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Mathematical Modelling and Experimental Study of Corrosion Rate on Carbon Steel Affected by Soil Moisture Content and Time

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Abstract. The degradation of soil poses a serious threat to the integrity of buried assemblies such as underground storage tanks, oil and gas pipelines. The effect of soil moisture content and time on the corrosion performance of steel in soils of dissimilar location of Basra (West Qurna , Foe and Majnoon) was investigated using weight loss measurement. The result showed that the corrosion is correlated with the high moisture content of soil and with increase time. Also, at the critical moisture content the corrosively of the considered soils is given in the request: Majnoon > West Qurna > Foe. In order to study the relationship between soil engineering properties and corrosion frequency, statistical analysis was performed. The findings of the site research show times as the most governance impact on the level of corrosion based on the coefficient of correlation. More studies using variance analysis (ANOVA) and multiple regression analysis showed good agreement between experiments and prediction corrosion rate.

INTRODUCTION

Soils, as the harsh environment is possibly of more complex than other environment. The corrosion process of buried metal structure is very variable and can range from rapid to slight. In fact pipe in soil can be burst within one year, presenting very localized or uniform corrosion attack. With experience information of the principle soil specifies and their influence on metal corrosion, the most serious corrosion problem can be avoided [1]. Soil properties had been found to be one of the parameter in influencing the corrosion of underground pipeline. The engineering properties of the soil clearly need to be concern by the pipeline company to a void their products corrode and last longer in different type of soil and their trust on transporting reactants and products using underground pipeline and could loss a huge amount of money if anything happen on their railways. At a result studying the impact of soil engineering properties to the corrosion of pipelines [2]. Research done by corrosion researchers has shown that soil corrosion can be correlated with soil resistivity activity, the presence of dissolved salts in soil, soil moisture content, soil PH, soil bacteria forms, soil oxygen content and elemental soil composition. [3].

Some researcher [4–8] investigated the fact of soil moisture content on steel corrosion. Moucheng et al.[4] used electrochemical techniques to study the influence of moisture content on the corrosion performance of carbon steel in neutral soil. The results shown that the soil corrosion current density of carbon steel had a maximum value with the dissimilarity of moisture content. The corrosion activity of x–70 pipeline steel in two forms of saline salts with variance humidity has been determined by electrochemical methods [5].It was found that the corrosion rate of pipeline steel increases as soil humidity increased reaching a maximum corrosion level. Xiaodan et al.[6] found that the content of moisture had a major impact on the corrosion actions of x – 70 steel in yellow pebble soil. A profit, they found that the growth rate of corrosion increased as the soil moisture increased to a peak when the moisture content was (25%). Yahaya et al. examine the effect of soil clay and moisture content on x-70 carbon steel corrosion;

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they find soil moisture content to be more corrosive than clay content based on qualitative assessment[7]. The relationship between soil characteristic and carbon steel corrosion was examined by Norhazilan et al.[8]. The plasticity index, moisture content, and clay content were the three soil characteristics. Ehteram et al.[9] recently studied the impact of soil moisture content on corrosion efficiency of x–60 steel in soils of "Saudi Arabia" dissimilar towns using weight loss and specific electrochemical methods. The results showed an increase in corrosion level of x – 60 steel with a rise in soil moisture content to a maximum value of (10%).The present study is an attempt to investigate the effect of soil moisture content and time on carbon steel corrosion in soils from different towns in Basra / Iraq (West Qurna, Fao, Majnoon) using weight loss methods. The corrosive parameters of the soils analyzed and the soils are associated. Also, the correlation model is established.

METHODOLOGY

Materials and Method

The pipe part used for this study was achieved by Basra Oil Company. The steel pipe part was (cut) in to coupons of (7.8 cm*3.84 cm*0.63 cm). Before installation, the simple was cleaned to avoid any contamination that might affect the practice of corrosion. The preparation and cleaning methods suggested (ASTM G 01.03). Using the metal analyzer, a sample was exposed to chemical analysis. This was done by exposing the specimen's polished surface to the spectrometer's light emission. The results shown in Table 1.

TABLE 1. Carbon steel chemical composition (wt. %).

