41.11	1.95		
	6	38.50	3.42	6	37.86	3.25		
	7	41.52	3.02	7	34.92	2.94		
	8	44.03	2.51	8	32.16	2.76		
	9	46.03	2.00	9	29.84	2.32		
	10	47.64	1.61	10	27.87	1.97		
	12	50.15	2.51	12	25.73	2.14		
	14	52.18	2.03	14	23.85	1.88		
	16	53.60	1.42	16	22.73	1.12		
	18	54.81	1.21	18	21.97	0.76		
	20	55.73	0.92	20	21.41	0.56		
	25	57.58	1.85	25	20.94	0.47		
	30	58.85	1.27	30	20.73	0.21		
	35	59.70	0.85	35	20.60	0.13		
	40	60.23	0.53	40	20.49	0.11		
	45	60.60	0.37	45	20.42	0.07		
	50	60.85	0.25	50	20.36	0.06		
30/	60	61.26	0.41	60	20.30	0.06		
	70	61.55	0.29	70	20.25	0.05		
27	80	61.73	0.18	80	20.20	0.05		
	90	61.84	0.11	90	20.17	0.03		
	100	61.91	0.07	100	20.17	0.00		
	120	61.96	0.05	120	20.15	0.00		
	140	62.01	0.05	140	20.15	0.00		
	160	62.04	0.03	160	20.15	0.00		
	180	62.06	0.02	180	20.14	0.01		87.8%
	210	62.08	0.02	210				
	240	62.08	0.00	240				
	270	62.09	0.01	270				
	300	62.09	0.00	300				
	330	62.09	0.00	330				
	360	62.09	0.00	360				
	420			420				
	480			480				

Pumping test team

1. JONAS SALIM Signed [signature]
2. KONDWANI ANDREAH Signed [signature]
3. Signed

Appendix C: Compiled Data for the 70 Boreholes Studied

				COORDINATES		DRILLING		INITIAL STATUS				CURRENT STATUS			
No	Site Name (Village)	GVH	BH No	EAST INGS	NORTH INGS	Date	BH Depth	DATE	SWL (m)	DWL (m)	Yield (l/s)	DATE	SWL (m)	DWL (m)	Yield (l/s)
1	Matanthwe	Mselema	WaSNan 102	706742	8414602	11/09/2009	69	11/09/2009	7.55	12.13	0.20	04/11/2014	14.33	62.09	0.14
2	Kundete	Saiti Tiputipu	WaSNan 25	695012	8392381	08/10/2007	56	n.d	40.50	40.78	1.00	13/11/2014	48.08	48.09	1.00
3	Chamba I	Chamba	WaSNan 24	693765	8408174	11/11/2007	28	n.d	5.20	22.40	0.20	25/11/2014	6.76	8.76	0.23
4	Chembe North	Chembe	WaSNan 84	703492	8397407	31/07/2008	60	19/08/2008	39.78	42.60	1.00	22/11/2014	52.82	N/A	0.00
5	Juwayeyi	Kella	WaSNan 92	702388	8407036	17/08/2008	83	20/08/2008	9.58	35.00	0.20	18/11/2014	13.75	19.68	0.23
6	Laisi	Chilonga	WaSNan 72	702166	8400271	13/08/2008	78	18/08/2008	16.30	43.80	0.20	20/11/2014	25.13	56.76	0.12
7	Kapyepye	Sombe	WaSNan 229	716727	8420285	09/08/2009	70	30/08/2009	7.56	53.07	0.20	02/11/2014	8.74	38.01	0.22
8	Ngaunje	Maloya	WaSNan 82	716727	8393066	03/08/2008	82	18/08/2008	40.41	51.00	1.00	23/11/2014	45.50	48.37	0.63
9	Chinganji Doko	Sosola	WaSNan 26	690108	8403533	28/10/2007	36	n.d	8.79	17.94	0.50	16/11/2014	11.23	22.27	0.40
10	Maloya Centre	Maloya	WaSNan 81	703032	8395217	29/07/2008	78	15/08/2008	41.29	55.91	1.00	22/11/2014	46.21	53.21	0.87
11	Kankhande	Sokole	WaSNan 23	692891	8400414	19/10/2007	41	n.d	6.12	34.80	0.20	13/11/2014	7.69	10.18	0.20
12	Macheke	Kaiche	WaSNan 99	706950	8411519	19/09/2009	56	27/09/2009	9.00	14.22	0.20	08/11/2014	11.91	12.19	0.20
13	Mgwirizano	Kaiche I	WaSNan 164	709212	8411360	19/08/2019	70	04/09/2009	8.81	13.95	0.20	09/11/2014	11.08	14.32	0.25
14	Chamba II	Chamba	WaSNan 22	694388	8408330	18/11/2007	40	n.d	4.78	7.04	1.00	25/11/2014	6.09	7.47	0.71
15	Chindamba	Chamba	WaSNan 29	694388	8408330	21/11/2007	37	n.d	5.58	13.42	1.00	25/11/2014	6.08	12.51	0.95

