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Investigating the Influence of Environmental Factors on Corrosion in Pipelines Using Geospatial Modeling

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ABSTRACT

This study integrated geographic information system (GIS) and remote sensing technology to identify areas around pipelines that are more susceptible to corrosion having the Kurdistan pipeline as a case study. Geospatial data are used to target factors such as rainfall, temperature, rivers, and minerals which increase the corrosion rate. Spatial data such as, the direction of slope, rainfall, proximity to rivers, and minerals, were collected and analyzed; maps were created for every individual factor to visualize their distribution. By overlaying these maps, regions that are at higher risk of corrosion were identified, which can be prioritized for further investigation or preventive measures. This paper's findings are significant for oil and gas industries, including pipeline operators and designers as corrosion can lead to devastating consequences. The novelty of this study is to identify areas along the pipeline at higher risk of corrosion through the application of geospatial information systems and remote sensing. This methodology holds immense potential for industries looking to proactively prevent corrosion through the implementation of preventative maintenance, monitoring programs, and the application of protective coatings and inhibitors. The results of this research demonstrate that environmental data, GIS, and remote sensing can predict corrosion in oil pipelines, offering valuable insights for better managing corrosion risk.

Index Terms: Corrosion, Pipeline, Minerals, Aspect, Geographic information system, Remote sensing

1. INTRODUCTION

The effects of pipeline corrosion have been extensively studied [1]. Pipelines serve as the primary mode for transporting substances between regions and countries. However, corrosion in pipelines poses one of the most significant challenges for the global oil and gas industry [2]. Pipeline corrosion refers to the deterioration of piping material due to exposure to the operating environment which incurs significant costs for the global economy amounting to billions of dollars annually [3]. Considering that pipelines transport flammable, substances ensuring pipeline safety is of utmost importance. Consequently, the design and selection of the most suitable systems and materials hold great significance for the oil and gas industry [4]. In the current study, it is intended to investigate the corrosion around pipelines using remote sensing and geographic information system (GIS). GIS is commonly used to model pipeline systems, and it plays an important role in the management and operation of pipelines [5].

To detect various types of corrosion, comprehensive monitoring techniques are required. Implementing a combination of these techniques enables effective identification and assessment of different corrosion types [6]. A large number of studies indicate that stress has a significant effect on corrosion processes, leading to the development

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of pressure corrosion [7]. Wang *et al.* [8] found that stress concentration at the base of corrosion pits can facilitate the transition of pitting corrosion from a metastable state to a stable one. In addition, atmospheric corrosion, which occurs as a result of electrochemical and other reactions between a material's surface and the constituents of the surrounding atmosphere, encompasses various forms of corrosion [9]. The utilization of GIS tools, which encompass computer software, hardware, and data, enables a wide range of functionalities such as data entry, satellite image processing, manipulation, analysis, spatial analytics, transportation management, and data presentation related to specific locations on the earth's surface [10]. By employing GIS technology, significant geological hazards can be mapped and efficiently managed within a GIS database [11]. This approach greatly enhances the efficiency of oil and gas pipeline planning, as potential dangers and risks can be identified in advance [3]. The operations within the oil and gas industry, spanning from locating and extracting resources to managing field labor and transporting materials, are significantly influenced by geography. GIS assists organizations in a variety of pipeline operations such as pipeline planning, taking into account site factors such as terrain, soil type, and population, as well as pipe type and material, pipeline usage, and environmental impact [12].

The majority of previous studies in the field of pipeline corrosion have focused on investigating localized corrosion, primarily attributed to the flow characteristics within the pipe. These studies typically employ various instruments and devices to detect corrosion at specific locations along the pipeline.

The research problem is the characterization monitoring and management of corrosion, primarily within onshore pipelines. The paper aims to provide concise information on the current state of pipeline corrosion control and management. The objective of this study is to use GIS and remote sensing in technology and the advancements made in this field based on the existing knowledge. The results of the current study indicate that multiple elements contribute to the overall deterioration and structural weaknesses observed in the pipes.

