Journal of Optimization in Industrial Engineering
Vol.12, Issue 2, Summer & Autumn 2019, 45- 54
DOI: 10.22094/JOIE.2018.568034.1563

Research Article

Investigating Water Supply System Electro-Mechanical Equipment Problems: A Case Study of Ethiopia

Dessie Tarekegn Bantelay*

Faculty of Mechanical and Industrial Engineering, Bahirdar Institute of Technology, Bahirdar University, Ethiopia.
Received 13June 2018; Revised 31October 2018; Accepted 31 November 2018

Abstract

Water is an essential element of life. The government of Ethiopia in collaboration with development allies' attempts to increase pure water supply. Even though the coverage boosted dramatically still there is critical challenges in maximizing equipment's reliability, improving service quality, maximizing capacity utilization, minimizing life cycle costs of water production machinery and reducing water waste. The objective of this study was to identify installation, operation, maintenance and related challenges, to evaluate the performance of pump station and to investigate the root causes so as improvements can be made deliberately. In this regard 20 town water supply stations were selected in Amhara region of Ethiopia and initially on site visit carried out and various existing situational surveys regarding the existing installation, operation and maintenance practice have been conducted. Next information collected using questionnaires, interview and focus group discussions. Then imperative performance indicating measurements taken and the data organized and important performance indicating parameters were analyzed using quantitative techniques. The study proved that all the pump stations run under the minimum performance requirements and the problems are deep enough to challenge the service quality and service cost of the pump stations. Unless the problems will be solved soon systematically the problems may be even mature to the nastiest situation that cannot handled.

Keywords: Submersible Pump; Electro-Mechanical Equipment; Pump Installation; Operation and Maintenance.

1. Introduction

Water is an essential element of life following to oxygen. Pure water supply is important for drinking, cooking, bathing, washing and other day to day human activities. Anything, weather it is technical or managerial hassle that disturbs the provision of pure water supply, consequently, tends to disturb the existence of humankind (Abraham O., 2018). Improved water supply and sanitation service is mandatory for improved social, economic and health status of the community as well. According to WHO and UNICEF reports, up to 84% of the world population lives in rural areas suffer from pure water supply(WHO - UNICEF 2010). Due to limited supply of pure water and sanitation service, water born disease increase from time to time. Currently Diseases arise from pure water supply, sanitation and contamination recorded as one of the principal causes of early death and serious illness in different developing countries (Fitsum D. and Fikirte D. 2014). Different literatures verified that more than 80% of diseases in the world are raised due to unsafe drinking water and limited sanitation practices (Ermiaset al., 2016). Provision of urban water supply system has been a major concern in developing countries now a day (Mahesh K. and Getu T. 2018).In this regard, Ethiopia has made an encouraging progress to improve access to safe drinking water and sanitation. Pure water supply infrastructures have been increased. The coverage increased from 35% to 65.8% in rural parts of the country. Similarly in urban areas it has been increased from 80% to 91.5% within five years (Thewodros, B. and Seyoum, L. 2016).

A typical pure water supply system in Ethiopia consists of multistage submersible centrifugal pump, water sealed electrical motor, water column (usually steel pipe), one or more check valves, pressure switch, flow meter, pressure gauge, hose bib or faucet, gate valve, control box and auxiliary components needed for proper functioning (Abebeet al., 2013). These include well casing, water level detector electrode, well screen or strainer (sleeve). When the heavy duty motor coupled with multi stage centrifugal pump rotates water enter to the pump through the strainer (inlet). As the water flow over the rotating impeller the blade will impart kinetic energy to the liquid. Then the water will convert the kinetic energy in to pressure head with the help of the guide vane or diffuser. This will takes place until the water exit the pump (Stelet al., 2015).

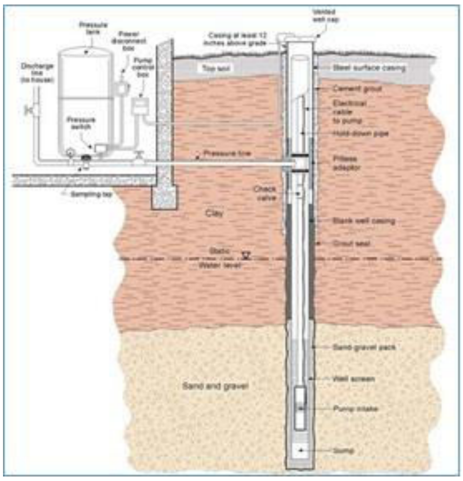

Fig 1.Submersible pump system typical installation. (Source: The Ground Water Atlas of Colorado)

