



Water Corrosion Problems and Sustainability of Water Supply Schemes

Hari Prasad Panday¹, Prof. Dr S. N. Khanal², Dr N. R. Khatiwada³, Dr. B. Adhikari⁴

^{1,2,3,4}Department of Environmental science and Engineering Kathmandu University Kathmandu, Nepal

ABSTRACT: Water supply schemes should be technically and socially sustainable for smooth running, smooth operation and maintenances. Failure in either one of these leads to the whole system failure. Once the system is technically feasible, we can manage its social aspects. In this paper, we deal with technical sustainability of corrosive water, its impacts and the remedial measures. Corrosive water can severely damage intakes, metal pipes, cemented chambers, concrete reservoir and household plumbing systems. Hence, it is necessary to identify the corrosiveness of the water and should be neutralized. There are several solutions to this problem, however, they are not sustainable and economical for semi urban and rural communities. In this paper, we propose a sustainable, natural and economical solution to determine the corrosiveness of water and to effective technology to neutralize it. The proposed solution uses naturally available resources, hence makes it sustainable and affordable. Once the proposed method is deployed, it doesn't require additional resources such as continuous monitoring, skilled manpower and electrical power cost etc. In this method, initially, the corrosiveness of the water is identified using parameters such as: total dissolved solid (TDS), pH, temperature, calcium and alkalinity. The corrosive water is then analyzed in laboratory. With carbon dioxide kinetic study, we verify the design of stabilization tank volume calculation. The research outcome is applied in the field to upgrade intake, pipe and fitting designs. The experiment in this research is conducted with the data obtained from several water supply schemes including Padampokhari water supply scheme in Nepal and tested in the same water supply scheme.

KEYWORDS: Aggressive water, corrosion of cementing structures and metal pipes, sustainability of water supply schemes, water stabilization, corrosion control natural technology.

I. INTRODUCTION

Sustainable water supply is the process of finding reliable approach to supply water without any failure in terms of social and technical aspect. The technical sustainability of water supply scheme is heavily impacted due to corrosion. Corrosion is a complex problem that occurs due to the reaction between the water and material in which water is stored and transported [1]. When the corrosive water is stored in heavy metal's utensils, it may dissolve the heavy metals within hours & has a potential presence of those metal such as aluminum, copper, lead in the water. This can cause a potential health related problem. Corrosive water can dissolve all cement parts and leads to the several structure leakages. These leakages are hard to identify since they are inside the ground where different structures are made. As a result, there will be a huge water loss and cannot be easily detected. Corrosive water corrodes the intakes, collection tanks, brake pressure tanks, reservoir tanks, the GI pipes and fittings too. In some extreme cases it can damage the whole water supply structures.

On the other hand, corrosive waters can have an inverse effect in human health. Excess intake of heavy metals which is due to corrosive water can cause serious damage in different organs such as brain, kidneys, nervous system, blood cells and even degrade an IQ level. Heavy metals especially aluminum, copper and lead are toxic in nature. Copper contamination can cause gastrointestinal problems in short term and damage the liver and kidneys over the time. Lead contamination can slow down the physical and mental development in children. In adults, it can lead to high blood pressure and kidney problems [2][3].

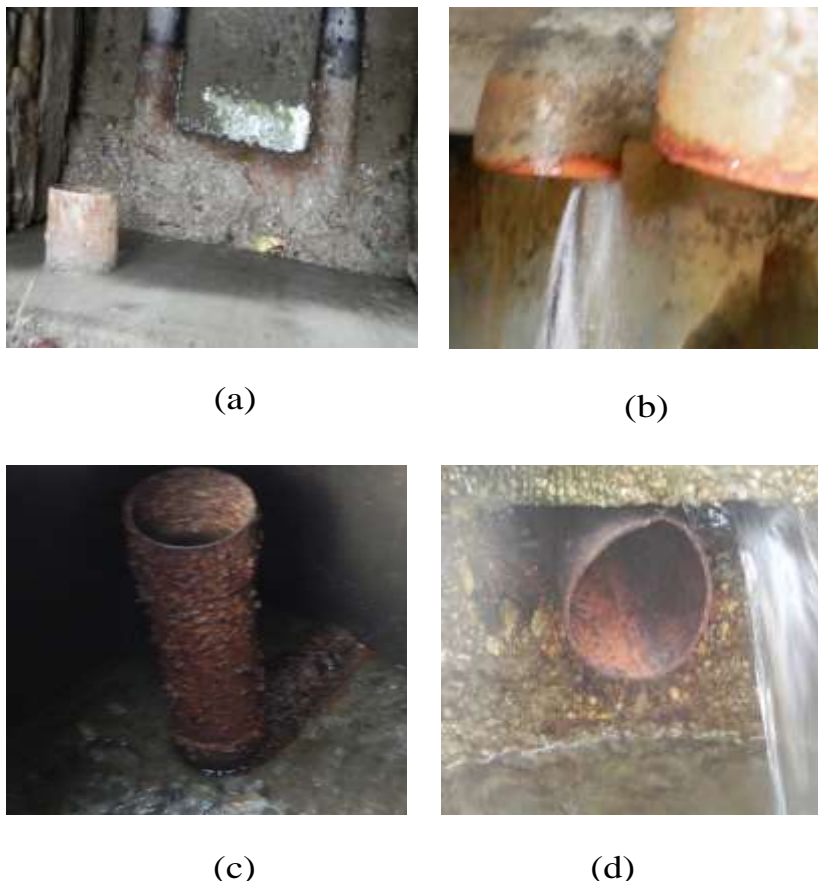
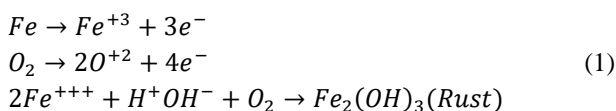


Figure 1: Corrosion of metal pipes: (a) Corrosion of GI pipes at Intakes (b) Corrosion of GI pipes at Reservoir tank (c) Corrosion of GI pipes at collection tanks (d) Corrosion of GI pipe in sump well

In drinking water supply schemes, corrosion damage the system in two ways: rusting of GI and other metal fittings as shown in Figure 1 and dissolving the cementing materials and damage the structures as shown in Figure 2. Corrosion is natural phenomenon that occurs when metal substances react with oxygen & hydrogen molecules and form metal oxides & hydroxides. The rate of corrosion depends on the factors such as oxygen concentration, water’s pH (pH due to carbon dioxide), temperature, and electrical conductivity[3]. In addition, metals even get corroded when the water is extremely low in dissolved salts and in the presence of certain water-borne ions. If the pH of water is low, it facilitates the corrosion rate and quantity too. The chemistry behind the rusting are as follows:



Oxygen accepts these electrons and changes to oxide ions O_2^{-} and form metal oxides & hydroxides. These oxides are called rust. The general form of rust are $Fe_2(OH)_3$, $FeO(OH)$, $Fe_2O_3 \cdot H_2O$. At low TDS mixing process of oxygen occurs rapidly, however, the escape process of carbon dioxide becomes slow. Hence, the corrosion occurs faster at low TDS & low pH than on high TDS and low pH water.



Figure 2: Rusting of cement structures, Corrosion of masonry wall of sump well (a) to (d)

The corrosive nature of water in water supply schemes , is detected easily by measuring a chief indicator parameter- total dissolved solid (TDS) and pH. By detecting TDS & pH of water in different locations of water supply schemes, the sustainability of the water supply scheme can be determined by their increase or decrease values. This phenomenon can be studied furthermore with Langelier saturation index test [7][8] which provides a further information on degree of corrosiveness.

Total dissolved solid (TDS) is made up of inorganic salts, as well as a small amount of organic matters. These minerals can originate from a number of sources: naturally or a result of human activities. In general, spring water contains high levels of total dissolved solids (TDS), because the water has flowed through the earth region where there may be rocks and other minerals. The spring water generated from rocky areas of calcium carbonate zone tends to have high levels of dissolved solids of calcium and magnesium salts. Similarly, pH is the measure of acidity or alkalinity of the water [4]. A change in the pH of water have a number of bad consequences. Excessive low and high pH may result harmful plants and animals or human or even killed them.

There are several existing techniques for the treatment of corrosiveness of water. Corrosion can be reduced with Acid-neutralizing filters. These filters are usually installed after the pressure tank. As water flows through the filter, pH increases which decreases corrosively. This process makes the water harder. It also may decrease water pressure. The neutralizing material must be replenished as it is dissolved. The chips can last from weeks to months, depending on the type of material, how corrosive the water is, and how much water you use. The filters usually must be backwashed to remove trapped particles and oxidized metals [5]. Another way to neutralize acidic water is to add a solution of sodium hydroxide or sodium carbonate (soda ash). This is usually done by installing a chemical feed pump before the pressure tank. This treatment system is simple, and inexpensive; it does not increase water hardness or reduce the water pressure. The injection rate should be adjusted to produce water with a pH of 7.5 to 8.0. Injection units require significant maintenance that includes filling solution tanks and maintaining the feed pump. Soda ash is preferable to sodium hydroxide, which is extremely caustic and requires special safety precautions; it should be handled only by trained individuals. The existing techniques proposed in the literature are either not sustainable, expensive or not suitable for the specific area.