C%	Si%	Mn%	P%	S%	Mo%	Ni%	Cu%	As%	Fe%
0.275	0.21	0.6625	0.0195	0.0227	1.0162	0.14	0.1525	1.225	98.25

Soil Sample

The soil samples investigated were achieved from three variation towns (West Qurna , Fao , Majnoon) in Basra/Iraq. Fig. 1 Demonstration of these cities ' geographical locations. All the soil samples are collected at a depth of approximately (1.5 m) in polyethylene bags that were taken to the laboratory to prove that they are chemical properties.

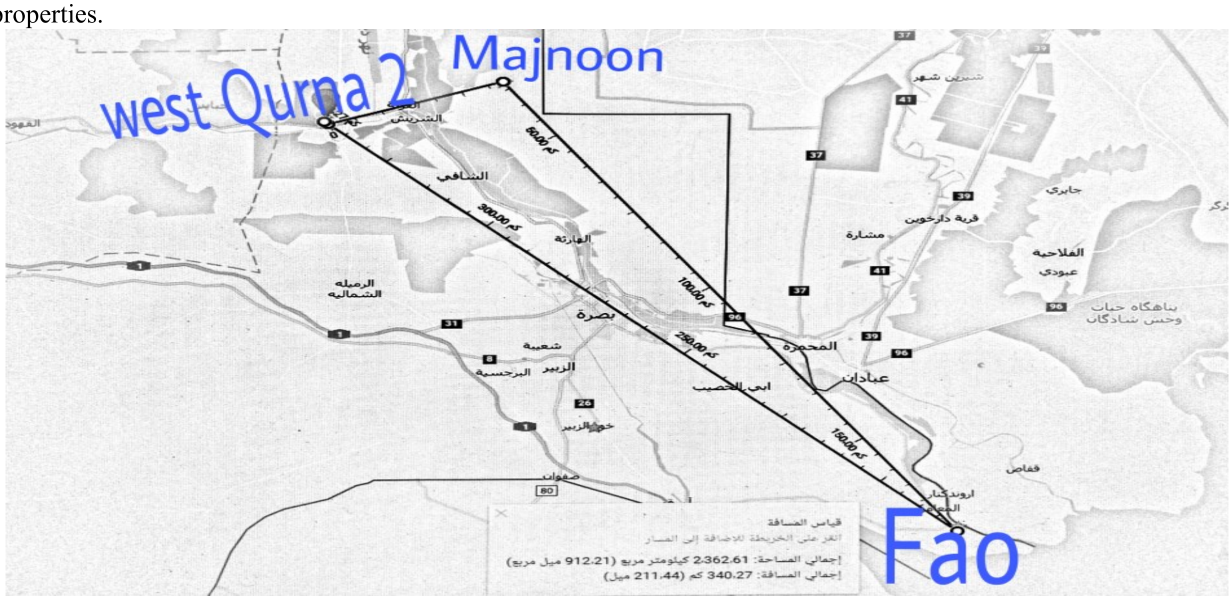


FIGURE 1. Locations for collection of soil samples in Basra / Iraq.

Soil Chemical Analysis

Soil PH

Measurement was conceded in 1:5 soils to water by means of PH meter, which was calibrated in the laboratory. The result, are presented in Table 2.

Soil Resistivity

Using a winning lab conductivity meter calibrated in the laboratory, electrical conductivity was conducted in 1:5 soils to water. Nevertheless, soil resistivity was measured as a reciprocal conductivity by:

$$ER = 1/EC \quad (1)$$

Where; ER: electrical resistivity
EC: electrical conductivity
Also; electrical conductivity proportional with Total dissolved solid (TDS), the results are shown in Table 2.

$$EC = 1.56 * TDS \quad \text{at } 25\,^{\circ}C \quad (2)$$

TABLE 2 Chemical Analysis of Experimental Soils.