16	Masakatira	Mvumba	WaSNan 94	697212	8410931	21/08/2008	55	24/08/2008	12.76	24.30	0.20	18/11/2014	18.11	23.85	0.25
17	Kachepa	Kaiche I	WaSNan 165	708822	8408406	18/08/2009	50	03/09/2009	7.64	8.57	1.00	02/12/2014	11.67	12.57	1.00
18	Suludi	Kaiche	WaSNan 97	705646	8408235	08/09/2008	31.68	14/09/2008	12.60	17.04	1.00	02/12/2014	15.78	17.64	0.74
19	Sangazi	Kaiche I	WaSNan 167	710393	8408527	24/08/2009	45	08/09/2009	9.66	13.93	0.50	11/11/2014	11.91	14.60	0.50
20	Chembe Centre	Chembe	WaSNan 83	702521	8395665	30/07/2008	69	21/08/2008	33.16	34.28	1.00	23/11/2014	40.26	40.78	1.00
21	Kanjoka	Makunula	WaSNan 86	696469	8393430	12/09/2008	69	19/09/2008	37.46	38.20	0.50	23/11/2014	44.36	44.95	0.54
22	Lino	Chizuula	WaSNan 225	710254	8430289	01/09/2009	52	16/09/2009	10.92	17.92	0.20	02/11/2014	13.24	24.36	0.25
23	Gotapini	Kaiche I	WaSNan 166	709976	8410873	21/08/2009	50	07/09/2009	9.88	16.63	0.50	09/11/2014	12.95	16.07	0.50
24	Nakundu	Kaiche I	WaSNan 159	712277	8410851	28/08/2009	60	10/09/2009	10.11	16.30	0.50	11/11/2014	14.50	17.88	0.44
25	Silaji	Ntola	WaSNan 224	706043	8418847	12/09/2009	70	22/09/2009	10.92	39.74	0.20	06/11/2014	12.80	41.07	0.12
26	Mdadada	Ntola	WaSNan 168	705024	8419984	14/09/2009	51	23/09/2009	8.34	14.14	0.20	06/11/2014	8.86	11.37	0.25
27	Chindamba 2	Chamba	WaSNan 30	695467	8408138	07/11/2007	39	n.d	4.60	27.85	0.50	16/11/2014	5.44	27.18	0.50
28	Namikango	Kaiche I	WaSNan 158	710565	8409975	26/08/2009	78	09/09/2009	8.79	39.85	0.20	11/11/2014	10.04	15.60	0.21
29	Saiti Tiputipu	Saiti Tiputipu	WaSNan 07	693674	8392144	11/09/2008	82	20/09/2008	42.40	44.68	0.20	13/11/2014	49.10	51.04	0.20
30	Chilanga	Chilonga	WaSNan 71	700956	8401711	10/10/2008	60	11/10/2008	19.00	30.72	0.50	20/11/2014	19.17	29.65	0.48
31	Manthambwe	Kanyenga	WaSNan 157	711084	8418011	29/08/2009	56	15/09/2009	10.72	39.40	0.50	04/11/2014	13.45	42.37	0.19
32	Ntongola	Kaiche I	WaSNan 163	708750	8412500	23/08/2009	80	06/09/2009	13.18	14.34	0.20	09/11/2014	14.34	23.87	0.20
33	Kupiri	Makokola	WaSNan 93	699724	8409053	19/08/2008	69	23/08/2008	18.12	38.43	0.50	18/11/2014	25.27	40.79	0.20
34	Chiwangula	Sokole	WaSNan 28	692057	8400897	25/10/2007	46	n.d	11.64	25.78	0.50	15/11/2014	12.08	24.54	0.45