Alternatively, corrosiveness of the water can be treated by the addition of calcium carbonate or other alkaline materials such as magnesium carbonate on the corrosive water [6] These alkaline materials are added either manually or mechanically in the dust form. It's a tedious process since it requires continuous monitoring by a skilled manpower and consumes high electrical power. Also, the application of this technique is complex in the rural area due to the lack of skilled manpower and the need of electrical power. To overcome these problems, we proposed a solution to neutralize the corrosive water using the existing natural alkaline materials. The proposed method uses aggregate of calcium and magnesium carbonate stones which is easily available in the Nepal. Once the proposed method is deployed, it doesn't requires continuous monitoring, skilled manpower and high electrical power.

During corrosion control, first, we aim to identify the corrosive nature of water by testing parameters such as total dissolved solid (TDS), pH, temperature, calcium and alkalinity using Langelier saturation index [7][8]. The Langelier saturation index is a tool that can provide tentative value to identify weather the water is corrosive or not. However, it still needs further testing. Hence, the sample water is further tested with the use of naturally available calcium and magnesium carbonate aggregates with increase or decrease TDS with time. A stable detention time is recorded. This detention time is the time required for the neutralization. Furthermore, the TDS and pH value are recorded to identify the amount of calcium & magnesium carbonate required for the design period. Once the water is neutralized, the water should be again tested according WHO guidelines or Nepal standard "NDWQS-2062" to ensure that that water is fit to drink. Finally, based on the conducted experiment, the water supply system is modified.

Rest of the paper is organized as follows. A detailed methods and methodologies are reported in Section II. In Section III, the experimental results are analysed and discussed. Finally, a concluding remark drawn in this study is presented in Section IV.

II. MATERIALS AND METHODOLOGY

The process flow diagram of corrosion control of corrosive water is demonstrated in the Figure 3 which is carried out in three steps 1) Problem identification and 2) Problem analysis and 3) Field application.

During problem identification, water quality test is performed by measuring different parameters of water such as temperature, calcium, pH, alkalinity and TDS/EC. Thereafter, Langelier saturation index is calculated using "Langelier saturation index calculator" [8]. This provides approximation of water being highly corrosive, normal corrosive, not corrosive. Based on the results shown from Langelier saturation index calculator, the water is further tested practically in the laboratory to confirm the corrosiveness of water and identify the detention period as well as stabilized TDS value. Detention period is the important factor while designing stabilization tank. Moreover, TDS value is required to determine daily reduction of aggregates. Moreover, further verification for laboratory study of detention period is done with the kinetic study of carbon species too. Finally, the conducted experiment is applied in the field to upgrade intake, stabilization tank and pipelines and fittings.

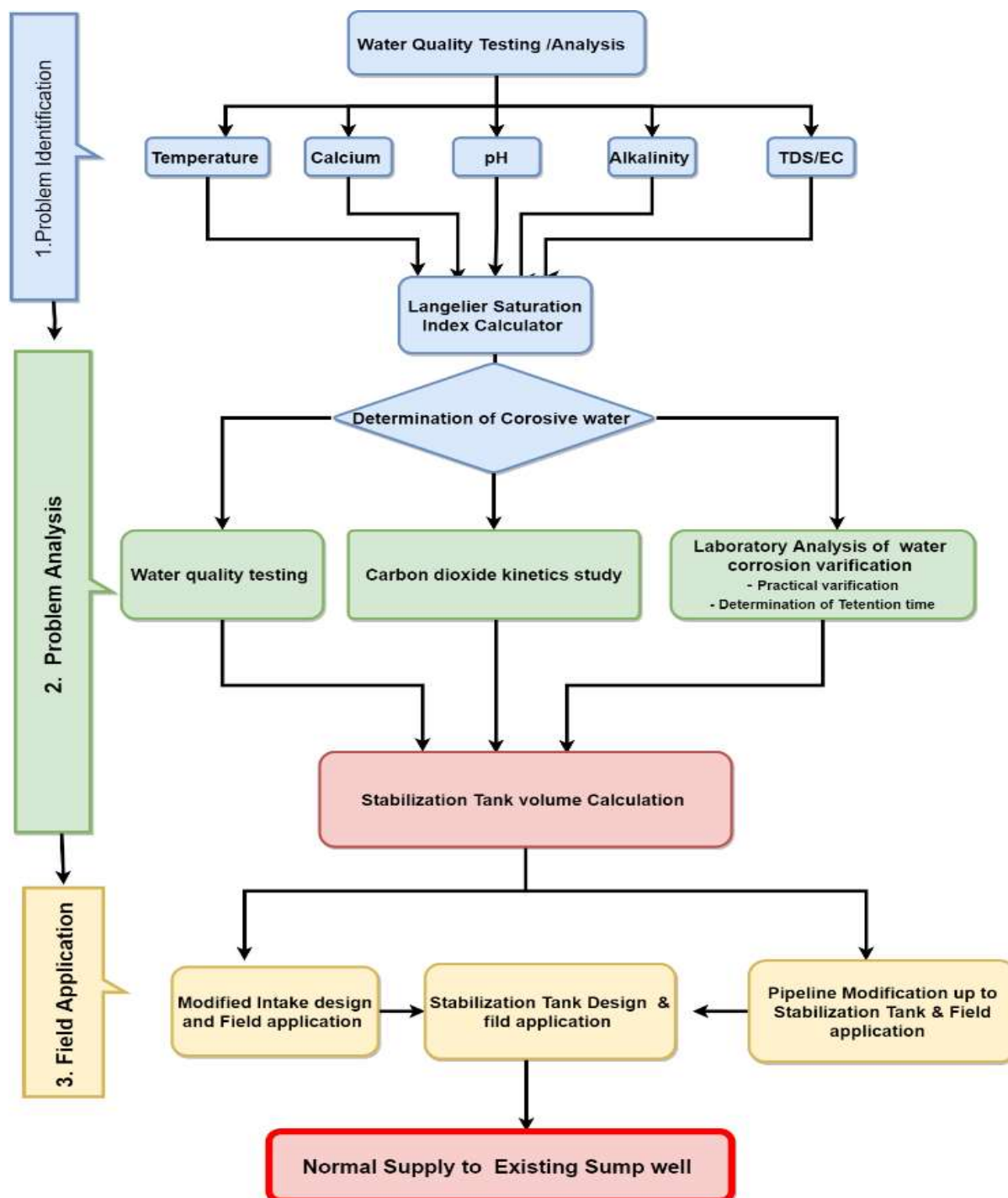


Figure 3: Process Flow Diagram

A. Problem identification

1) *Water Quality Testing and analysis*

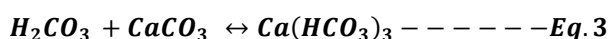
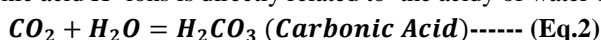
From several water quality testing in problematic and non-problematic schemes, it is found that water temperature, calcium, pH, alkalinity, carbon dioxide and total dissolved solid (TDS) or electrical conductivity (EC) play main role of water corrosion or scale forming. These parameters are interlinked each other [10].

2) *Acidity, alkalinity pH and relationship*

The pH scale ranges from 0 to 14; a pH of 7.0 represents the point where acidic and alkaline materials are in balance. Water with a pH value below 7.0 is considered acidic, while water above 7.0 is alkaline. Total alkalinity is the total bases in water that can neutralize acid. These include bicarbonates, carbonates, hydroxides, and some phosphates and silicates. Alkalinity is reported in milligrams per liter of calcium carbonate[10].

3) Carbon dioxide, carbonic acid and pH and its relation

Due to the decay of organic matters in earth crust, there is formation of carbon dioxide (CO₂). Carbon dioxide is heavier than air, when it forms inside the earth crust, it penetrates inside ground. When it comes in contact with water it dissolved in ground water. Mixing with water, it forms carbonic acid (H₂CO₃) or 2H⁺ + CO₃⁻ as shown in Eq 2. This 2H⁺ ion is directly related pH of water. Dissolving power of carbon dioxide in water is 26 times greater than oxygen. In water it becomes carbonic acid and start dissolving matters in contact with it. This carbonic acid H⁺ ions is directly related to the acidity of water or water pH.



Same for Mn Mg etc.

This carbon dioxide remains in different form in water and shows different characters. Total carbon dioxide is divided in two forms free carbon dioxide and bond carbon dioxide as shown in Figure 4. Free carbon dioxide is further divided into equilibrating carbon dioxide (which remain in water and maintain equilibrium state in water) and aggressive carbon dioxide (which is quite aggressive). On the other hand, bond carbon dioxide is in the form of carbonate and bicarbonate. Bicarbonate form is unstable, and it may change into carbonate form whenever equilibrium breaks down.