Parameter	West Qurna	Fao	Majnoon
PH	6.4	5.8	6.2
Soil Resistivity (Ω)	$1.885*10^{-3}$	$1.6026*10^{-4}$	$5.087*10^{-4}$
Soil cond. (1/ Ω)	530.4	6240	1965.6
TDS (mg/l)	340	4000	1260

Mechanical of Physical Analysis of Soil

Soil Texture

Soil consists of plants and animals, both living and dead, and mineral materials such as salt, silt and clay. It is expected to consist of rocks and minerals (about 45%), water (25%), air (25%) and organic matter (5%). Soil texture refers to relative forms of soil-composed rocks and minerals, the main of which is salt, silt and clay. Soil texture is an important indicator of soil's ability to absorb and keep water and nutrients from plants. By weighing (500 g) of soil and sieving it, the soil texture was determined. Use the following formulas to determine the relative percentage of salt, silt and clay in the soil sample:

$$\%\ sand = (\text{mass of sand} / \text{total soil mass})*100 \quad (3)$$

$$\%\ silt = (\text{mass of silt} / \text{total soil mass})*100 \quad (4)$$

$$\%\ clay = (\text{mas of clay} / \text{total soil mass})*100 \quad (5)$$

The soil type can be determined by using soil texture triangle. The results are shown in Table 3.

Soil moisture content

The method is developed by oven to dry a coil sample until the weight remains constant, or remove soil moisture. The moisture content (MC %) was determined by the formula below from the weight of the sample before and after drying. And the results are shown in Table 3.

Moisture content $MC\% = \{(W_2-W_3)/(W_3-W_1)\}*100 \quad (6)$

Where :-
W_1: weight of tin (gram)
W_2: weight of moist soil + tin (gram)
W_3: weight of dried soil + tin (gram)

TABLE 3 The Mechanical and Physical Examination of Experimental Soil.

States	%sand	%silt	Clay%	Soil type	Moisture%
West Qurna	2	1	97	Clay	45.98
Fao	65	15	20	Sand	17.49
Majnoon	0.5	0.5	99	Clay	52.52

The resource weight (30 g) of the soils examined were dehydrated in the open air and combined with the relevant water content, resulting in a moisture content of (72.58, 32.56 and 77.12) % for West Qurna, Fao, Majnoon; respectively.

Burial of Specimens

The samples were buried entirely in plastic containers, including the unique soils collected in a laboratory from different states. A maximum of three steel samples were buried and permitted to corrode (1 week to 1 month) for a period of time.

Weight Loss Method

There were two approaches of cleaning to eliminate corrosion contamination from the samples. Mechanical cleaning was performed using a soft brush to remove the soil particles on the sample surface. All the samples had been neutralized after washing (5 % Na2CO3) and a profit washed with steam. The samples were soaked in water after neutralization for (5 min.) and allowed to dry well in the sun. The weight of the prose samples (w1) and was reported using an electronic weighing to measure the corrosion level after exposure to soil (w2).

Investigation of Variance

The experimental results was analyzed with analysis of variance (ANOVA), which is used for determining the factors affecting the corrosion levels of the samples. The model equation was achieved by representative the corrosion rate value by CR, the response function can be stated by equation below :

$$CR=F(X_1, X_2)$$

Where ,X_1 is the moisture content ,and X_2 is the time. The level of the two factors and treatment are tabulated in Table (4 and 5); respectively. Regression analysis was used to produce an equation to predict corrosion rate using multiple independent variables related to soil properties. The general equation is written as:

$$CR= B_0+B_1X_1+B_2X_2+\ldots\ldots+B_nX_n \quad (7)$$

Where, B_0 is average response of CR and B_1 & B_2 are coefficient associated with each variable X_1 & X_2 and interactions the factors (main & interaction) were recognized by (ANOVA) method and SPSS program.

TABLE 4. Factorial Design of the Corrosion Rate (CR).

Positions	Factors	Low level	High level
West Qurna	Moisture content	45.98%	72.58%
	Time (hour)	168	672
Fao	Moisture content	17.49%	32.56%
	Time (hour)	168	672
Majnoon	Moisture content	52.52%	77.12%
	Time (hour)	168	672

TABLE 5. Factorial Design of the Corrosion Process Displaying Treatment Combination.