*Corresponding author Email address: dessie2000ec@gmail.com

Pure water supply is a common problem in the country. Unsatisfied demand of the city inhabitants were widening from year to year. Shortage of water at the sources, frequent failure of electromechanical equipment's, rapid population growth and rapid urbanization are among the major causes that resulted in water supply shortage (Desalegn B. 2014). Electrical submersible pumps systems are perhaps the most efficient equipment for removing large amounts of water from wells. However, the equipment's become an expensive hassle due to improper installation, operation and maintenance practice (Ministry of water and energy (2013).According to different surveys conducted on water supply system at national levels studies focused mainly on large urban settlements. There were no active researches still now in small and medium level water utilities to investigate the sector challenges and recommend a means of alleviation (Chala, 2011). The research findings focused on national level indicated that even though the coverage boosted dramatically still there is critical challenges in maximizing equipment's reliability, improving service quality, maximizing capacity utilization, minimizing life cycle costs of water production machinery and reducing water waste (Abebeet al., 2013). So the objective of this research was to point out installation, operation, maintenance and related challenges, to evaluate the performance of pump station and to examine the root causes so as improvements can be made deliberately.

2. Literature Review

In today's challenging business environment on time and cost effective service delivery is very important for survival. So it is mandatory to improve utilization of electro-mechanical equipment's by ensuring an efficient and effective schedule at all level (Zhiqiang et al., 2015). Maintenance management, production management and quality control are interdependent to each other. Since high initial investment require to install equipment's having high excellence, most of water production equipment's used in the country have inherent inferiorities(Solomon et al 2011). So to reimburse the gap it is crucial to apply preventive maintenance technique. But production schedule commonly in clash with preventive maintenance tasks, they have to perform one after the other. As a result, production and maintenance plans are often not efficient with respect to cost reduction and on time service provision (Mustapha et al., 2016). When improper attention given to preventive maintenance machine availability will increase but conversely downtime will increase. Therefore, it is important to optimize the preventive maintenance schedule with production management and maintain equipment availability at the highest possible operating parameters (Lei et al., 2016). In addition to improving service availability, effective maintenance practice have high role in reducing maintenance cost, improve system reliability and improve customer satisfaction (Jun et al., 2015)). This will yield in reductions of costs related to break down maintenance, service quality inferiority and machine depreciation. Consequently the extra preventive maintenance cost will compensated. So it is more cost-effective to maintain equipment in best condition (Ben-Daya M). Evaluating the effectiveness of maintenance operations needs the integration of several sources of information. These includes; current machine status, maintenance history, availability of maintenance manpower, availability of spares and consumables(Koren Y., 2010). In reality, preventive maintenance (PM) is crucial for any pure water supply system equipment's. The water production process and maintenance operations should be well integrated (Xiaojun et al., 2012).

3. Methodology

To meet the study objective on site visit was carried out initially and various existing situational surveys regarding the existing installation, operation and maintenance practice have been conducted. During field visit strategic plans, reports, manuals and regulations documents which are available in each town water service office have been collected and reviewed critically.

Then questionnaires developed and information were collected from board members, management members, operation and maintenance experts and users. Interviews were also held with key informant who can figure out the current situation of the water service of each water utilities centers. In addition to interview focus group discussions were held with government representatives, management members and users and important information's were gathered about the overall condition of pumping stations.

Next on site inspection done to assure availability of on sight delivery inspection, proper casing positioning, well-suited ground piping systems, appropriate protection mechanism, power supply, motor control system and drop cable, check valve, proper electrical grounding, auxiliary equipment's adjustment and others. Similarly imperative measurements including capacity of units, flow rate, pressure, mechanical measurements and electrical measurements had been made and important performance indicating data collected. Finally the data organized and important performance indicating parameters were analyzed using the following quantitative analysis techniques.

Over all equipment effectiveness depends on equipment availability. It is used to point out losses related to system and equipment performance (Bulent et al., 2000)). To determine the probability that the pumping system, when used under specified conditions, operates satisfactorily and effectively Percentage of equipment availability evaluated. It is determined using (Peter et al., 2008):

Percentage of equipment availability (EA) (1)

$$\text{EA}\,\% = \frac{\text{HEA}}{\text{TOH}} x100\%$$

Where HEA denote the amount time each unit is available to run at full capacity(hr), determined by deducting down time, speed time loss and quality time loss from total operation time of the pump stations and TOH denote the total planed operation time (hr).

Percentage of schedule compliance (SC)

$$\mathrm{SC}\ \% = \frac{\mathrm{THWS}}{\mathrm{THS}}\ x100\% \qquad (2)$$

Where THWS denote the total time worked on scheduled jobs and THS denote the total time scheduled.

Percentage of emergency maintenance (EMP)

$$\mathrm{EMP}\ \% = \frac{\mathrm{THWEM}}{\mathrm{THSM}} x100\% \ (3)$$

Where THWEM denote the total time worked on emergency jobs and THSM denote the total time spent on maintenance worked.