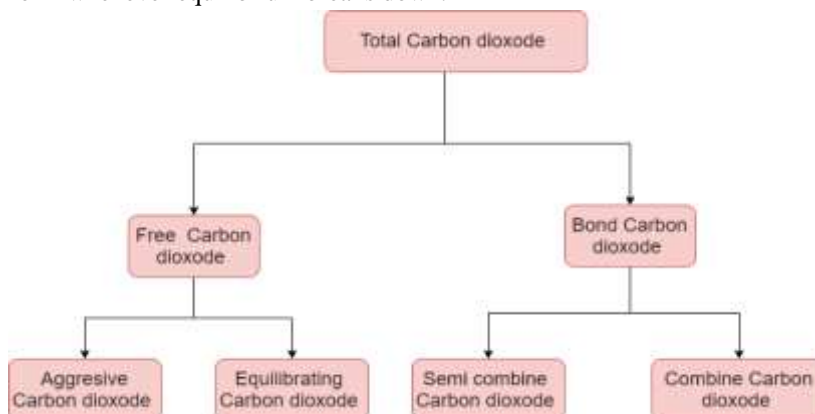


Figure 4: Different form of Carbon dioxide

4) Carbon dioxide with calcium and magnesium metals

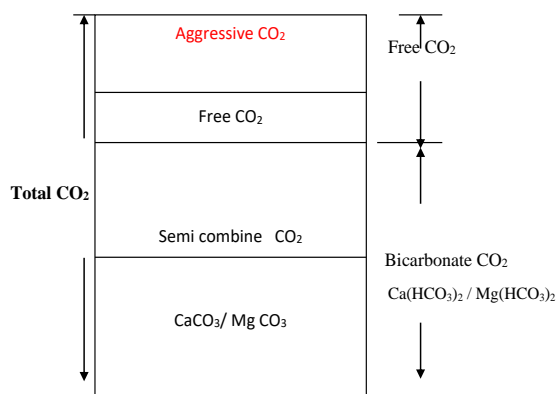


Figure 5: Free and bond carbon dioxide



Another way as shown in Figure 5 it can be explained that water has different form of carbon dioxide. It may be in the form of free and bond with Ca and Mg metals and combination of all of these forms of carbon dioxide is known as total carbon dioxide as shown in Figure 5.

Also, natural water always contains greater or lesser quantity of dissolved ions derived from the partial dissolution of rocks encountered during runoff or during percolation of rainwater through the soils. Among the most frequently found are anions (Cl⁻, SO₄²⁻, HCO₃⁻, CO₃²⁻) and cations (Na⁺, K⁺, Ca²⁺, Mg²⁺, Fe²⁺, Mn²⁺).

5) *Water temperature*

Corrosion is more likely and more rapid at higher water temperatures. The rate of corrosion triples or quadruples as water temperature rises from 60°F to 140°F. Above 140°F, the rate of corrosion doubles for every 20°F increase.

B. Problem analysis

First of all, we should test all the water quality parameters such as TDS, pH, hardness etc. as per the WHO or "National Drinking Water Quality standard 2062 – (NDWQS-2062)". The obtained values are compared with the standard values. If the obtained values exceed standard limit, the water needs to be treated.

The water is further tested using the Langelier saturation index calculator to observe the corrosiveness of water. This calculator basically provides the approximation whether water is corrosive or precipitative. Hence, the verification is required which is done via laboratory experiments.

1) *Langelier Saturation index*

There are many methods for determination of corrosiveness of water. Among them Langelier saturation index calculator is one of them. For this calculator, we should measure the following water quality parameters: pH, TDS\EC, calcium content, bicarbonate alkalinity and temperature of water. Once the value of these parameters is obtained from the sample water, these values are used in the Langelier saturation index calculator as shown in the Figure 6. Table 1 and Table 2 shows the Langelier saturation Index (LSI), LSI by Carrier values and the indication. [8]

The screenshot shows the Langelier Saturation Index Calculator interface. It includes a navigation bar at the top with links for Applications, Processes, Systems, Products, Industries, Services, More, and Contact us. The main heading is "Langelier Saturation Index Calculator". Below the heading, there is a brief description: "This calculator helps you determine the scaling potential of the water by using the Langelier Saturation Index." and a note: "Give the values of your water analysis. All the fields with * are required." The interface is divided into two main sections: "Table 1: Input table" and "Table 2: Additional data".

Table 1: Input table

pH *	<input type="text"/>	
Conductivity / TDS *	<input type="text"/>	mg/L
[Ca ²⁺] *	<input type="text"/>	mg/L
[HCO ₃ ⁻] *	<input type="text"/>	mg/L
Water temperature *	<input type="text"/>	degree C

Buttons: Calculate the Langelier Saturation Index, Erase input values

Table 2: Additional data

If you do not have a water analysis you can use the values in table 2. Click on a button at the bottom of table 2.

pH =	7.7	8	8.6	
TDS =	20	34483	273	mg/l
[Ca ²⁺] =	5	400	49	mg/l
[HCO ₃ ⁻] =	10	140	121	mg/l
T =	20	20	20	degree C

Buttons: Example, Seawater, Tap water

Table 3: Results Langelier Saturation Index

Figure 6: Sample of Langelier saturation Index calculator



Table 1

LSI	Indication
LSI<0	Water is under saturated with respect to calcium carbonate. Under saturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.
LSI=0	Water is considered to be neutral. Neither scale-forming nor scale removing.
LSI>0	Water is supersaturated with respect to calcium carbonate (CaCO ₃) and scale forming may occur.

Table 2

LSI (Carrier)	Indication
-2, 0<-0, 5	Serious corrosion.
-0,5<0	Slightly corrosion but non-scale forming.
0, 0	Balanced but pitting corrosion possible.
0,0<0, 5	Slightly scale forming and corrosive.
0,5<2	Scale forming but noncorrosive.

III. RESULTS AND DISCUSSION

A. Identification of corrosive water using Langelier saturation index

The water quality tests are performed as shown in Table 3. Moreover, the LSI is calculated on the sample water using LSI calculator as shown in Figure 7. This calculator gives us tentative indication whether the water is corrosive or not.

Table 3. Water quality of three sources of Padampokhari DWSS

Name of Project:-Padampokhari Water Supply and Sanitation Project Name of work : - Water Quality Test Project Area :-Padampokhari VDC, Hetauda, Makwanpur								
S.No	Particular	Existing Intake Source 1		Existing Intake Source 2		Existing Intake Source 3		Remarks
		Value	Unit	Value	Unit	Value	Unit	
1	PH	5.7		5.5		6.6		
2	TDS	11	ppm	12	ppm	14	ppm	
3	Temperature	12	degree centigrade	12	degree centigrade	11	degree centigrade	
5	Calcium	10	mg/l as CaCO ₃	10	mg/l as CaCO ₃	10	mg/l as CaCO ₃	
6	Alkalinity	20	mg/l as CaCO ₃	20	mg/l as CaCO ₃	36	mg/l as CaCO ₃	
7	Hardness	44	mg/l as CaCO ₃	40	mg/l as CaCO ₃	50	mg/l as CaCO ₃	
8	Iron	< 0.1	mg/l	< 0.1	mg/l	< 0.1	mg/l	