Exp. No	Moisture content	Time
1	-1	-1
2	+1	-1
3	-1	+1
4	+1	+1

Coded = -1 (low level) Coded= +1 (high level)

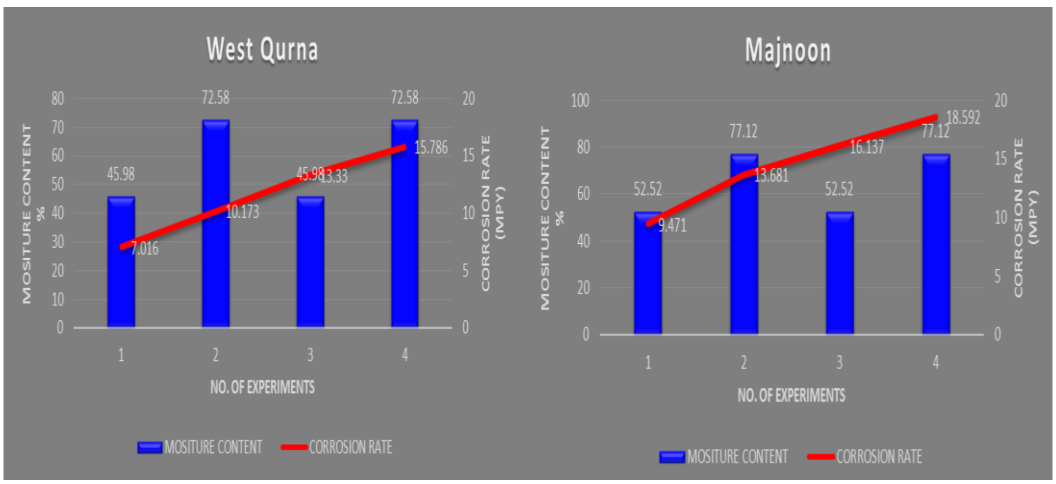
RESULTS AND DISCUSSION

Weight Loss Method

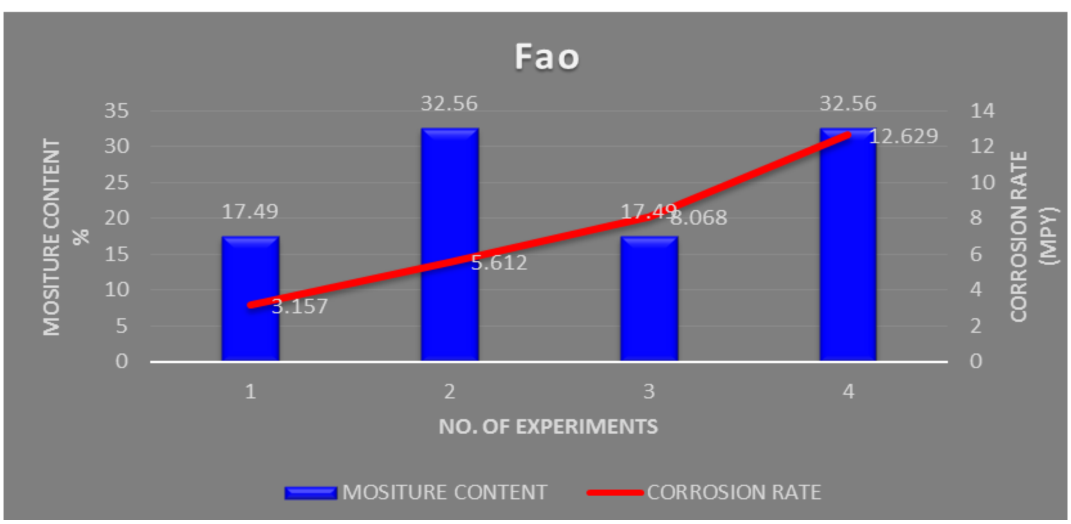
Evaluated the impact of soils from a different location on the buried samples, the initial weight of the specimens was recorded and the weight difference was measured over time.

Effect of Moisture content

There are three types of sources that provide soil moisture: free soil water, gravitational water, and capillary water, which have a major influence on corrosion rate determination. Free groundwater is present in the ground below the surface and typically only river crossing pipelines are enclosed in such a state by groundwater, corrosion is known to occur in an aqueous environment The main sources of gravitational water are ice, precipitation irrigation and floods into which this water flows through the soil, controlled by soil physical properties comprising pores of capillary spaces in soil profile variants. The capillary water denotes an important reservoir water in soil moisture / water as an essential element which serves as an electrolyte for corrosion processes. It can directly affect the rate of corrosion [10]. Fig. 2 (a,b,c) shows just how highly the moisture content of the studied soils influenced the corrosion level of steel. As was revealed, the corrosively of the studied soils (i.e. The corrosion rate) increases with an increase in soil moisture content. The essential moisture content is not added and can vary from soil to soil. As observed in both very dry and very humid soils, the corrosion level increases. Hydration of iron ions in drier soils (i.e. low moisture content) is partial, thus iron ionization in the soil is reduced, suggesting low corrosion level while increasing moisture content is greater than buried steel. surface is enclosed with the soil solution leading to accelerate the corrosion rate until the critical moisture content is reached [11]. Fig watching. 2 It has been shown that the critical moisture content; the corrosion rate of steel in the soils studied can be as follows: Majnoon > West Qurna > Feo.



