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Water corrosion and scale formation problem and its solution in water supply schemes – A case study on Padampokhari and Mahendranagar scheme

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Abstract

The water with low total dissolved solid (TDS) and pH value is corrosive in nature. Moreover, the water with high TDS and low pH values is scale forming. A low TDS and pH value dissolves intake structures, GI pipes, concrete reservoir, household plumbing systems and cementing structures when it comes in contact with it. Furthermore, the corrosive water causes nuisance and health-related problems. Excess intake of lead, aluminum, copper, iron, chromium etc. in human body due to corrosive water causes serious damage to the different human organs such as brain, kidney, nervous system, blood cells, and even degrade an IQ level. High TDS and low pH value causes scale formation which blocks the whole water supply system. This paper presents a method for identification of corrosive and precipitative water and propose a solution to normalize it. The corrosive and scale forming water is detected easily by measuring a chief indicator parameter, TDS. The increasing value of TDS from intake to tap stand notifies that the water is corroding, and its decreasing values denotes the scale formation. Corrosive water is stabilized using calcium carbonate stones which is easily available in nature. On the other hand, scale forming water is controlled by the structural modifications of intake, collection tank, pipeline and reservoir etc. which we have constructed or going to construct. To verify the proposed methods, case study on Padampokhari and Mahendranager water supply schemes are studied and presented here in detail.

Keywords: Corrosive water; Corrosion; Scale formation; Blocked pipelines; Control of scale formation and corrosion

1. Introduction

Water is one of the main compounds that is vital for survival of all leaving creates. Water is the most common liquid on earth used for the various purposes like drinking, washing, agriculture, and bathing [1]. Safe drinking water is essential for human survival [2]. Water supply for drinking water is either ground water or surface water. The water from each source contains sediments or dissolved solids. If the high value of dissolved, solids (Higher than National Drinking Water Quality Standard 2005) present in water, they are harmful to human body and environment, and it requires treatment.

Water quality is combination of the chemical, physical, and biological characteristics of water, generally in terms of suitability for a particular or designated use [3]. Several parameters are used for the analysis and measurement of quality of water. However, physical and chemical parameters are considered as an important factor for the structural damages such as corrosion and blockage of water supply schemes.

Many water quality parameters affect the durability of water supply schemes [4]. Among them, this paper considers total dissolved solid (TDS), pH, and CO2, since these are the major water quality parameters that affects the water supply schemes. TDS represents the total concentration of dissolved substances in water. TDS is made up of inorganic salts, as well as a small amount of organic matter. Common inorganic salts that is found in water such as calcium, magnesium, potassium and sodium are all cations. Carbonates, nitrates, bicarbonates, chlorides and sulphates are anions. Cations are positively charged ions and anions are negatively charged ions [5]. These minerals can originate from a number of sources: natural and a result of human activities. In general spring water contains high levels of total dissolved solids (TDS), because water flows through different regions with rocks having high salt content. The spring water generated from rocky areas of calcium carbonate zone tends to have high levels of dissolved solids.

The pH value of a water source is a measure of its acidity [6]. A change in the pH of water have a number of bad consequences. As a result, plants and animals are harmed, or even killed, as a result of acidification.

This paper discusses about the physical and chemical water quality parameter and their affects in drinking water supply schemes in Nepal. A case study on two schemes: Padampokhari and Mahendranagar has been presented in detail for the problem identification. Furthermore, the solution has been suggested for the problems observed.

2. Material and methods

2.1. Major chemical impurities in water

Due to the decay of organic matters in earth crust, there is a formation of carbon dioxide. Carbon dioxide is heavier than air and penetrates inside ground. When rain fall percolates inside the ground, it converts CO_2 into carbonic acid and start dissolving matters and increases the TDS of water as shown in Eq. 1 and 2.

$$CO_2 + H_2O \rightarrow H_2CO_3 \text{ (carbonic acid)} \quad (1)$$

$$H_2CO_3 + CaCO_3 \rightarrow Ca\left(HCO_3\right)_2 \quad (2)$$

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Table 1: Total hardness distribution in Dang, Dailekh, Rukum and Jajarkot districts (total 520 sample).