Percentage of preventive maintenance (PPM)

$$\mathrm{PPM}\ \% = \frac{\mathrm{TTWPM}}{\mathrm{THSM}}\ x100\% = 1 - \mathrm{EMP}\ (4)$$

Where TTWPM denote the total time worked on preventive maintenance jobs and THSM denote the total time spent on maintenance worked.

Percentage of preventive maintenance budget (PMB)

$$\mathrm{PMB}\ \% = \frac{\mathrm{PMC}}{\mathrm{TMC}}\ x100\%(5)$$

Where PMC denote the preventive maintenance cost and TMC denote the total maintenance cost.

4. Results and Discussions

4.1. Installation challenges

Proper installations is critical in minimizing maintenance challenge and maximize reliability, improve service quality, reduce waste, maximize capacity utilization and minimizing life cycle costs of water production machinery. Conversely, improper installation is a chronic source of downtime, poor service provision, reduced capacity utilization and high cost of operating. In this regard the basic installation requirements were assessed critically and the result shows that:

- Delivery Inspection:

It is routine inspection of equipment before installation for damage, the material received matches the description on the Bill of Loading, the motor nameplate to assure that the correct HP, voltage, phase, and frequency were cheeked properly in all pumping stations.

- Improper Casing Position:

If the inner diameter of the bore hole casing is not large enough, the electrode and power cable will distracted during lowering of the pump unit into the well. In this regard there is no significant problem. But in 10% of the deep well the casing openings position is not installed at appropriate depth and direction to prevent sand suction.

- Above Ground Piping Systems:

The above ground piping system must fit the flow rate and pressure produced by the pump. If the systems allows the pump to run at high pressure and low flow conditions for extended periods of time can cause the motor to overheat and burn out. Similarly.

If the systems allows the pump to operate at low pressure and high flow conditions can cause cavitation and damage the pump couple. In this regard, even though a pressure relief valve is important for each pump stations, 75% installing incorrect pressure relief valve at wrong position.

- Frequency of start

Frequent start of pump will damage the motor. When there is frequent interruption of power (it is common phenomena in Ethiopia) to limit the number of start and the time interval between starts the board has to provide with the necessary control device. In this investigation, it is found that only 55% of the system designed and provided with proper protection mechanism so that the pump is not restart several times due to frequent power interruption and other problems.

- Providing a Proper Power Supply

The power supply must be compatible to the system capacity (KVA), voltage, phase, and frequency requirements to match the pumping systems. Similarly the power cable should be selected and installed with adequate care.

Fig2.Currentpoor electric cable installation practice in pumping stations.(Source: on site visit)

The study reveals that in 35% of the re-installations were used low-grade electrical cable or there were poor electrical cable installations practice as shown in the figure 2.

- Motor Control System

The motor control system must be sized to safeguard the pump motor from abnormal conditions. It should protect the motor from current unbalance, low/high voltage, phase loss, overload, overheating and lightening. In 15% of the pumping stations, control boxes or equipment’s replaced by inappropriate one when the initial one fail to operate.

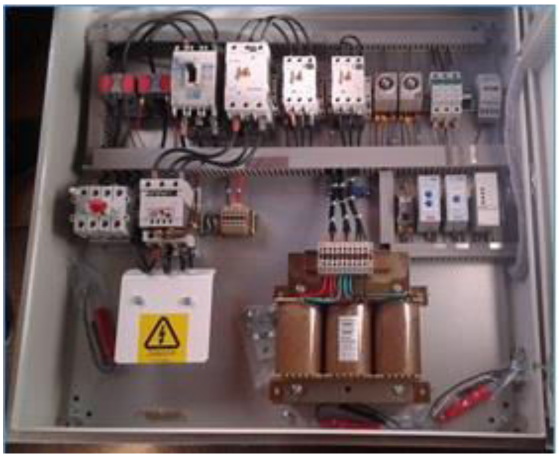

Fig. 3.Typical control box used in pumping stations.(Source: on site visit)

Submersible pump control boxes are designed for indoor operation. Control boxes should never be mounted in direct sunlight or high temperature locations. If not capacitor life reduced and pointless overload protectors tripping exist.

Fig.4.Current installation practice of pumping station control box. (Source: on site visit)

In addition, if control boxes are designed with voltage relays they have to install vertical upright. Mounting in other positions will affect the operation of the relay. In addition they have to be far from heating elements. But during field assessment it had been observed that the electric control box/panels are placed near to high temperature corrugated sheet wall, exposed to direct sun light and lay down on a wooden panel horizontally.

- *Selecting Proper Drop Cable*

Submersible pump drop cables are especial electrical cable designed for this purpose only. They are covered with a special waterproof heavily insulator materials. The cable size must match with the motor size and the distance between motor and control panel. But 15% of them fail to select the right cable during re-installation of the pump motor.