35	Mologeni	Sokole	WaSNan 12	692955	8398858	15/10/2007	47	n.d	3.99	27.12	0.50	15/11/2014	7.05	28.73	0.50
36	Kamangazula 3	Sokole	WaSNan 31	693127	8403305	09/11/2007	51	n.d	2.15	45.57	0.50	16/11/2014	5.60	41.49	0.33
37	Lipere	Balamanja	WaSNan 223	704911	8434399	06/09/2009	48	18/09/2009	32.93	35.16	1.00	01/11/2014	30.40	31.74	1.25
38	Mululu	Kaiche I	WaSNan 160	708774	8406739	17/08/2009	55	02/09/2009	6.40	10.12	0.50	08/11/2014	8.18	14.12	0.67
39	Mpandamoyo	Kaiche I	WaSNan 162	707936	8405967	12/08/2009	70	01/09/2009	13.97	23.54	0.20	08/11/2014	18.67	22.96	0.20
40	Kaiche Centre	Kaiche	WaSNan 96	706736	8409536	09/09/2008	78	15/09/2008	3.08	47.36	0.20	02/12/2014	3.12	56.78	0.08
41	Kundete	Kundete	WaSNan 04	693480	8393127	09/10/2007	56	n.d	36.62	39.20	1.00	30/11/2014	37.15	40.46	0.94
42	Saiti Tiputipu Centre	Saiti Tiputipu	WaSNan 06	692396	8391804	04/10/2007	56	n.d	26.90	27.30	1.00	19/11/2014	34.11	34.29	1.00
43	Madalitso	Chilonga	WaSNan 73	700197	8400024	09/08/2008	51	17/08/2008	8.00	9.38	1.00	12/11/2014	8.76	9.33	1.00
44	Zomba	Mbapi	WaSNan 95	696740	8416191	16/09/2008	46	21/08/2008	7.34	17.36	1.00	30/11/2014	16.03	30.74	1.00
45	Jambo	Kella	WaSNan 91	701342	8404223	02/09/2008	51	13/09/2008	12.50	17.43	1.00	01/12/2014	16.09	20.42	1.00
46	Ngongomwa	Chilonga	WaSNan 87	703609	8398650	17/09/2009	54	26/09/2009	14.86	15.75	1.00	12/11/2014	16.67	17.02	0.95
47	Nkhalango II	Mputa	WaSNan 115	704204	8424336	16/09/2009	52	25/09/2009	5.98	14.84	1.00	14/11/2014	10.85	15.26	1.00
48	Nkhalango I	Mputa	WaSNan 169	704528	8426123	15/09/2009	51	24/09/2009	9.42	14.09	1.00	14/11/2014	13.69	16.11	1.00
49	Saiti Tiputipu	Saiti Tiputipu	WaSNan 08	691731	8494487	05/10/2007	41	n.d	18.20	19.82	1.00	19/11/2014	26.52	27.23	1.00