No. of sample	% Value	Results	
0 - 25	67	12.88	~13%
26 -50	56	11	
51 -75	24	5	
76 -100	59	11	
101 -125	58	11	
126 -150	45	9	
151 -175	38	7	
175 -200	38	7	
201-225	20	4	
226-250	40	8	
251-275	30	6	
276-300	0	0	
301-325	15	3	
326-350	15	3	14%
351-375	2	0	
376-400	6	1	
401-425	7	1	
Subtotal	520	100	

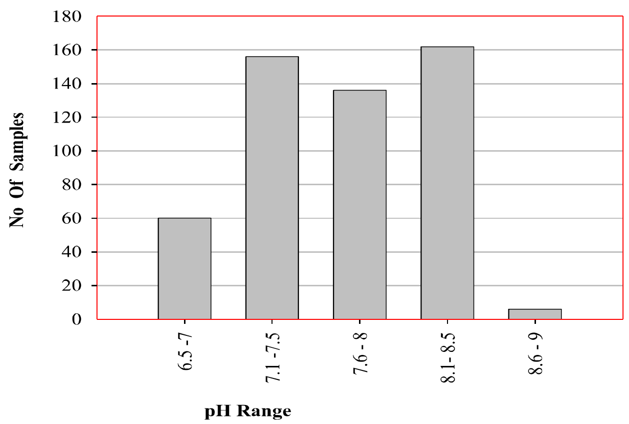

Figure 1: pH distribution.

Eq. 2 applies only for calcium mineral. Moreover, it delivers similar results for several other chemicals such as magnesium, manganese, silicon, iron, etc. Hence, the combination of these chemicals dissolved in water represents the total dissolved solid (TDS) [7]. If the TDS in water is less than 50 mg/l and pH is less than 7, water is highly corrosive. If calcium and magnesium content is high and hardness is greater than 300 mg/l as $CaCO_3$, and source pH is low (<7), water is hard and shows scale forming nature.

$$CaCO_3(\text{scale in pipeline}) + H_2O + CO_2 \Longleftrightarrow Ca\left(HCO_3\right)_2(\text{liq.}) \quad (3)$$

This is reversible reaction. (Corrosive nature if TDS and pH of water is too low and precipitative nature if too high TDS and low pH of water).

2.2. Water quality status in Nepal

Different water supply schemes have been observed and experimented in Nepal. Surveys related on water quality parameters, especially pH, TDS and Hardness [9,10] of five hundred and twenty samples of four districts Dang, Dailekh, Rukum and Jajarkot were tested and results are presented as in Table 1.

Fig. 1 shows the pH distribution of 520 samples and demonstrates that most of the water samples have pH values ranging from

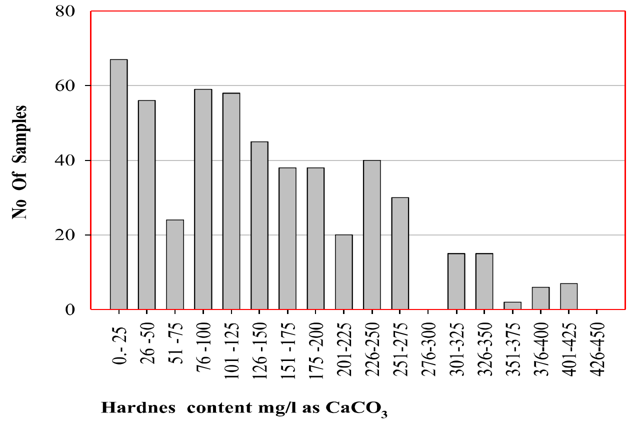

Figure 2: Hardness distribution.

6.5 and 8.5. However, 1% of the sample exceeds the pH value beyond the national drinking water quality standard 2005 of Nepal (NDWQS 2005) [8]. Fig. 2 depicts the hardness distribution of 520 samples. As per NDWQS 2005, total hardness value should be within 500 mg/lit as $CaCO_3$ [7,8]. All of the samples are within the "NDWQS -2005" of Nepal range. However, around 14% of sample exceeds hardness 250 mg/lit as CaCO3, having high chances of lime encrustation problem as shown in Table 1. Similarly, approx. 13% of sample hardness <25 mg/lit as $CaCO_3$, having high chances of corrosion problems.