- Making and Evaluating Electrical Tests:

Proper installation, operation and maintenance of a submersible pump needs voltage, current, resistance, continuity and current unbalance test. The use of electrical testing as a troubleshooting tool can very often quickly identify the problem and prevent the unnecessary time and expense of pulling the pump. But 80% of them have no skilled man power and tools to perform these tests.

- Selecting & Installing Auxiliary Equipment:

Submersible pump installation require auxiliary equipment such as pressure switches, flow switches, level switches, time switches, etc. The need for this equipment during project design is not critically evaluated and proper equipment selected and installed for 25% of the pumping stations.

- Pre-Installation Service

Pre-installation servicing that is required before installation such as filling motor with oil or water performed properly in95% of the pumping stations as per the description of the manual.

- Grounding

The control board have to ground properly. If the power supply is not ground properly the system can result in fatal shock or equipment damage less attention is given by 45% of the pumping stations.

- Check Valve

Check valves are used to maintain unidirectional flow of water during stop. In submersible pump installations one or more check valves have to install. But during the field assessment it has been observed that in 35% of the pumping stations either there is no check valve at the recommended position or they are not functional.

4.2. Operation Challenges

Properly installed submersible pump in a clean well will run for a long period of time without troubles. However, conditions are not always ideal and can change for the worse in the course of time. In addition the use of automatic control devices to control operation and protect the unit from abnormal conditions help the system run unattended. But the need for proper adjustment and maintaining each apparatus in good working condition is a mandatory precondition that must be fulfilled. Failure of an automatic control can easily cause the failure of a pump that is in excellent condition. Unfortunately these protective devices may not protect the installation from all of the hazards that may be misshapen.
A regular inspection and testing of each unit should be established to assure that potential problems are identified and corrected as soon as possible. Considering this the current operation practice of selected 20 pumping stations were reviewed and the result shows that:

1. Pumping stations having well defined operation procedure, schedule and plan account only 35%.
2. Dry running of the pumps recorded in 10% of the pumping stations.
3. Pumps recommended to run under optimal or best operating head and discharge range. But only95% of the stations operated within the range.
4. Control board devices including voltage regulator,

overload regulator and timer set within the recommended range only in 54% of the stations.

5. In 15% of the pumps started against closed delivery valve recorded.
6. Delivery valve have to operate gradually. It is well done in 95% of the stations.
7. From Parallels operated pumps 55% started and stopped within the recommended time lag
8. From series operated pumps 75% of them started or stopped one after the other with minimum time gap. After the delivery valve of the previous pump opened the next pump started immediately. In addition proper care taken to keep the air vent of the pump before running the pump.
9. In 85% of the pumping stations duty and standby pumps scheduled and utilized optimally.
10. Unequal running of pump station avoid the possibility of simultaneous failure and subsequent overhaul. In this regard only 15% of the pumping stations fail to schedule and maintain unequal running of pumps.
11. In 55% of the pumping station there is proper attention and practice to rectify and solve abnormal operation symptoms immediately.
12. In 55% of the pumping station frequent starting and stopping managed and prevented properly.
13. Well-developed log book used only in 55% of the pumping station to record the hourly operation observations, which cover:

- Timings and days when the pumps start/stop operation.
- Voltage variation in all phases.
- Current drawn by pump motor.
- Frequency of start.
- Pressure gauges and flow rate meter readings.
- Motor winding temperature (optional).
- Bearing pump temperature (optional).
- Water level indicator
- Any specific problem or event observed during operation including burst in pipeline, power failure and tripping.

4.3. Maintenance challenges

Preventive maintenance extend the equipment service life. It is a planned maintenance performed on a regular schedule. It is used to reduce component degradation. It should be performed at predefined interval of time regardless of whether the repair is needed. Even though preventive maintenance tasks are more cost effective than reactive ones, preventive maintenance still requires substantial human resources and spare parts inventory(Rakesh et al., 2013).Preventive maintenance tasks include inspection, cleaning, tightening and oiling. It is a crucial task to retain the healthy condition of equipment and prevent unscheduled failure of equipment's through the prevention of deterioration.

- **Performance Evaluation**

Pumping stations need an effective preventive and predictive maintenance practice. To evaluate the effectiveness of maintenance work availability of important preventive maintenance components were analyzed and the result summarized in table 1.

Table 1
Summarized result of pumping stations effectiveness parameters.