50	Binali	Sokole	WaSNan 09	694860	8397145	15/10/2007	51	n.d	18.43	23.82	1.00	21/11/2014	21.14	24.09	0.92
51	Binali	Sokole	WaSNan 10	695399	8397846	16/10/2007	31	n.d	7.60	13.86	1.00	21/11/2014	12.49	17.91	1.00
52	Binali	Sokole	WaSNan 11	694669	8398101	18/10/2007	31	n.d	5.74	6.80	1.00	24/11/2014	8.36	9.04	1.25
53	Mkombe	Mambo	WaSNan 230	715001	8411872	04/08/2009	32	27/08/2009	13.84	15.02	1.00	29/11/2014	17.56	18.99	0.96
54	Mtetelezi	Chigonere	WaSNan 226	708739	8426888	04/09/2009	40	17/09/2009	11.70	11.87	1.00	01/11/2014	15.43	15.98	1.00
55	Malinga	Katole II	WaSNan 170	703030	8428720	08/09/2009	46	20/09/2009	9.06	13.89	1.00	01/11/2014	10.04	13.14	1.00
56	Makunula Centre	Makunula	WaSNan 85	700666	8392902	28/07/2008	87	14/08/2008	34.37	46.55	1.00	28/11/2014	39.37	51.54	1.00
57	Sosola	Sosola	WaSNan 13	694324	8407570	17/11/2007	40	n.d	13.06	16.65	1.00	27/11/2014	16.87	19.43	1.00
58	Sokole	Sokole	WaSNan 16	694376	8401925	02/11/2007	32	n.d	4.85	6.07	1.00	26/11/2014	7.97	9.38	1.00
59	Kamangaz ula	Sosola	WaSNan 15	692751	8402326	28/10/2007	31	n.d	3.29	6.40	1.00	27/11/2014	7.66	9.97	1.00
60	Idi	Maloya	WaSNan 80	701808	8395440	04/08/2008	65	15/08/2008	36.39	36.70	1.00	29/11/2014	37.88	38.73	1.00
61	Chilenje	Mtalika	WaSNan 79	699568	8398829	06/08/2008	51	16/08/2008	10.38	12.18	1.00	17/11/2014	15.73	17.34	0.95
62	Lumwira	Chamba	WaSNan 18	689450	8410077	14/11/2007	34	n.d	4.06	4.62	1.00	05/11/2014	6.56	6.92	1.00
63	Sosola 2	Sosola	WaSNan 27	693766	8407710	13/11/2007	34	n.d	5.78	10.39	1.00	28/11/2014	11.98	17.58	0.91
64	Sawerenga	Mtalika	WaSNan 78	698725	8397373	05/08/2008	60	16/08/2008	11.16	12.69	1.00	17/11/2014	18.14	18.78	1.10
65	Mkanamw ano	Jumam'ba nga	WaSNan 77	698726	8399847	08/08/2008	50	17/08/2008	4.14	35.65	1.00	03/11/2014	8.96	41.81	0.87
66	Jailos	Chilonga	WaSNan 74	703048	8401986	13/09/2008	57	16/09/2008	16.36	23.09	1.00	07/11/2014	20.01	28.89	1.00
67	Lumwira	Chamba	WaSNan 19	692467	8406374	15/11/2007	45	n.d	3.94	10.82	1.00	05/11/2014	6.11	11.32	0.98
68	Makunje	Chilonga	WaSNan 75	705565	8399437	14/08/2008	51	19/08/2008	21.38	21.68	1.00	07/11/2014	24.04	24.12	1.00
69	Tsanya	Jumam'ba nga	WaSNan 76	688742	8402473	01/10/2008	50	02/10/2008	17.70	39.27	1.00	03/11/2014	20.34	41.15	0.93
70	Sauka 2	Sokole	WaSNan 32	694665	8400809	03/11/2007	28	n.d	4.38	18.94	1.00	26/11/2014	9.21	18.22	0.88

Appendix D: Maintenance Card Used for Carrying Out Leakage and Discharge Tests

Maintenance Card for Afridev Handpumps

A) Weekly Checks

- **It is most important to fasten the special nuts of the fulcrum pin tightly.**
- Check also the flange bolts for tightness and keep the pump platform and the drainage channel clean.