2.3. Corrosion and scale formation problems

It is observed that approx. 13% of drinking water sources in Nepal have corrosion problem with low TDS and pH (hardness <25 mg/lit as $CaCO_3$ and pH <7 i.e. low TDS and pH). It corrodes intakes, pipelines and other cementing structures within a short period of time. Consequently, it generates a leakage in the intake within a year and fails the whole system. Similarly, 14 % sample have high hardness and low pH (i.e. high TDS and low pH). Fig. 3 shows the different structures corroded due to low TDS and pH. Fig. 3 (a) and (b) demonstrates the intake structures are corroded. Similarly, Fig. 3 (c), (d) and Fig. 3 (e), (f) shows the reservoir and collection tank corrosion respectively. Sump well corrosion is displayed in Fig. 3 (g) and (h).

The parameters such as hardness, alkalinity, pH, and TDS in the water are initially in the equilibrium state. When the Carbon dioxide (CO_2) escapes from the water, the germination of solid particle is initiated and settled down in the pipe resulting scale formation.

Fig. 4 shows the scale formation problem inside the pipes. In STWSSP- Mahendranagar, the scale formation was rapid and blocked the whole system within a couple of year due to the scale forming problems.

3. Results and discussion

Firstly, water is tested in the laboratory to determine the quality of water (corrosive, neutral or scale forming). If the water is corrosive, it is necessary to stabilize the corrosive nature by passing the water through calcium carbonate stone. If the water is scale forming, an equilibrium state is maintained by modification process.

3.1. Corrosive water: Low TDS and pH

3.1.1. Lab Analysis

Initially, we conducted a laboratory analysis for stabilization of water. A stabilization value was determined from the water collected in DWSS-Padampokhari by using natural calcium carbonate stone from the surrounding village. Fig. 5 depicts the graph of TDS

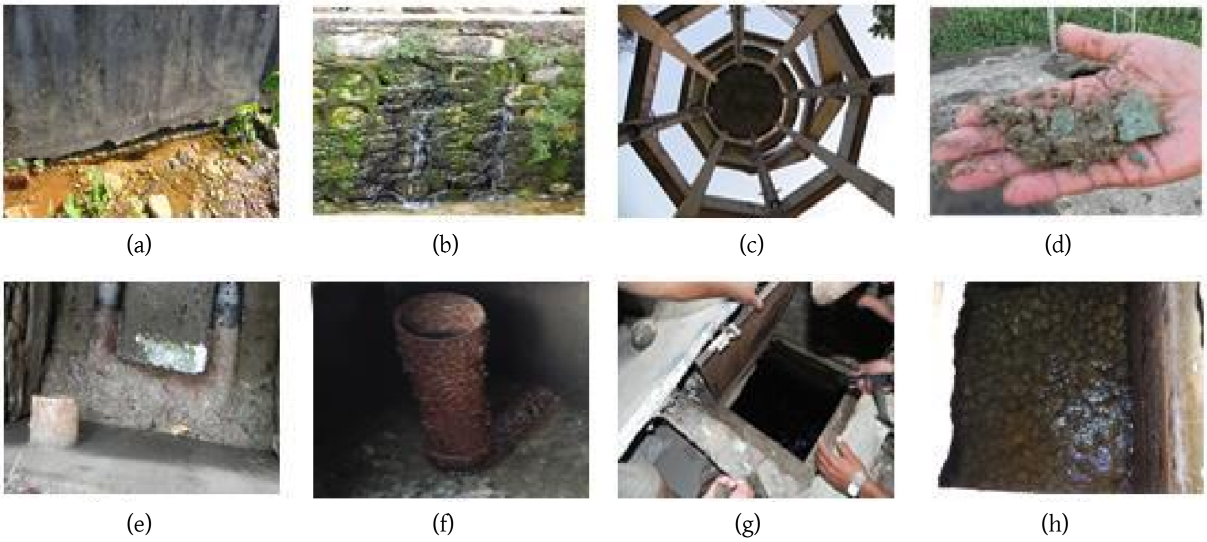

Figure 3: Corrosion problems due to low TDS and pH. (a, b) Intake corrosion, (c, d) Reservoir corrosion, (e, f) Collection tank corrosion, (g, h) Sump well corrosion.