Pump Stations	Performance parameters (%)				
	Equipment Availability (%)	Schedule Compliance	Emergency Maintenance (%)	Preventive Maintenance (%)	Preventive Maintenance Budget
PS - 1	73	78	77	23	14
PS - 2	77	74	73	27	16
PS - 3	63	67	87	13	9
PS - 4	84	76	66	34	12
PS - 5	78	74	72	28	13
PS - 6	55	45	95	5	11
PS - 7	76	41	74	26	13
PS - 8	73	52	77	23	18
PS - 9	76	45	74	26	11
PS - 10	63	38	87	13	9
PS - 11	79	47	71	29	11
PS - 12	89	87	61	39	26
PS - 13	77	75	73	27	23
PS - 14	77	87	73	27	26
PS - 15	84	85	66	34	24
PS - 16	83	72	67	33	20
PS - 17	81	79	69	31	24
PS - 18	72	61	78	22	12
PS - 19	88	87	62	38	26
PS - 20	76	63	74	26	15
Average valve	76.2	66.65	73.8	26.2	16.65
Standard Bench Mark	> 95%	> 90%	< 10%	> 90%	15% – 18%

The result summarized in table 1and figure 5 shows equipment availability have direct relation to preventive maintenance and inverse relation to percentage of emergency maintenance. As preventive maintenance percentage increase equipment availability increase too. In addition the result indicates all the pump stations run under the minimum performance requirements and they have similar preventive maintenance trend. This shows how the problems are deep enough to challenge the service quality and cost of the pump stations. The study proved that in order to increase the availability of pump station machinery it is worthy important to increase preventive maintenance activities and avert emergency maintenance.

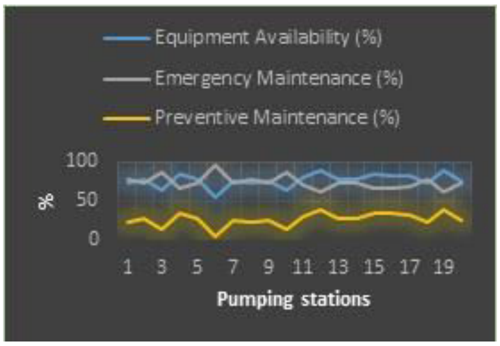

Fig. 5.Relation between pumping stations availability, preventive maintenance and emergency maintenance.

Similarly preventive maintenance practice were assessed and the result summarized in the table 2. The result proved that preventive and predictive maintenance given less attention.

Table 2
Availability of preventive maintenance components analyzed for 20 pumping stations.

Description	Availability (%)
Preventive maintenance plan/schedule	10
Spare stocks	25
Inspection check list	20
Inspection hand tools	50
Maintenance history log book	45
Maintenance man power	30

If the problems will not be addressed properly and immediate action will not take systematically, the problem may be even mature to the nastiest situation that cannot handled. To secure the system the following preventive maintenance components have to be introduced as soon as possible.

- **Routine Inspections:** quick inspection on a periodic basis should be performed. The inspection task should be performed using check list and have to include the following:
  - Check for any abnormal conditions regarding leakage, loosen part or damage.
  - Check for excessive noise and excessive heat.
  - Check for electric panel alarms, losses wires, blown fuses, etc.
  - Check for melted or burn electrical components and other abnormal conditions.

Then any problems observed during inspection should be recorded, carefully examined and corrected immediately. But only 55% of the pumping station perform routine inspection effectively.

- **Routine Testing:** a type and frequency of tests should be performed on a periodic basis commonly recommended by pump set manufacturers. But there are basic tests must be taken at any time the pump is started up after a prolonged shutdown. All test readings should be recorded for future replacement and similar analysis. If the record changes gradually it indicates a gradual deterioration of equipment's. But large changes can indicate rapid deterioration with a potential for sudden failure of parts in the near future. The following tests must be performed before pump starting after a long shutdown:
  - Measure the resistance between the drop cable and ground.
  - Measure the resistance of the drop cable and motor windings.
  - Measure the voltage and the current. Compare the readings with previous readings. If the voltage or the current record has changed significantly, check the current unbalance. Excessive current is an indication of a problem somewhere in the system which should be corrected immediately.
  - Measure the water level in the well. A drop in the water level may indicate over pumping of the well or clogging of the well screen which can result in damage of the pump or the motor. The pump have to be always under the water. If the water level reduced permanently lowering the pump by installing additional column pipe should be considered if the pump suction is submerged 1.52meter or less when pumping.

- **Performance Testing:** Performance testing of the pump station for analyzing the status of the system and future action consists of measuring and recording of:
  - Discharge pressure
  - Pumping level
  - Flow rate
  - Input including power input, line voltage on all phases and current in all three phases.

The above information should be taken at four operating points: shutoff, slightly less than rated flow rate, rated flow, and slightly greater then rated flow.

1. Maintenance Managements Practice

The management operation and maintenance practice are vital aspect for effective service. Considering this the management practice in pump stations were evaluated and the result summarized below:

- **Preventive Maintenance Schedule:**

Preventive maintenance schedule should be prepared for tasks to be performed on a daily, monthly, quarterly, semiannual and annual basis. It has to consider availability of manpower, resource and production schedule. When the work has been completed and the data should be recorded with standard format for further tasks. But only 35% of the station have such type of records.