(a) (b)



(c)

FIGURE 2 (a,b,c). The Moisture Content Effect on Carbon Steel Corrosion.

Effect of time

Corrosion rate is a function of time documented on inspection-based test results, it appeared that the corrosion rate of specimens increased over time. it was observed that the passivity film might have been broken down which currently led to the observed weight loss [12]. Table 6 showed the influence of time on corrosion rate and Majnoon sample would be the most corrosive with time.

TABLE 6. Effect of Time on Corrosion Rate process of Carbon Steel

No. Exp	Name of Field	Moisture Content	Time	W(g)	CR(Mpy)
1	West Qurna	45.98	168	0.20	7.016
2		72.58	168	0.29	10.173
3		45.98	672	1.519	13.330
4		72.58	672	1.80	15.786
1	Fao	17.49	168	0.09	3.157
2		32.56	168	0.16	5.612
3		17.49	672	0.919	8.068
4		32.56	672	1.440	12.629
1	Majnoon	52.52	168	0.27	9.471
2		77.12	168	0.39	13.681
3		52.52	672	1.840	16.137
4		77.12	672	2.119	18.592

Regression Investigation

Multiple linear regression analysis approach was used to investigate the impact of the corrosion level of the parameter towards studied, Table 7 (a,b,c) shows the summary of regression analysis with the average corrosion rate as dependent variable (response) while moisture content of time are regarded as independent variable (predictors) for west Qurna site ,the coefficient of correlation R_2 for the regression is (0.997) while the value of adjusted R_2 decrease to (0.992) while for Faw site R_2 (0.977) and adjusted R_2 (0.932) and for Majnoon site , R_2 (0.983) and adjusted R_2 (0.949) shows that approximately (99% , 97% and 94%) of the variation in the depend variable can be clarified by the independent variables.

The findings in Table 8 (a,b,c) indicate the value of significance F is greater than 0.05 , therefore the regression is found to be statistically not significant to express the relationship between the response of predictors this is agreed with the above mentioned value of adjusted R_2 .

Table 9 (a,b,c) shows the coefficient of regression model of significance (p-value) of all predictors to words response.

The regression model equation responses are shown in equations (8,9 and 10) :-

$$CR_{(\text{Wes tQurna})} = 11.576+1.403(MC)+2.982(t) \quad (8)$$

$$CR_{(\text{Faw})} = 7.367+1.754(MC)+2.982(t) \quad (9)$$

$$CR_{(\text{Majnoon})} = 14.470+1.666(MC)+2.894(t) \quad (10)$$

Where :-

CR : corrosion rate (mpy)

MC : moisture content (%)

t : time (hours).

The following deductions were made:-

1-the standard error (S_E=0.35500, 1.053000, 0.8777500) for west Qurna ,Fao ,and Majnoon; respectively What suggests the experimental deviation from the predicted appears to be very low, showing how good the models are [13].

2- The time coefficient from the regression is greater than that of the moisture content, which suggests the time has a greater effect on the corrosion level of the buried samples.