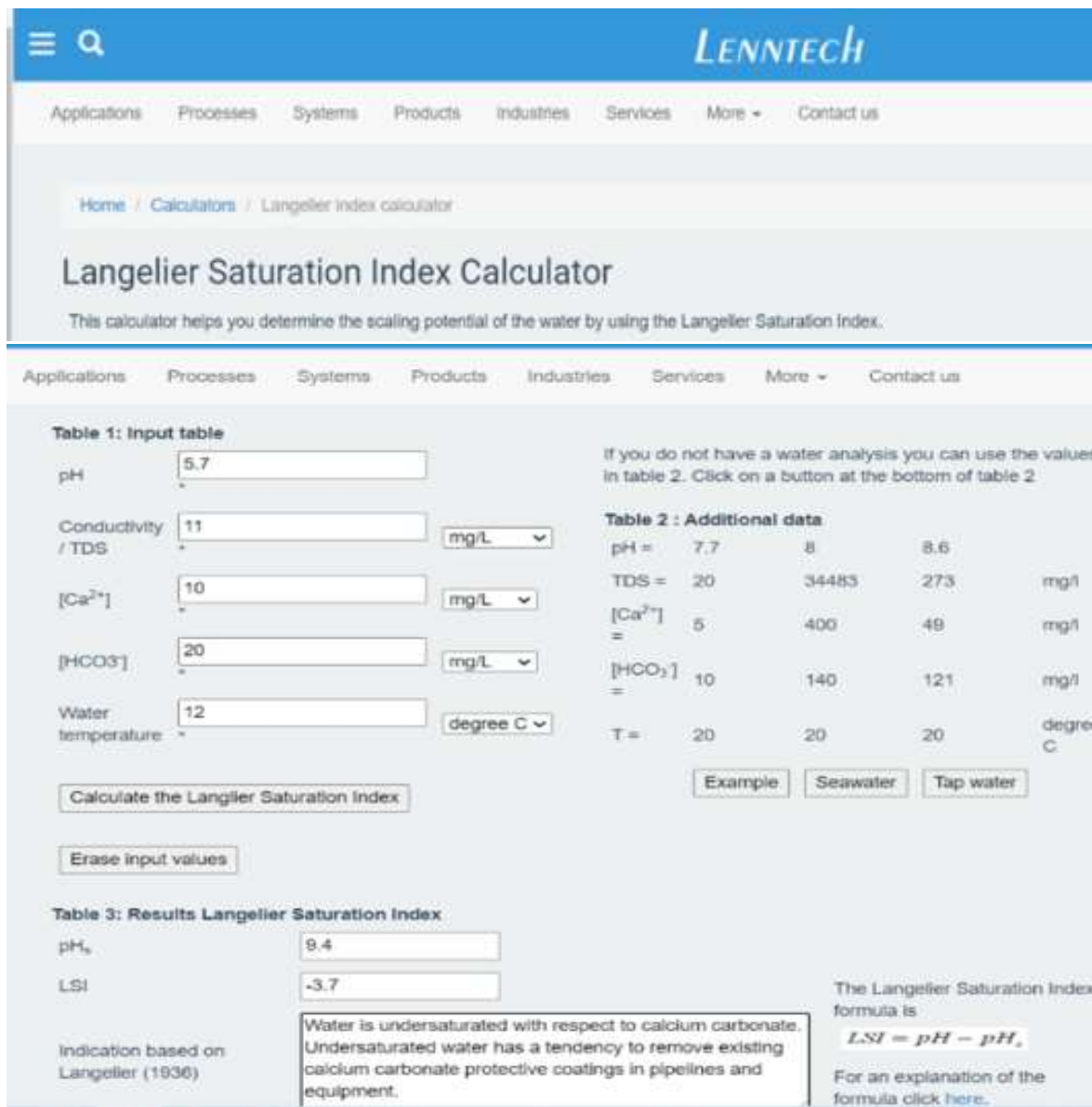


Figure 7: Sample calculation Langelier saturation Index

Figure 7 shows the sample result from Langelier saturation index calculator. It is observed that the LSI value is -3.7 and display result as "Water is under saturated with respect to calcium Carbonate. Under saturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment". This provides us tentative evidence that the sample water is highly corrosive.

B. Laboratory analysis of Sample water with calcium carbonate (stone) aggregates

Once the water is tentatively determined as corrosive from Langelier saturation index calculator, further test is carried out for the verification. Experiment is carried out for the determination of stabilization value of corrosive water; we take a conical flask which is filled with aggregates of 10 to 20 mm dia. The sample water which needs to be stabilized is taken in the vessel. The sample water is poured into the conical flask and mixed homogeneously, and TDS and pH are recorded with time.

Same experiment was conducted by taking two different water samples and the data is recorded accordingly as shown in Table 4 and Table 5.



Table 4 : Water Sample 1

Time	pH Change With Time	TDS Change With Time	Rate of TDS change /min
0	5.5	11	
2.5	5.7	13	0.8
8	6	23	1.8
32	6.5	43	0.8
44	6.6	48	0.4
50	6.7	51	0.5
68	6.9	57	0.3
78	6.95	59	0.2
82	7	60	0.3
92	7	63	0.3
155	7.2	66	0.0
187	7.2	66	0.0

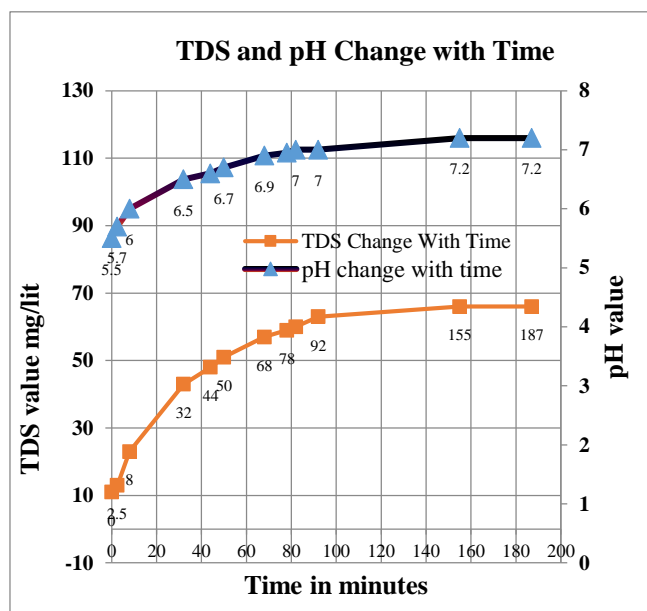


Figure 8: Laboratory analysis of Water sample 1

Table 5 : Water Sample 2

Time IN MINUTES	TDS change with time (mg/lit)	pH change with time	Rate of TDS change (per minute)
0	20	5.5	
2	29	6	4.5
5	43	6.3	4.7
10	56	6.5	2.6
15	66	6.6	2
20	71	6.7	1
25	74	6.8	0.6



30	79	6.9	1
35	83	7	0.8
45	88	7.2	0.5
50	91	7.25	0.6
55	92	7.3	0.2
60	93	7.3	0.2
70	94	7.35	0.1
80	95	7.4	0.1
90	95	7.4	0

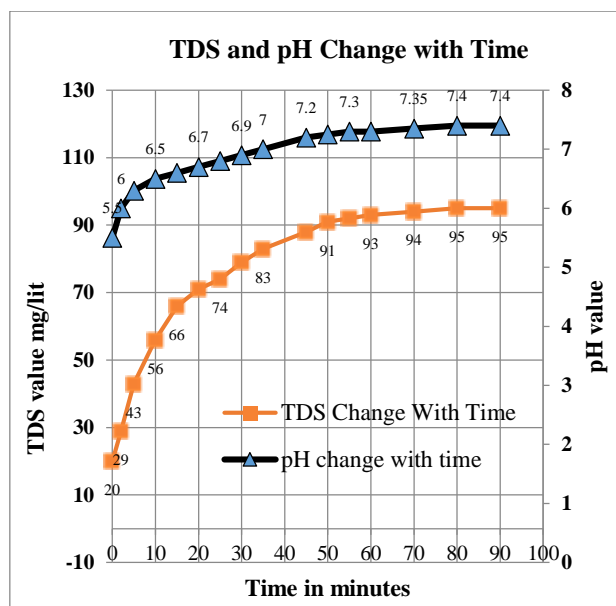


Figure 9: Laboratory analysis of water sample 2

The data obtained from water sample 1 and sample 2 are represented in the form of graph as shown in Figure 8 and Figure 9 respectively. From the first graph, it is observed that after 155 min, TDS and pH of water is nearly stable. From the second graph, it is observed that after 80 min, TDS and pH of water is nearly stable. Furthermore, it is seen from the both graphs that, incremental rate of TDS and pH is fast in the initial phase and incremental rate decreases as the time increases. After sometime it become nearly stable. This time is recorded as a detention time. It is seen from the experiment that after pH 7, the increment rate of pH and TDS is very slow. It seems that the fast and active corrosive value decreases after pH 7.

The water sample was taken from different water supply schemes and tested. It is identified that the water becomes nearly stable according to the corrosive value of that water sample. When the corrosiveness of the water is high, it will take more time to neutralize. Based on the experiments, it is found out that the detention time for different water supply schemes will be different and has to be carefully calculated.

C. Carbon dioxide kinetics and its importance

The stability of water which we studied in the above section can also be verified by studying carbon dioxide kinetics. Carbon dioxide kinetics is the study of the movement of inorganic carbon speciation with respect to pH, TDS and temperature.

The kinetics study of carbon dioxide is studied from the standard graph as shown in the Figure 6 [7]. This graph shows the correlation between pH, temperature, alkalinity, TDS and carbon dioxide. It is observed that higher TDS and higher the alkalinity, and higher alkalinity can hold higher value of carbon dioxide even in same pH. The data are derived from the Nomograph of "Standard test method of water and wastewater 23rd. edition*" [12].

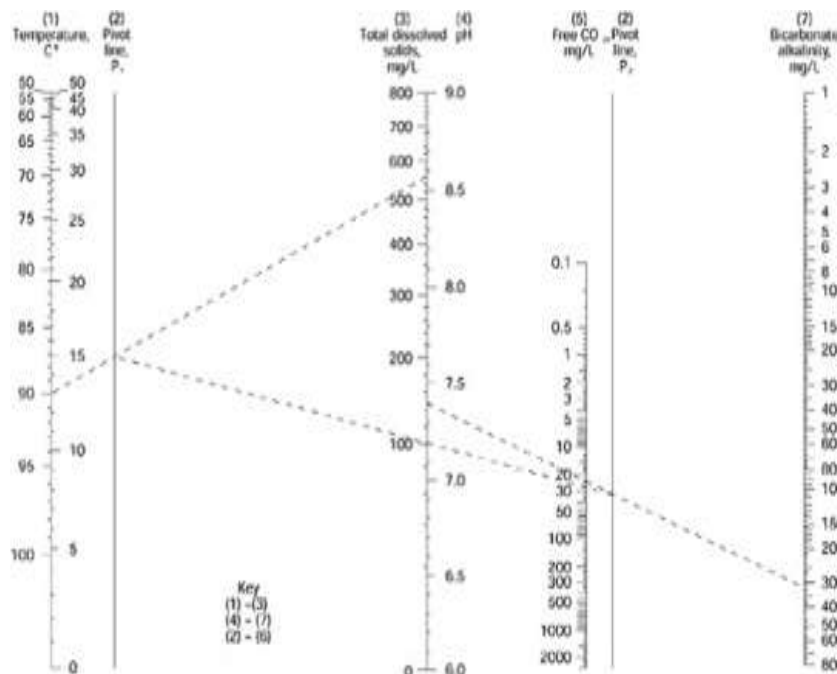


Figure 10: Nomograph *Figure Procedure-4500-CO₂ standard test method of water and waste water 23 rd. edition*".
 *Source: CO₂ calculated from -Standard Test Procedure-4500-CO₂ Nomograph

The correlation between these pH, temperature, alkalinity, TDS and carbon dioxide in different condition can be derived from the Nomograph. The study is carried out in 5 different scenarios as mentioned in Table 6. The experiments are carried out by observing the correlation between different parameters in different scenarios.