- **Unscheduled Work Order Requests:**

A report form for unscheduled work performed should be prepared and record have to be taken, analyzed and an improvement task should be performed deliberately. The record have to show the type of unscheduled work performed, why it was performed, costs, labor, equipment and consumables used. If possible using information management data base is recommended. All forms should be turned into the Information Management System manager for entry. This will help to take an improvement action deliberately. Observations shows that most of them have no such records.

- **Modifications Made to the Station:**

Only18% of the pumping station kept up to date drawings and plans to facilitate future expansion work and to evaluate pump station performance.

- **Written Reports:**

Written reports providing details unusual conditions occurred, task performed, how repairs made, time taken, root causes of failures, special equipment and material used, an improvement opportunities, additional maintenance scheduling required if the job needs special attention or must be repeated in the future need to be recorded and store for future action. But 17.5% of them have this report.

- **Operational Data**

Operational records needed to evaluate operational performance should be maintained. These records include flow records, working hours, equipment lapsed time, meter readings, water waste. But there is no any well-organized performance indicating records in all pumping stations.

4.4. Root Causes Analysis

❖ ***Operators***

Professional relevance: Based on assessment result and information collected from literatures, the operators need enough skill and knowledge at least on basic electricity and basic mechanics, multistage centrifugal pump, electric motor, control box equipment's, IC engine and generator. In Ethiopia context this courses are given to electro-mechanical technicians and other occupations which considered for operator are far from this stream.

Experience: Most of the technicians assigned for operators neither have enough experience on the area nor taken any on job training before hand over the task. They train them self by trial and error.

Quantity: Utmost of the pump stations are far apart each other. They needs independent operators. But due to budget constraints and board members less attentions one operators assigned for more than one pump stations.

❖ Skill and knowledge gap

This factor include both technical and managerial knowledge and skill an operator is required to hand over reinstallation, operation and maintenance tasks properly. The evaluation result summarized in the table 3 shows that only 18% of the employees have the required skill & experience to handle the task.

Table 3.
Existing pump stations operators skill and experience assessment result summary

Description	Share
Skilled & well experienced	18%
Skilled with limited experience	42%
Unskilled & well experienced	32%
Unskilled with limited experience	8%

Whenever the technology update or new equipment is installed skill gap training must be assessed and given. In this regard records show the need for skill gap training on the following major points:

- Proper operation and parameters setting
- Routine Inspections
- Routine Testing
- Performance Testing
- Record keeping and reporting

❖ **Poor performance evaluation criteria**

Electromechanical operators and maintenance technician's performance evaluation takes place at least once a year in all pumping stations. But all work station use outdated performance evaluation criteria. The criteria have no any components that measure the effectiveness of the crafts performance quantitatively. Even it cannot measure the crafts contribution in reducing power losses, down time, maintenance cost and improving service quality and availability of the equipment. So new performance evaluation criteria that can measure has to develop. This must include at least the following components:

Attitude: stands for the degree of enthusiasm an employee exhibits when given responsibility and the manner in which employee interaction with other personnel in carrying out their accountability.

Quantity of Work: Refers to the amount of satisfactory work accomplished during a given period of time. It is important to assure the employees can complete a full day's work and produce adequate work.

Quality of Work: It is the measure of customer satisfaction. In rating this factor, attention should be given to the consequence of poor quality of work.

❖ ***Poor Incentive mechanism***

One of the best strategy to motivate employee is design and communicate a reliable motivation scheme that can faster the achievement of the organization's objective. In this regard there is no clear and communicated motivation scheme in all water supply. Even they do have flat salary for a years. The wage mechanism did not consider their performance. If they cannot set performance based salary scale as given below, the workers cannot motivated to produce more quality output.

Monthly Salary = *Basic Salary + Yearly Incentive Increments*
= Basic salary + aX + bY + cZ

Where a, b and c are denote constant, X denote yearly production increment in %, Y denote yearly maintenance cost reduction in % and Z denote yearly machine availability increment in %.

❖ **Inadequate hand tools**

In most pumping stations there is no enough quantity hand tools, measuring devices and spare stock to handle operation and maintenance activities properly. In addition in some of the work stations there is outdated and irrelevant devices in large quantity. This impose the effectiveness of preventative maintenance task. So the pump stations at least has to full fill and take proper use of the following devices:

Normal mechanic's tools.

- Set of screw driver both flat and Philips
- Set of open and closed wrench, Socket wrench, Adjustable wrench, Allen wrench
- Different size Pliers
- Rubber mallet
- Ball hammer
- Mechanic hand level
- Measuring tap

Normal electrician's tools.

- Watt meter
- Tester (electric tester)
- Multi meter or independent meters.
- Voltage detector
- Needle nose and side cutter plier
- Wire Strippers
- Infra-red thermometer
- LED Flashlight and/or Headlamp

Performance test tools.