TABLE 7 (a,b,c): Model Summary

(a)

Model	R	R Square	Adjusted R Square	Std. Error
1	.999a	.997	.992	.350500

(b)

Model	R	R Square	Adjusted R Square	Std. Error
1	.989a	.977	.932	1.053000

(c)

Model	R	R Square	Adjusted R Square	Std. Error
1	.991a	.983	.949	.877500

TABLE 8 (a,b,c): ANOVA

(a)

ANOVA(b)

Model		Sum of Squares	Df	Mean Square	F
1	Regression	47.875	2	23.938	21.589
	Residual	1.109	1	1.109	
	Total	48.984	3		

(b)

ANOVA(b)

Model		Sum of Squares	Df	Mean Square	F
1	Regression	47.875	2	23.938	21.589
	Residual	1.109	1	1.109	
	Total	48.984	3		

(c)

ANOVA(b)

Model		Sum of Squares	Df	Mean Square	F
1	Regression	44.612	2	22.306	28.969
	Residual	.770	1	.770	
	Total	45.382	3		

TABLE 9 (a,b,c): Coefficients

(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Siq.
		B	Std. Error	Beta		
1	(Constant)	11.576	.175		66.056	.010
	X_1	1.403	.175	.425	8.007	.079
	X_2	2.982	.175	.904	17.014	.037

(b)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Siq.
	B	Std. Error	Beta		
1	7.366	.527		13.991	.045
(Constant)	1.754	.527	.501	3.331	.186
X_1	2.982	.527	.852	5.664	.111
X_2					

TABLE 9 (Continued).

(c)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Siq.
	B	Std. Error	Beta		
1 (Constant)	14.470	.439		32.981	.019
X_1	1.666	.439	.495	3.798	.164
X_2	2.894	.439	.859	6.597	.096

Goodness of Corrosion Fit Rate as Two Parameters Impact

In order to test the inconsistencies between the experimental values of the expected corrosion frequency, we use the following statistics to evaluate the fitness goodness [14].

$$X^2=\sum(CR_{exp}-CR_{thero})^2/CR_{thero} \quad (11)$$

Table 10 showed that (x^2=0.0115, 0.204, 0.055) for west Qurna , Faw , Majnoon ; respectively for 3 degrees of freedom.

Data analysis is correct with a confidence level of 95 %. Table 10 shows the experimental values of their predictive values of the corrosion rate to confirm the goodness of the predicted model. Table 10 also indicates the error of prediction and residuals if the corrosion rate which calculate from equations below. It have been realized the high and low error value for corrosion rate are (0.024 and 0.0109), (0.199 and 0.043) and (0.044 and 0.0230) for (west Qurna , Faw , Majnoon) ; respectively.

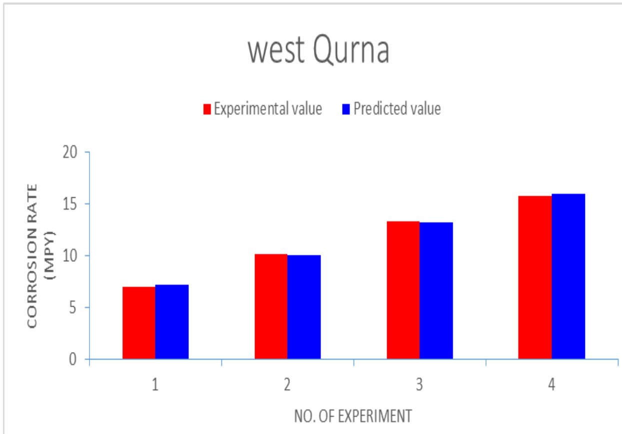
The relationship of actual and predicted values of corrosion rate are shown in Fig. 3(a,b,c).

$$Error\%=|CR_{exp} - CR_{thoer}|/CR_{thoer} \quad (12)$$

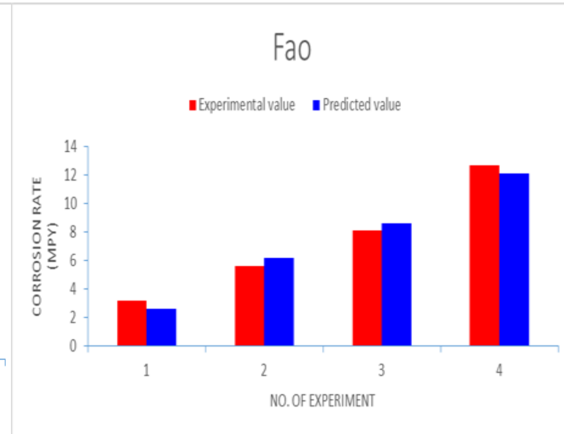
$$Residual=CR_{exp}–CR_{theor} \quad (13)$$

TABLE 10. The relation between the Corrosion Rate (CR) experimental and expected values.