In scenario 1 and 2, we fixed pH and Temperature and observed the carbon dioxide variation over variable TDS and Alkalinity as shown in Figure 11 and Figure 12. It is observed that under same condition, equilibrium carbon dioxide value is mainly dependent upon **pH value**.

In scenario 3, we fixed pH, temperature, TDS and observed the carbon dioxide variation directly proportional to alkalinity value as shown in Figure 13. It is observed that carbon dioxide is directly related to the alkalinity. In high alkalinity, the carbon dioxide value is also high.

In scenario 4, we fixed pH, temperature, alkalinity and observed the carbon dioxide variation over variable TDS as shown in Figure. It is observed that If the alkalinity is fixed, equilibrium carbon dioxide is same as shown in Figure 14.

In scenario 5, we fixed pH, temperature, TDS and observed the carbon dioxide variation over variable Alkalinity as shown in Figure 15. It is observed that Carbon dioxide is directly related to the alkalinity. Also, we have observed the graph on low alkalinity. In low alkalinity, the Carbon dioxide value is also low. Hence, it is verified that carbon dioxide holding capacity of water is directly related to alkalinity, pH and temperature of water and alkalinity value is directly related to TDS value of water.

Table 6. Data derived from Standard Test Procedure-4500-CO₂ Nomograph

	pH	Temp	TDS	Alkalinity	Carbon dioxide (Result)	Conclusion drawn
Scenario -1	6.5	20	5, 10, 25, 50, 80, 100, 120	1, 2, 5, 10, 15, 20, 25	0.7, 1.2, 3, 7, 10, 12.5, 15	Under same condition, Equilibrium carbon dioxide value is mainly dependent upon pH value.
Scenario- 2	7	20	5, 10, 25, 50, 80, 100, 120	1, 2, 5, 10, 15, 20, 25	0.2, 0.8, 0.9, 1.8, 1.8, 2.5, 5	



Scenario -3	7	24	460	200, 240, 280, 320, 360, 400, 440, 480, 520, 560, 600	35, 40, 50, 60, 70, 80, 85, 90, 95, 100, 105	Carbon dioxide is directly related to the alkalinity
Scenario- 4	6.5	20	25,50,80,100 ; 120	15	10	If the alkalinity is fixed, equilibrium carbon dioxide is same.
Scenario -5	6.5	20	50	1, 2, 5, 10, 15, 20, 25	0.7, 1.2, 3, 7, 10, 12.5, 15	Carbon dioxide is directly related to the alkalinity

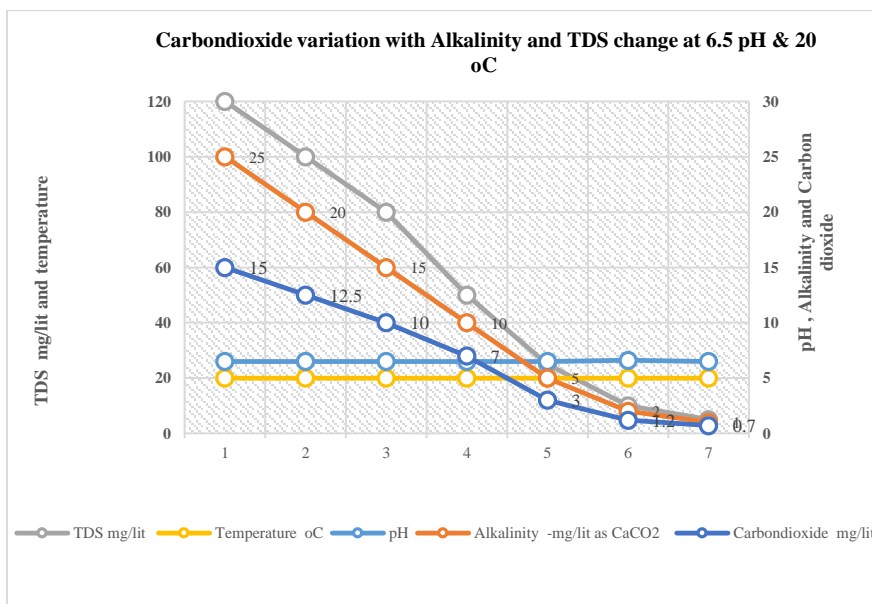


Figure 11: Carbon dioxide variation in contest of low TDS and at constant pH 6.5 & temperature 20 °C-Scenario 1

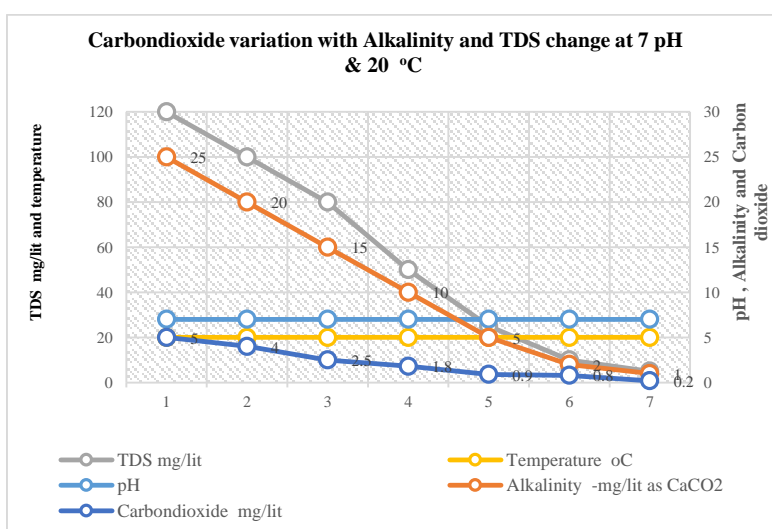


Figure 12: Carbon dioxide variation in contest of low TDS and constant pH 7 & temperature 20 °C-Scenario 2

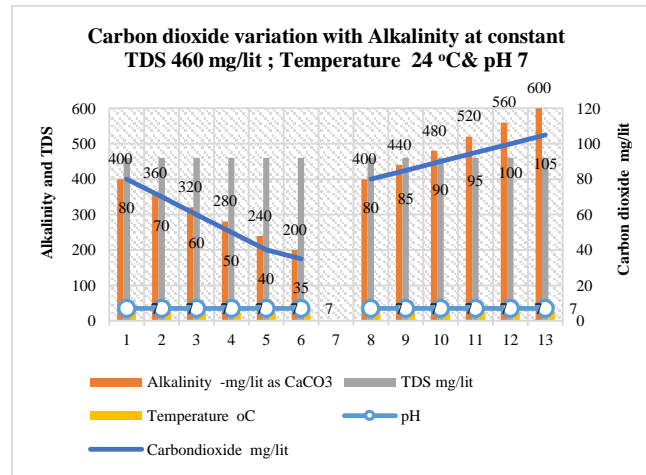


Figure 13: Carbon dioxide variation at constant TDS 460mg/lit, temperature 24oC and pH 7 with different alkalinity (200 to 600 mg/lit as CaCO₃)-Scenario 3

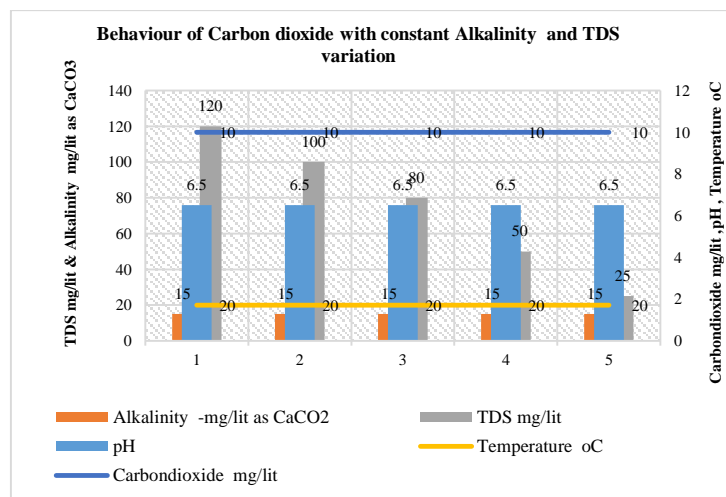


Figure 14: Carbon dioxide variation with TDS variation at constant alkalinity, pH & temperature-Scenario 4