- Water level gauge.
- Discharge pressure gauge.
- Water leakage detectors
- Non-contact water flow meter

❖ Poor documentation

Important records for operation and maintenance and decision making are not recorded and maintained systematically. Any pump station in Ethiopia context has to record and maintain at least the following records:

- Installation, operation and maintenance documents provided by manufacturer
- Machine installation records
- Production records
- Maintenance history records

But during the study it was observed that none of them have well organized documentation.

❖ Less exposure for further education

During the field study it has been observed the shortage of skilled man power in the area. In Ethiopia there is no enough man power who have advanced knowledge and skill in the area (electromechanical technology). Most of the pump stations described that there is no firm or individuals who can provide technical service in the area. So the ministry of water, regional water bureau, higher educations has to consider the need for well-trained Electro-Mechanical technicians/engineers. This include upgrading the standing operators in regular, summer and distance programs and educating new graduates.

❖ Police gap

In this regard there is well visualized gap in considering capacity development effort. Most of the attention is given to the development of the infrastructure. Less attention is given to the effectiveness of the system after endorsed. Even during the development process the need for hand tools, measuring devices and maintenance equipment's is not given proper attention similar to system development training and education. So these all has to be considered during project design and implementation.

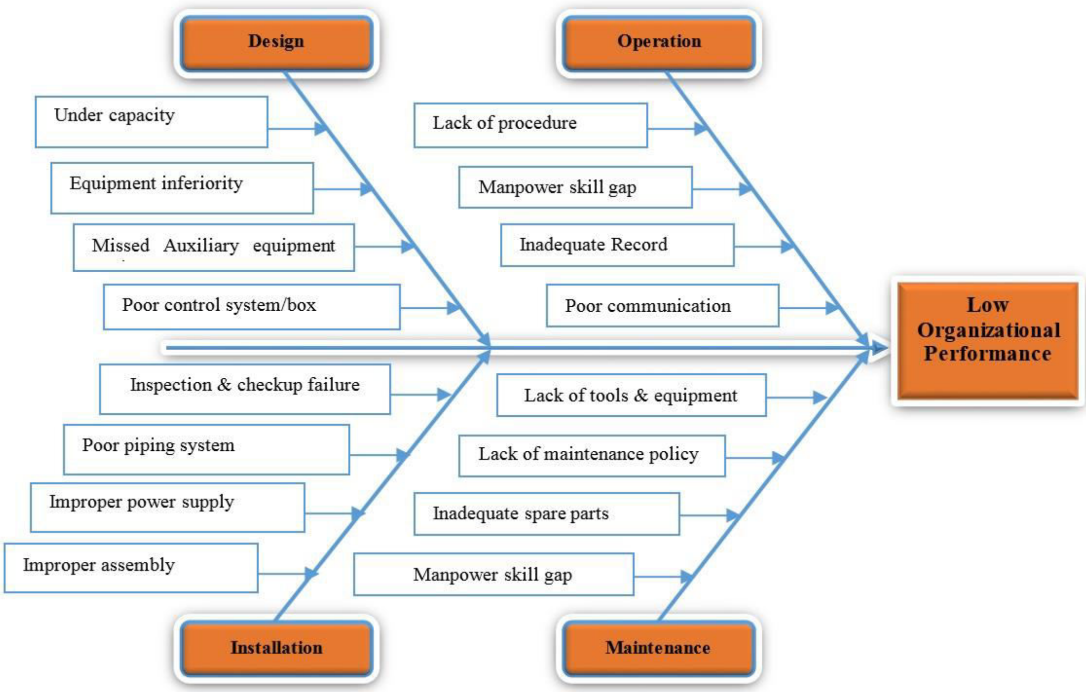

Fig. 6. Root cause analysis for pumping stations performance challenges.

5. Conclusion

From this study it is possible to conclude that most of the pump stations have well visualized installation, operation and maintenance challenges. In this study the following installation problems were observed and results showed that 10% improper casing position, 75% installing incorrect pressure relief valve at wrong position, 55% did not provided with proper protection mechanism to control frequency of start, 35% providing an improper power supply, 15% fail to selecting and installing a proper motor control system, 80% of them have no skilled man power and tools to perform electrical tests, 25% fail in selecting & installing auxiliary equipment, 45% lack grounding, 35% fall in selecting and placing check valve:

In addition, during operation more than half of the pumping stations have no qualified manpower, well-defined operation and maintenance procedure, schedule and plan, developed log book to record the hourly operation observations. In addition, there is great mismatch control board voltage regulator, overload regulator and timer setting within the recommended range, there is no proper attention to rectify and solve abnormal operation symptoms immediately, frequent starting and stopping were not managed and prevented properly.

Furthermore the study proved that maintenance practices are not up-to-date and efficient. From total pumping stations only 10% of them has maintenance procedure, schedule and plan, 25% spare stocks, 20% inspection check list, 50% inspection hand tools, 45% maintenance history log book and 30% maintenance man power. These enforces the stations to run less than the expected effectiveness level and incur high operation and maintenance cost.