Figure 4: Scale formation problems due to high TDS and low pH. (a, b) Scale formation in outside and inside the pipe. (c) Scale formation in riverbed. (d, e) and (f) Scale formation in STWSSP –Mahendranagar.

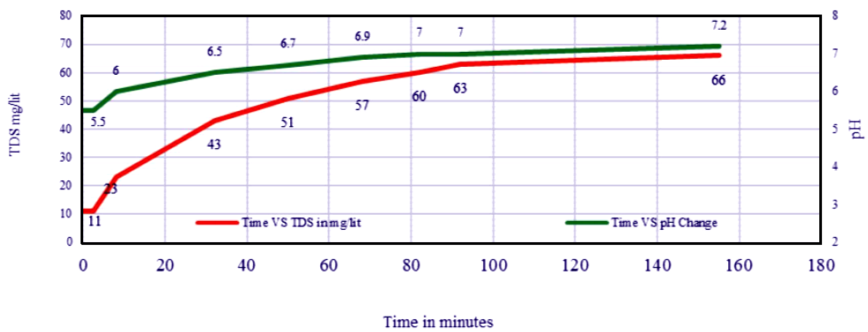

Figure 5: Time Vs TDS and pH change reaction with natural locally available calcium carbonate stones from Makanwanpur district, Nepal with Padampokhari DWS source water.

and pH change over the time, when the water is passed through natural calcium carbonate. From this experiment, it is observed that the water got stabilized after 92 minutes and TDS reached 63 mg/lit and neutral pH 7. Previously, the TDS and pH value of corrosive water was recorded as 11 mg/lit and 5.5 respectively. After stabilization, the TDS and pH value were recorded as 63 mg/lit and 7.

A number of experiments with calcium carbonate stones of different types and sizes of stones (10 mm to 20 mm) was done. The reaction time was governed by the types and size of stones aggregates. Finally, easily available good quality and sizes of calcium carbonate stone was selected and tested for final design.

3.1.2. Practical implementation for stabilization of water

On this basis of laboratory analysis, detention time was determined and based on the detention time, the stabilization pond was designed. Also, the size of utilized natural calcium carbonate should be equal as per the laboratory analysis. The detention time is continuously measured batch wise. Note that the output water quality parameters should be tested every time to confirm that the water does not contain hazardous elements. Also, we modified the conventional intake in such as a way that source water does not directly get into contact with cementing structures. Moreover, the intake was constructed inside the ground. The plastic lining was done between cementing structure and water. Also, the cavity RCC dam was constructed and filled with clay materials. TDS and pH value were continuously monitored during the construction. Three intakes were constructed on the new design and functioning well till now.

3.2. Precipitative water: High TDS and low pH

3.2.1. Lab Analysis

The laboratory analysis to maintain the equilibrium state of the water is very important. Moreover, the testing must be conducted precisely with the standard methods else the whole design might fail. We conducted our experiment in accredited laboratory in Kathmandu applying standard methods as listed below:

1. CO_2 was analyzed with NaOH solutions by titration method.
2. pH is measured with electronic and colorimetric pH meter.
3. Alkalinity was determined by titration with sulphuric acid by using standard methods.
4. TDS was measured with Electronic TDS meter.
5. Hardness and calcium were determined by titration with EDTA solution and EBT indicator.

The water from different schemes are tested to determine the trend of TDS which is shown in Fig. 6. From this trend of graph, we can determine rate of scale formation in the respective water supply system. To maintain the equilibrium state, a structural modification of intake, collection tank, pipeline and reservoir is one sustainable option for verification which was applied and tested successfully in Mahendranagar STWSSP.

3.2.2. Practical implementation for maintaining equilibrium state of water

Traditional method for a scale controlling scale formation problem are using (1) Polyphosphate treatment, (2) Acid treatment, (3) Magnetic treatment, (4) Carbon dioxide addition. These methods are not sustainable for rural water supply schemes. Hence, we develop a sustainable and low cost solution for this problem and applied in Mahendranagar water supply scheme. We modified different structures such as manhole cover, reservoir, inlet, outlet and washout as shown in Fig. 7. Water quality parameters of different sections of the scheme were tested after one year of completion.