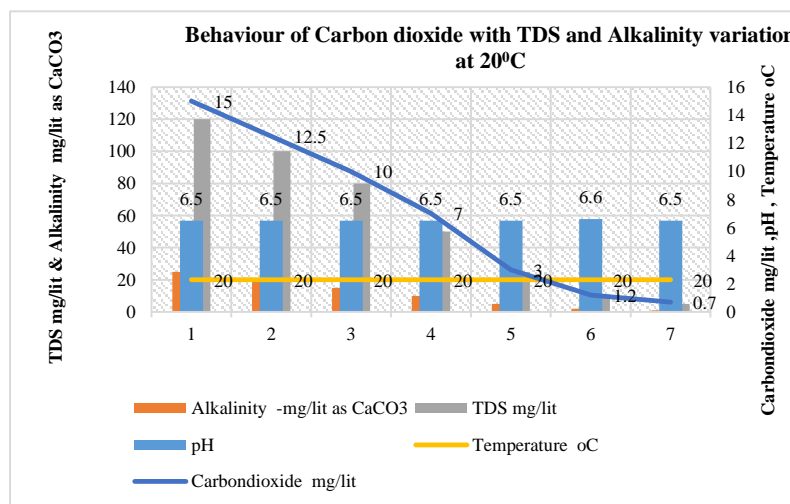


Figure 15: Carbon dioxide variation with variable alkalinity & TDS at constant pH 6.5 & temperature 20 °C-Scenario 5

From the analysis in carbon dioxide kinetics, we draw out several important conclusions. First, it is verified that carbon dioxide holding capacity of water or equilibrium carbon dioxide is directly related to alkalinity, pH and temperature of water and alkalinity value is directly related to TDS value of water.

Second, we found out that at low TDS, alkalinity and pH, saturation carbon dioxide value is low but it is quite corrosive than high TDS, alkalinity water. The carbon dioxide in air is 0.045 mg/lit. The mass gradient in water and in air is quite low. So, diffusion rates of carbon dioxide from water to air is low and it takes long time for equilibrium state.

Third, the diffusion rate of oxygen from air to water is comparatively more in water with low TDS than the water with high TDS. We cannot deny the fact that oxygen is a good oxidizing agent. Hence, rusting of ferrous metal or oxidation of iron is more with quick addition of oxygen and it accelerates with the available carbon dioxide in the water. So, water with low TDS & pH, rusting rate is higher than high TDS water. The chemical phenomena of rusting due to carbon dioxide is shown in the Figure 16 [13].

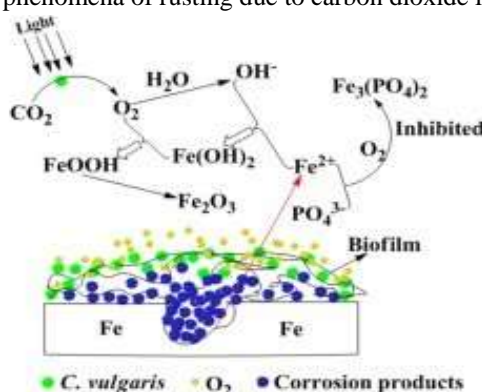


Figure 16: Chemical phenomena rusting due to carbon dioxide

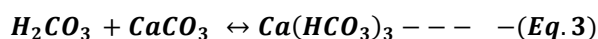
Moreover, we draw the conclusion that due to presence of oxygen and carbon dioxide in low TDS and low pH, water remains aggressively corrosive until it becomes neutral.

Finally, we found out that saturation carbon dioxide value is more in low temperature than high temperature. Furthermore, equilibrium carbon dioxide value is directly proportion to alkalinity value. When we have high alkalinity, high value of carbon dioxide exists in water.

D. Design of stabilization tank

From the laboratory experiment no 2 as shown in Table 2, it is observed that initially the value of pH and TDS is 5.5 and 20 mg/lit respectively. After 35-minute, the value of pH and TDS changes to 7 and 83 mg/lit. Moreover, after 80-minute pH and TDS reaches to 7.4 and 95 mg/lit. Finally, at 90 minutes, the value of pH and TDS remains same i.e. 7.4 and 95 mg/lit. Hence, it is observed that the rate of change of pH and TDS is faster at initial stage and slows down later on. After 80 minutes there are no changes in the obtained values of pH and TDS which provides a clear insight that the water is stabilized after 80 minutes.

It is observed from the Table 2 that there is an increment of pH and TDS. The reason behind it is due to the reaction of already available carbon dioxide with the water which results in forming carbonic acid. Moreover, the carbonic acid dissolves calcium carbonate stone and form calcium bicarbonate which is dissolved form and increased TDS. When the carbonic acid decreases, there is a decrease in H+ ions and increase in pH value. This phenomenon can be observed from equation 2 and 3.



Same for Mn Mg etc.

The performed experiment and its outcome can be verified using Bjerrum plot as shown in Figure 17. Bjerrum plot { which shows the behavior of dissolved inorganic carbon -DIC speciation over pH}. It is observed from the Bjerrum plot that carbon dioxide value is 80% at pH 5.5 and ~2.5% at pH 7.5. At this point, bicarbonate alkalinity is at highest peak and fast rate of decreasing bicarbonate alkalinity and fast rate of formation of carbonate alkalinity after this peak. So, our laboratory experiment is in right directions.

Also, the performed experiment and its outcome can be further verified from carbon dioxide kinetics study in different pH, TDS, alkalinity and temperature. It is observed from carbon dioxide kinetics that if the value of pH is 7 or higher, carbon dioxide value is lower by 10%. This means the carbonic acid is minimum and reaction rate is quite slow and it became nearly zero after pH 7.4.

Hence, we verify the experiment we performed via observation, Bjerrum plot [11] and carbon dioxide kinetics. Finally, we conformed the detention time of 80 minutes with the gravel size of 10 to 20 mm while designing the stabilization tank.

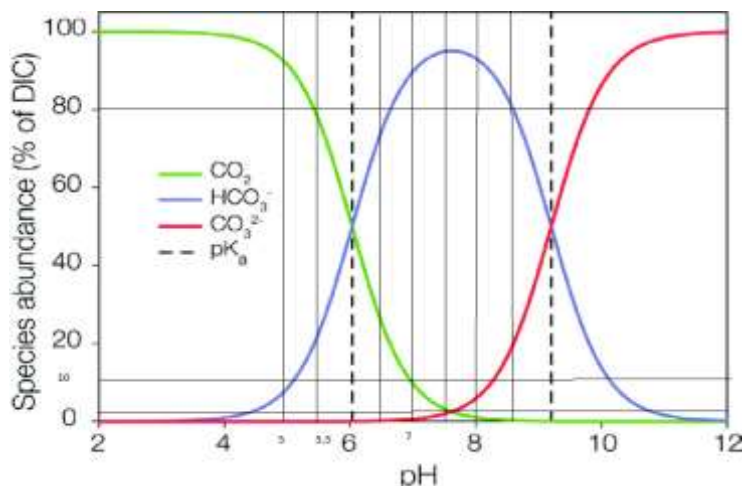


Figure 17: Bjerrum plot, showing dissolved inorganic carbon (DIC) speciation over pH (temperature = 20°C, pressure = 1 dbar, salinity = 32)

If the gravel size is decreased, the stabilization time will be reduced as well. It is worth mentioning that, we can use any size of gravels based on the availability. However, the experiment is required to find the detention time.

The volume of gravel (10 to 20 mm) required is 14.33 cum per year which is calculated as:

The discharge if water supply is ~ 10 lit/sec

increased TDS value is (95 - 20) mg/lit = 75 mg/lit

Quantity of aggregates needed per day = 10 * 3600 * 24 * 75 mg = 64.8 kg

Quantity of aggregates needed for one year = 64.8 kg * 365 = 23,652 kg

Let density of aggregate = 1650 kg/cum

Total aggregates needed per year = 23652/1650 cum

= 14.33 cum per year

If a truck can carry 5 cum, aggregates needed per year = 14.33/ 5 trucks of 5 cum

= 2.86 trucks ~ 3 trucks of 5 cum per year.

Based on these experiments, we have designed the water stabilization tank with natural calcium carbonate stones. This detention time mainly depends on the contract areas of calcium carbonate that aggregates with water. It is observed that the smaller the aggregates higher the contract areas and lesser the detention time.

Hence, for every batch and locations, it is required to make the aggregates samples and should be equal or lesser than the designed detention time. We should also examine that the dissolved stone should not have any hazardous chemicals present in it. Dissolved water quality should be checked batch wise.