References

Stel, H., Sirino, T., Ponce, F., Chiva, S., and Morales, R. (2015). Numerical investigation of the flow in a multistage electric submersible pump.*Journal of Petroleum Science and Engineering* 136, 41–54.

Abraham, O.(2018). Urban Water Supply in Hosanna Town of Hadiya Zone, SNNPR, Ethiopia.Civil and Environmental Research, 10(7), 2225-0514.

WHO - UNICEF (2010).Progress on Sanitation and Drinking - Water 2010 Update. Joint monitoring programme for water supply and sanitation. Geneva.

Fitsum, D. and Fikirte, D. (2014).Challenges of Potable Water Supply System in RuralEthiopia: The Case of GonjiKolelaWoreda,WestGojjam Zone, Ethiopia. Natural Resources and Conservation, 2(4), 59-69.

Ermias, M., Brook, A. and Kannan, N. (2016). Assessment of Urban Water Supply and Sanitation: The Case of Bedesa Town, DamotWoydeWoreda of Wolaita Zone, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 6(5), 2224-3208.

Mahesh, K. and Getu, T. (2018).Assessing the Challenges of WaterSupply and Consumption Systems ofTora Town, SNNPR, *ETHIOPIA.International Journal of Creative Research Thoughts (IJCRT),* 6(2), 2320-2882.

Thewodros, B. and Seyoum, L. (2016). Water Supply and Health: Drinking water and Sanitation Coverage in Ethiopia 1990 – 2015. *International Journal of Environment, Agriculture and Biotechnology (IJEAB)*, 1(1).

Desalegn, B. (2014). Assessing Causes and Challenges of Urban Water Supply: The Case of Mekelle City. *International Journal of Science and Research (IJSR),* 3(7), 2319-7064.

Ministry of water and energy (2013).Technical manual for urban water supply and sewerage utilities, EDRE, March 2013.

Chala, D. (2011). An Assessment of Urban Water Supply and Sanitation the Case of Ambo Town.Unpublished thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Abebe, T., Techane, B. and Girma, G. (2013), Rural Water Supply Management and Sustainability:The Case of Adama Area, Ethiopia, *Journal of Water Resource and Protection*, 5, 208-221.

Zhiqiang, L., Weiwei, C. and Xiaole, H. (2015).Integrated production and preventive maintenance scheduling for a single machine with failure uncertainty. Computers & Industrial Engineering, 80, 236–244.

Solomon, T. and Roy, B. (2011). Estimation of the public benefits of urban water supply improvements in Ethiopia: a choice experiment. Applied Economics, Taylor Francis (Routledge), 2011, 45 (09), 1099-1108.

Mustapha, N., Nabil, N. and Mohamed, B. (2016).Integrated preventive maintenance and production decisions for imperfect processes. Reliability Engineering and System Safety, 148, 21–31.

Lei, X., Sanling, S., Xiaohui, C. and David, W. (2016).Reliability Engineering and System Safety.Joint optimization of production scheduling and machine group preventive maintenance, 146, 68–78.

Jun, N., Xi, G. and Xiaoping, J. (2015).Preventive maintenance opportunities for large production systems. CIRP Annals – Manufacturing Technology 64, 447–450.

Mohamed, B. (2002).The economic production lot-sizing problem with imperfect production processes and imperfect maintenance. *International Journal of Production Economics;* 76:257–264.

Xiaojun, Z., Zhiqiang, L., Lifeng, X. (2012). Preventive maintenance optimization for a multi-component system under changing job shop schedule. *Reliability Engineering and System Safety*, 101, 14–20.

Bulent, D., Tugwell, P. and Greatbanks, R. (2000).Overall equipment effectiveness as a measure of operational improvements - A Practical Analysis. *Internal Journal of Operation & Production Management*, 20(12), 1488-1502.

Peter, M. and Liliane, P. (2008). Performance measurement using overall equipment effectiveness

(OEE): Literature review and practical application discussion. *International Journal of Production Research,* 2008, 46 (13), 3517-3535.

Rakesh, R., Jos, B. C., and Mathew, G. (2013).FMEA analysis for reducing breakdowns of a sub system in the life care product manufacturing industry.International *journal of engineering science and innovative technology*, 2(2), 218-225.

Peter, M. and Liliane, P. (2008). Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. *International Journal of Production Research,* 46 (13), 3517-3535.

This article can be cited: Bantelay, D. T. (2019) Investigating Water Supply System Electro-Mechanical Equipments Problems: A Case Study of Ethiopia. *Journal of Optimization in Industrial Engineering*. 12 (2), 45-54

http://www.qjie.ir/article_545832.html
DOI: 10.22094/JOIE.2018.568034.1563