The obtained outcomes are shown in Fig. 8. It is observed that TDS parameter are seen in the increasing trend when measured with the water that flows from overhead tank to the tap stands. This is because, we maintained corrosive nature (by preserving carbon dioxide) in the water from overhead tank to the tap stands. Initially, there is a decreasing trend of TDS from pump and overhead tank (reservoir) to the tap stands as shown in Fig. 6(c) which results in scale formation. However, after the structural modifications, the TDS is in increasing trends which cleans the deposited scale inside the pipelines. This is due to the preservation of the existing carbon dioxide. Similarly, electrical conductivity (EC), alkalinity, hardness and calcium content were high when compared with pump water and overhead tank (reservoir) water which verifies that there is no scale formation in the pipeline.

Aeration, temperature and diffusion plays a vital role for scale formation. So, these effects are minimized by structural modification.

4. Conclusion

In this paper, we proposed a sustainable solution to stabilize a corrosive water by natural calcium carbonate stone and maintaining the equilibrium state of scale forming water by structural modifications of intake, collection tank, pipeline and reservoir. Experimental results on two different schemes show that the proposed solution is sustainable and outperforms the traditional methods. Thus, this method could be a good solution to resolve problems in the schemes with corrosive and precipitative water in rural water supply schemes. For determination of corrosion or precipitation a cheap and simple electronic TDS meter can be used. If TDS is increasing order from intake to tap stands it denotes there is corrosion in the scheme and if it is decreasing order, there is scale formation in the scheme. If no changes, the scheme is running smoothly.

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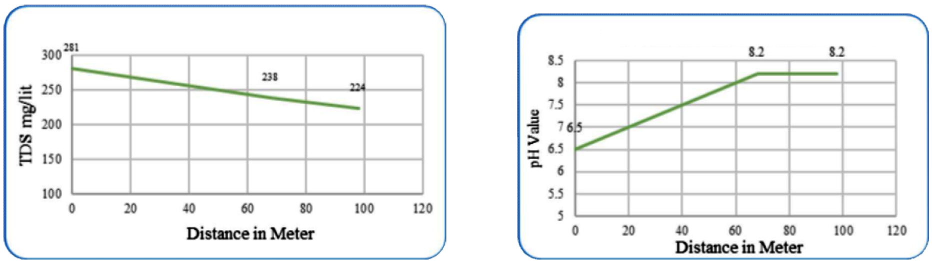
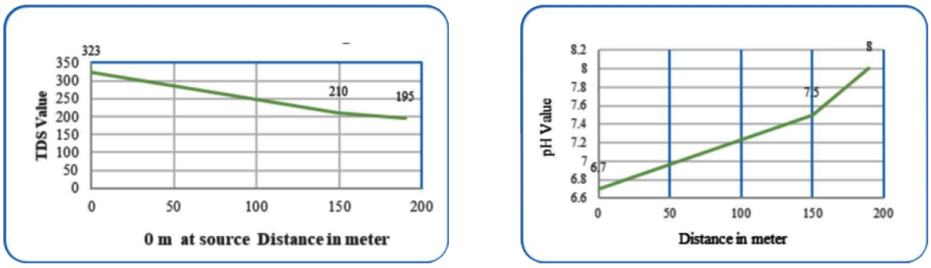
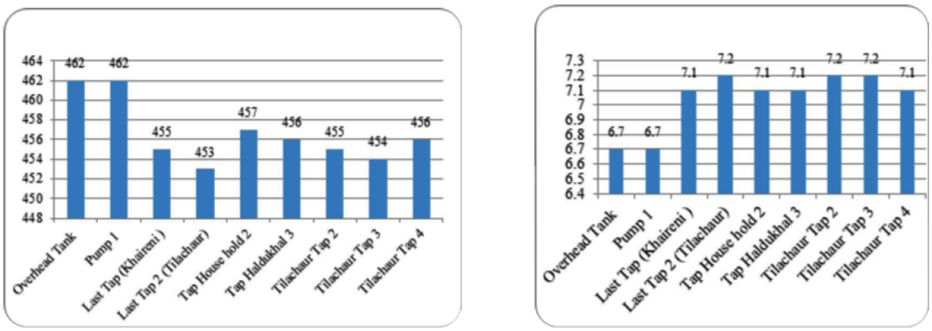