1) *Detail Design of stabilization tank:*

While designing the stabilization tank, we should consider some designing criteria as mentioned:

- Aggregates size: 10 mm to 200 mm size crusher aggregates of calcium carbonate stone
- Detention time 80 minutes

- Sources: Three sources, the discharge in three intakes (total) = ~10 lit/sec (Intake I-3.6lps, Intake II= 3.3 laps Intake III = 3.0lps)
- Volume of voids = 40% (Actual Analysis of selected aggregates)
- As the side condition, we should also fill the gravel in intakes. Instead of normal gravel, let's take calcium carbonate gravel in the intake. It may reduce the stabilization tank volume.

Calculation of the volume of aggregates required for filling the three intakes.

Intake 1: Discharge of intake 1 is 3.6 lit/sec. Total discharge in 80 minutes is $3.6 \times 60 \times 80$ lit = 17.28 **cum**. Let, 40% voids in aggregates, Total volume of media = $17.28 / 0.4$ = **43.20 cum**. Figure 18 shown the area which was calculated from AUTOCAD drawing is 62.91 sq. meter. Depth of intake is 0.75 m. While designing the stabilization tank, we assume that 60 cm calcium carbonate gravel (10 mm to 20 mm) is submerged in water.

Hence, Volume equals 62.91×0.6 = **37.74 cum**. The calcium carbonate aggregates (Media) required for intake 1 which has source discharge of 3.6 lit/sec is 43.20 cum. The volume 37.74 cum is used in the intake catchment areas is and remaining discharge ($43.20 - 37.74$ = **5.46 cum**) is used in the stabilization tank

Intake 2: Discharge of intake 1 is 3.3 lit/sec. Total discharge in 80 minutes is $3.3 \times 60 \times 80$ lit = 15.84 **cum**. For 40% voids in aggregates, Total Volume of media is **39.60 cum**. Figure 19 shown the area which was calculated from AUTOCAD drawing is 20.36 sq. meter. Depth of intake is 0.75 m. While designing the stabilization tank, we assume that 60 cm calcium carbonate gravel (10 mm to 20 mm) is submerged in water.

Hence, the volume equals $20.36 \text{ sqm} \times 0.6 \text{ m}$ = **12.21 cum**. The calcium carbonate aggregates (Media) required for intake 2 which has source discharge of 3.3 lit/sec is **39.60 cum**. The volume **12.21 cum** is used in the intake catchment areas is and remaining discharge ($39.6 \text{ cum} - 12.21 \text{ cum}$ = **27.39 cum**) is used in the stabilization tank

Intake 3: Discharge of intake 1 is 3.0 lit/sec. Total discharge in 80 minutes is 14.4 **cum**. For 40% voids in aggregates, Total Volume of media is **36.00 cum**. Figure 19 shown the area which was calculated from AUTOCAD drawing is 20.36 sq. meter. Depth of intake is 0.75 m. While designing the stabilization tank, we assume that 60 cm calcium carbonate gravel (10 mm to 20 mm) is submerged in water.

Hence, the volume equals $20.36 \text{ sqm} \times 0.6 \text{ m}$ = **12.2 cum**. The calcium carbonate aggregates (Media) required for intake 3 which has source discharge of 3.0 lit/sec is 36.9 **cum**. The volume **12.21 cum** is used in the intake catchment areas is and remaining discharge ($36.00 \text{ cum} - 12.21 \text{ cum}$ = **23.80 cum**) is used in the stabilization tank

So, **Total volume of calcium carbonate needed for stabilization tank** = 5.46 cum + 27.39 cum + 23.8 Cum = 56.65 cum.

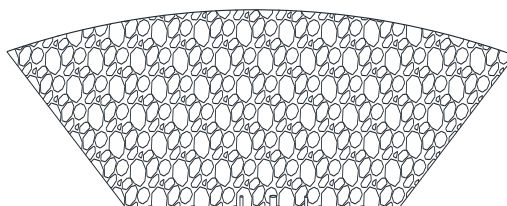


Figure 18: Gravel filled areas of intake 1

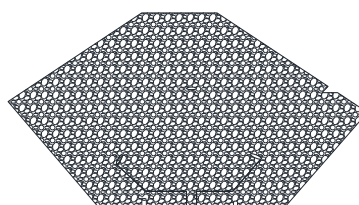


Figure 19: Gravel filled areas of intake 2 and 3

For designing the stabilization tank let design the tank just like roughing filter, which is designed 3 components .Let fill the of same gravel size 10 mm to 20 mm in three compartment of 4m, 3m & 2m . It will be easy for residue cleaning. Total length = 9 m. Depth Tank = 1.5 m , Breadth of tank = $56.65 / (1.5 * 9) = 4.196 \text{ m} = 5 \text{ m}$ (say)

Let consider 20 cm of free board and 10 cm of sludge depth. Therefore, the total depth will be $1.5 + 0.20 + 0.10 = 1.8 \text{ m}$ and the size of tank will be equal to $(4\text{m}+3\text{m}+ 2\text{m}) * 5 \text{ m}$ (Breath) * 1.8 m (height). Moreover, the total volume of aggregates = $5 \text{ m} * 9 \text{ m} * 1.6 \text{ m} = 72 \text{ cum}$.

Generally, the size of stabilization tank is big, there may not be a sufficient space to construct the stabilization within the intake area. In this case, the water from intake should be carried out to the place where stabilization take can be constructed. When the water is corrosive, it may corrode the cementing structure of intake & GI pipe and fittings. Hence, an intake and the water carrier have to be redesigned to prevent the material from corrosion. In this case, we have used plastic materials and clay soil in the intake as shown in Figure 20, 21 and 22. These intakes are newly designed and already implemented in the field and they are functioning well. Figure 23 shows the layout of the water supply scheme where the proposed methods is designed for implementation. Also, the UPVC & HDPE pipes and fittings are used to prevent from corrosion. Corrosive water cannot corrode these materials. Once the stabilization tank is constructed, for the additional protection, the interior wall is painted with anticorrosive paint.