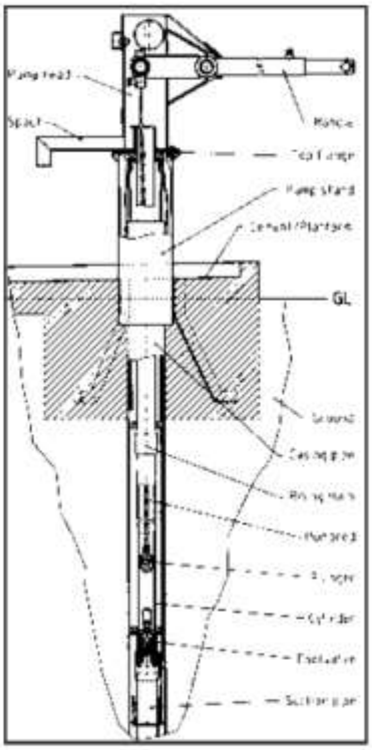
B) Monthly Checks

- **Make a Leakage Test:**
  a) Operate pump handle until water is flowing from the spout.
  b) Stop operating the pump handle for approximately 30 minutes.
  c) Then operate the handle and count exactly how many strokes are required until the water is starting to flow again.

  If more than 5 handle strokes are required to make the water flow again, there must be a leakage in the rising main or the footvalve. **Report to a pump mechanic!**

- **Make a Discharge Test:**
  a) Operate pump handle until a constant water flow is achieved. (pump ratio approximately 40 full handle strokes per minute).
  b) Place a bucket in the continuous water flow for exactly one minute.
  c) Take the bucket off the water flow and check the amount of water.

  If the discharge is less than 15 litres, there might be a problem with the bobbins or the cup seal. **Report to a pump mechanic!**



Appendix E: Trouble Shooting Manual Used for Identifying Mechanical Faults of the Hand Pump

Trouble Shooting Chart			Afridev Handpump Maintenance
Problem	**Operation**	**Cause**	**Remarks**
No water	Handle operation is easy	Pumprods are disconnected	Pull out all Pumprods and replace broken and corroded rods
	Handle operation is difficult	Riser pipe is disconnected	Pull out complete Rising main, repair/replace pipes (solvent cement joints)
	Handle operation is normal	Cup seal is defect	Replace seal
		Borehole is clocked (silt or sand)	Rehabilitation of borehole (cleaning with compressed air or by bailing)
		Water level dropped below cylinder	Add Riser pipes and Pumprods
Delayed flow of Water	Handle operation is normal	Leaking of valve Bobbins	Check and replace Bobbins (Plunger and Footvalve)
		Leaking of Footvalve O-ring	Replace O-ring
		Leakage in pipe joints or Rising main pipe is perforated	Pull out complete Rising main, repair/replace pipes (solvent cement joints)
Reduced discharge	Handle operation is difficult	Cup seal is too tight	Replace with seal of correct size
	Handle operation is normal	Full stroke is not possible	Check and adjust length of the Top rod
		Cup seal is worn	Replace seal
		Leaking of valve Bobbins	Check and replace Bobbins (Plunger and Footvalves)
		Leaking of the cylinder (cracked)	Pull complete Rising main, repair/replace cylinder (solvent cement joints)
Abnormal noise during operation	Handle operation is normal	Pumprods rubbing on Riser pipes	Check and replace worn Pumprod Centralisers
		Pumprod centralisers worn	Check and straighten bent Pumprods, replace worn Pumprod Centralisers
	Handle operation is inconvenient	Pumprods are touching Riser pipes	Straighten or replace bent Pumprods, replace worn Pumprod Centralisers
		Bearingsare worn, Handle fork touching the sides of Pump head	Check and replace Bearing sets (4 off)
Pump handle shaky	Handle is shaky when operated	Bearings are worn	Check and replace Bearing sets (4 off)
		Fulcrum pin is loose	Check Fulcrum pin (and Bearing sets) and tighten both nuts fully
		Hanger pin is loose	Check Hanger pin (and Bearing sets) and tighten both nuts fully
	Pump head is shaking	Flanges are loose	Tighten all bolts and nuts of the flanges
	Pumpstand is shaking	Pump platform is cracked	Repair Pump platform or Well cover (for dugwells)