(a) Sat dhara- DWSS Hetauda



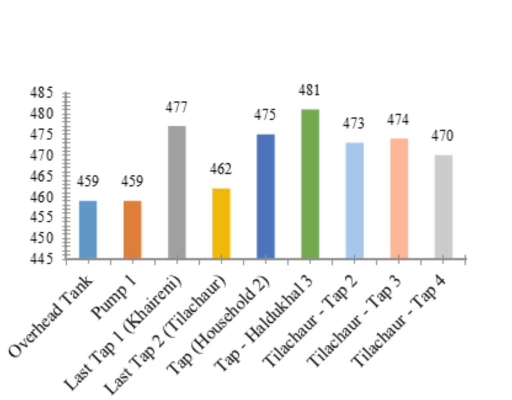
(b) Gumba- DWSS Hetauda



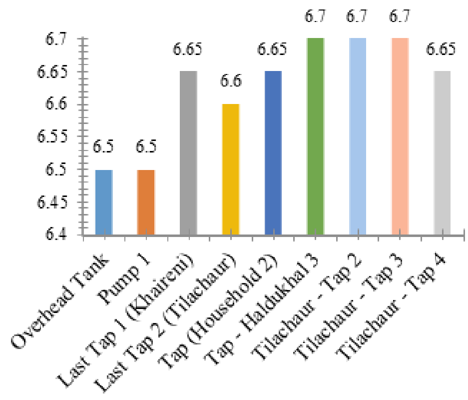
(c) Mahendranagar- STWSSP, Kanchanpur

Figure 6: Changing trend in water quality parameters in different water supply schemes.

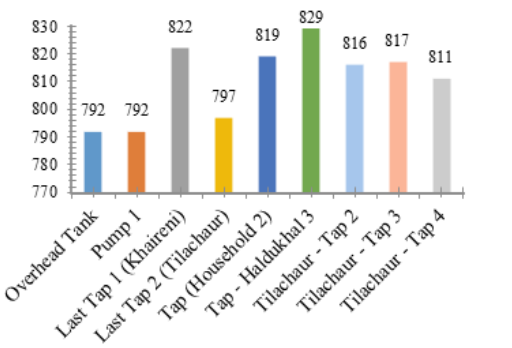
Figure 7: Modified models of Mahendranagar STWSSP.



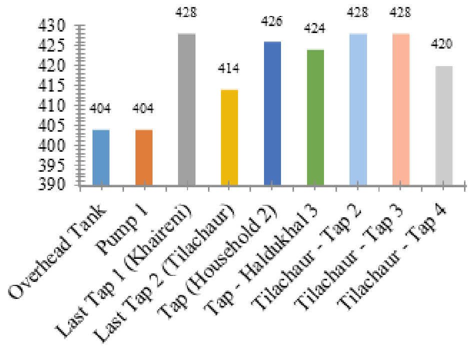
(a) TDS (mg/l) variation in different locations



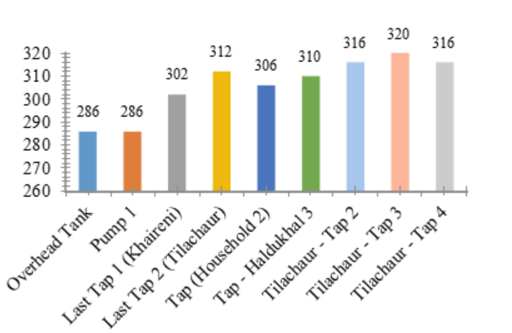
(b) pH variation in different locations



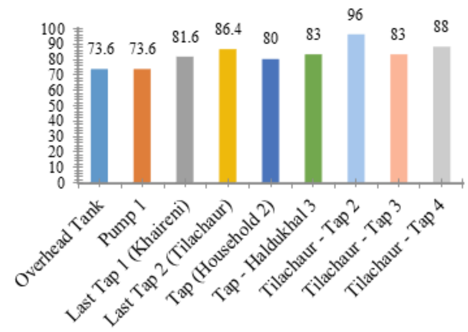
(c) Electrical conductivity (μS/cm)



(d) Total alkalinity (mg/l as $CaCO_3$)



(e) Total hardness (mg/l as $CaCO_3$)



(f) Calcium (mg/l)

Figure 8: Water quality test reports after modification of intake, collection tank, pipeline and reservoir in Mahendranagar STWSSP.

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