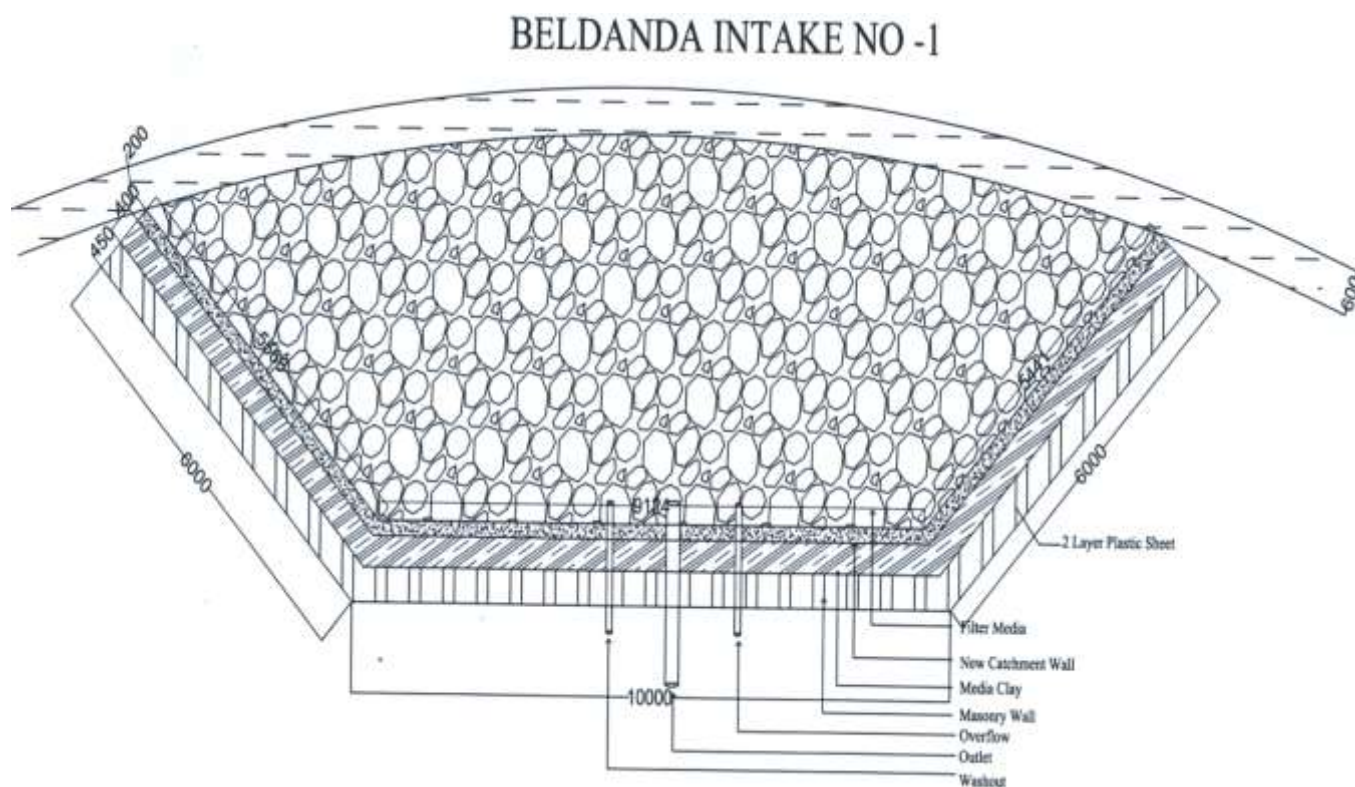


Figure 20: Modified Intake plan Intake no 1

PLAN FOR INTAKE NO-2

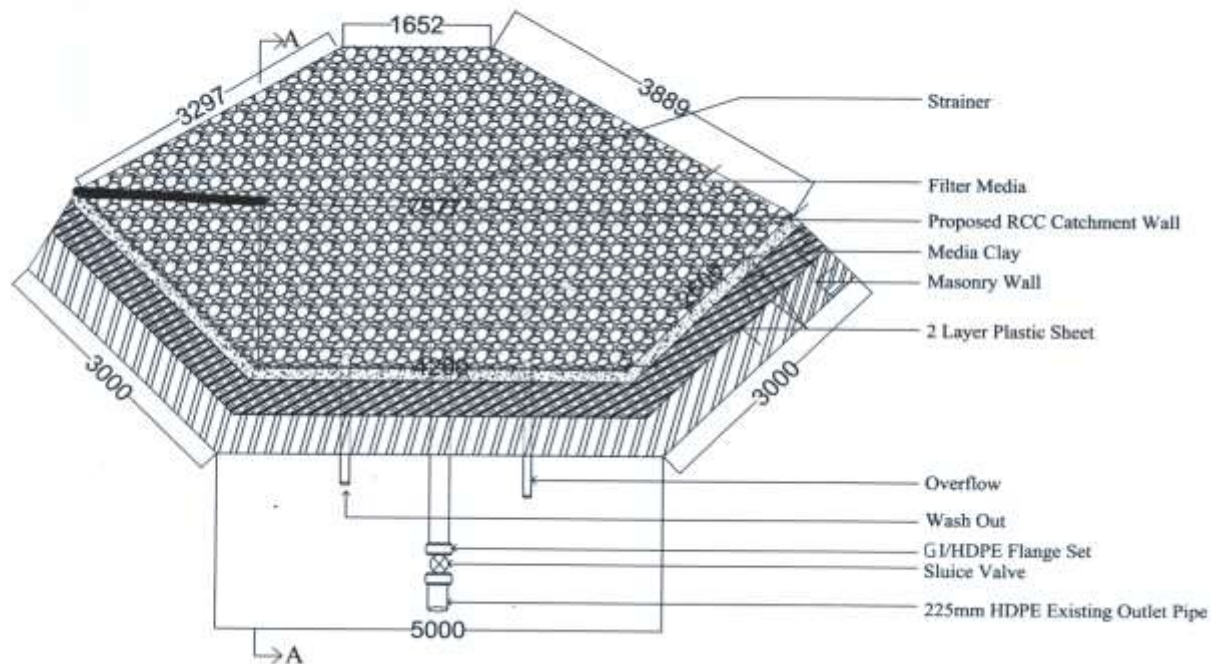
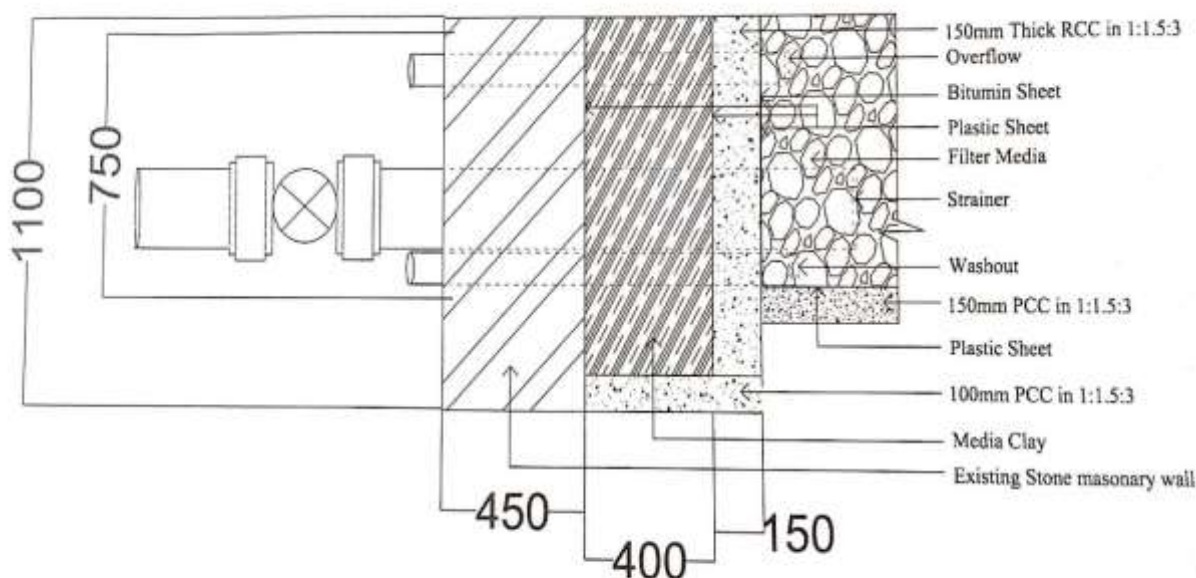


Figure 21: Modified intake Plan Intake -2



SECTION OF INTAKE 1,2&3

Figure 22: Sectional view of modified intakes 1, 2 & 3

Pipeline modification:

UPPVC & HDPE pipelines are changed instead of GI pipes. As far as possible, PVC & HDPE fittings are used.

2) **CC, BBT, RVT modification**

There is not and CC/DC before stabilization tank.

3) **Layout of Padampokhari DWSS**

Figure no 23 shows the layout of designed water supply scheme.

**PADAMPOKHARI WATER SUPPLY AND SANITATION PROJECT
Layout Plan**

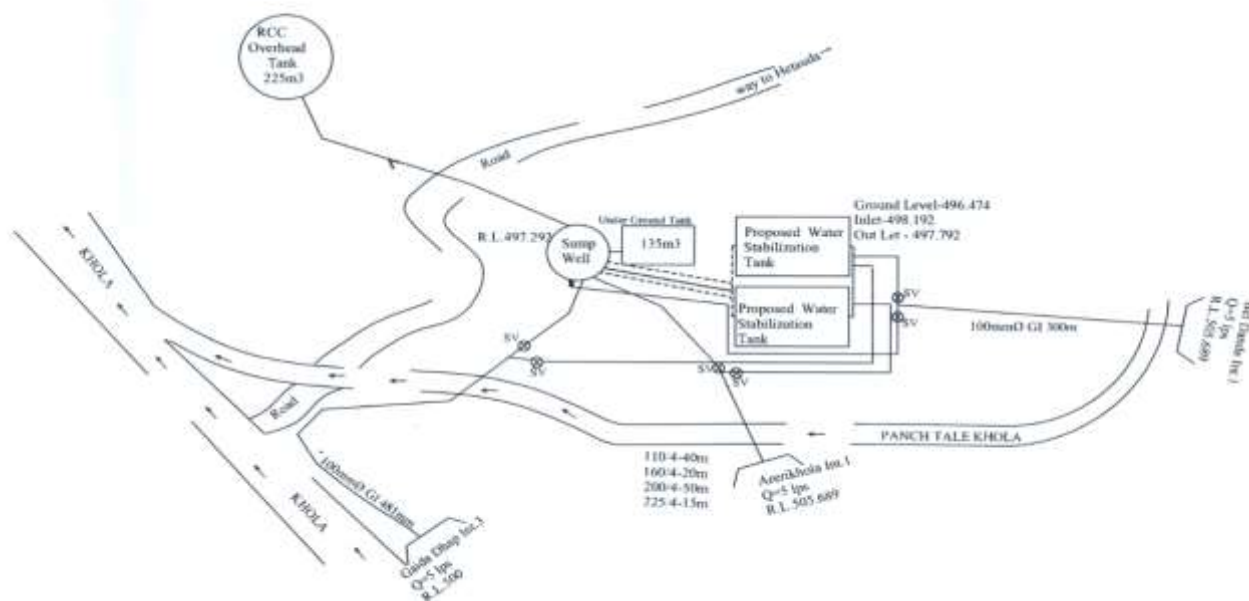


Figure 23: Layout of Padampokhari DWSS

IV. CONCLUSION AND FUTURE RECOMMENDATION

In this paper, we proposed a sustainable, natural and economical technology & solution to determine the corrosiveness of water and to neutralize it. This efficiency of the proposed solution has been tested and cross verified. It is observed that corrosive water can be confirmed in laboratory using the same water and cementing materials of the schemes. The detention time was figured out by doing several experiments. And it is found out that stabilization detention time mainly depend on water quality & the size aggregates. Finally, a stabilization tank is constructed to stabilize the corrosive water. Additionally, the intake, GI pipes and fittings, collections tanks are modified to prevent corrosion & provide a more efficient solution.

Instead of aggregates, calcium carbonate dust can even be used. Initial phase of research shows that, using calcium carbonate dust will reduce the detention time and the volume of stabilization will be smaller. However, additional research is required to verify its sustainability & benefits and its ongoing research.

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