No .of Exp.	Soil	Water Content	Time	Cr_{exp}	Cr_{theor}	Residual	%Error	Goodness of Fit X^2
1	West Qurna	-1	-1	7.016	7.191	-0.175	0.024	4.225×10^{-3}
2		1	-1	10.173	9.997	0.176	0.0176	3.098×10^{-3}
3		-1	1	13.330	13.155	0.175	0.013	2.308×10^{-3}
4		1	1	15.786	15.961	-0.175	0.0109	1.918×10^{-3}
								$\sum X^2$=0.0115
1	Faw	-1	-1	3.157	2.631	0.526	0.199	0.105
2		1	-1	5.612	6.139	-0.527	0.085	0.045
3		-1	1	8.068	8.595	-0.527	0.0613	0.032
4		1	1	12.629	12.103	0.527	0.043	0.022
								$\sum X^2$=0.204
1	Majnoon	-1	-1	9.471	9.910	-0.439	0.044	0.019
2		1	-1	13.681	13.242	0.439	0.033	0.014
3		-1	1	16.137	15.698	0.439	0.027	0.012
4		1	1	18.592	19.030	-0.438	0.0230	0.010
								$\sum X^2$=0.055



(a)



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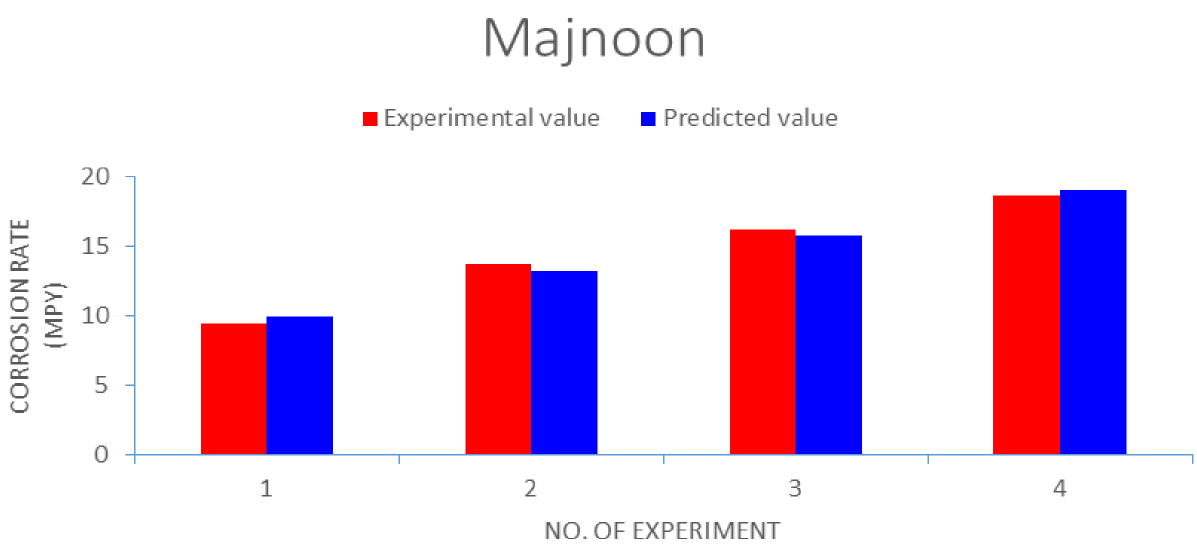

(c)

FIGURE 3 (a,b,c). The relation between the Corrosion Rate (CR) experimental and expected values.

CONCLUSIONS

The following results can be drawn from this study:

1) Experimental weight loss method data showed increased corrosion rate for all sites with increased moisture content and time.

2) The corrosive of the investigated soils is given at the critical moisture content as: Majnoon <West Qurna < Fao.

3) Time was found to have greater effect than moisture content to corrosion dynamic at greatest of the sites.

4) Using (ANOVA) analysis, the individual factor special effects are identified and it is established that the influence of time is one factor with a further effect when matched with the moister content..

5) Multiple regression analysis methods have been used to improve predictive corrosion rate models using predictors such as moisture content and different soil time. A multiple regression model is being developed to get up from different sites all the soil type. These models demonstration good a compatible with experimental data.

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