2. METHODOLOGY

This research uses GIS to predict and monitor corrosion in pipelines and other infrastructure and create a corrosion risk map by combining data on soil minerals, moisture content, and other factors that contribute to corrosion. This map can be used to identify areas that are at high risk of corrosion and prioritize maintenance efforts. The information utilized for this investigation comprises a map delineating oil reservoirs and oil and gas transmission lines within the Kurdistan Region of Iraq. This particular map was formulated by the Ministry of Petroleum of the Kurdistan Region. In addition, a digital elevation model (DEM) map, sourced from the archives of the US Geological Survey, was employed. Landsat 8 satellite images, obtained from the US Geological Survey archive, were also incorporated. Furthermore, annual rainfall data for the study area were acquired from the Kurdistan Regional Meteorological Organization.

It uses data that are attached to a unique location [13]. First, we obtained a hard copy of the Ministry of Petroleum's map and georeferenced it. Then, we digitized the oil transmission lines using digital tools [14]. To extract slope information, we utilized the digital elevation model from the map [15]. For the hydrology section, to extract river routes from a DEM, the following steps were undertaken. First, the DEM data were obtained from the US Geological Survey archives, specifically DEM of the study area with a resolution of 28^2 m. This data can be acquired from various sources such as government agencies, research institutes, or commercial providers. Next, the DEM was pre-processed in hydrology tools in Arc GIS software to eliminate anomalies or errors, such as spikes or dips, which could impact the accuracy of the river extraction process. Subsequently, the flow direction was determined using the D8 algorithm, assigning a flow direction value (e.g., North, Northeast, East) to each cell based on the steepest slope, enabling the identification of potential water paths. A flow accumulation raster was created, representing the total number of cells with the flow in each cell, indicating areas with higher accumulation values that suggest potential river courses with increased flow [16]. In addition, a threshold value was determined based on the flow accumulation raster, which set the minimum accumulation required for a cell to be considered part of the river, thereby influencing the level of detail in the extracted river network. Finally, the river routes were extracted using the threshold flow accumulation raster through raster-to-vector conversion techniques, transforming the raster representation into polyline vectors. The extracted river courses were then validated by comparing them with Google Earth imagery [17,18].

To examine the impact of rainfall on pipeline corrosion rate, the initial step involved gathering data on the total rainfall from the previous year. Subsequently, employing the inverse weighted distance method[19], the precipitation amount for each pixel was computed. To analyze minerals in the soil, Landsat 8 satellite images of study areas were obtained from the USGS website. Image pre-processing and maps displaying the distribution of minerals were generated using the available remote sensing indices that are presented in equations (1-5) [20]-[22]. It is important to highlight that these indicators were executed within the ArcGIS software.

$$Gossan\ Index = \frac{\frac{Band\,6}{Band\,4} - 1}{\frac{Band\,6}{Band\,4} + \frac{Band\,7}{Band\,5}} \tag{1}$$

$$Fe2^{+}\ Index = \frac{(Band\,3 + Band\,4) - (Band\,2 + Band\,5)}{(Band\,3 + Band\,4) + (Band\,2 + Band\,5)} \tag{2}$$

$$\text{Ferric Minerals Index} = \frac{\frac{Band\,6}{Band\,4} - 1}{\frac{Band\,6}{Band\,4} + 1} \tag{3}$$

$$Laterite\ Index = \left(\frac{Band\,6}{Band\,4} - 1\right) * \left(\frac{Band\,5}{Band\,7} - 1\right) \tag{4}$$

$$\text{Clay Minerals Index} = \frac{\frac{Band\,7}{Band\,6} - 1}{\frac{Band\,7}{Band\,6} + \frac{Band\,5}{Band\,6} + 1} \tag{5}$$

Subsequently, employing the fuzzy membership function [23], [24], the criteria maps were initially standardized, ensuring that the output values fell within the range of 0.0–1.0 [23], [24]. Following this, all standardized maps were overlaid. In the end, the standardized maps were consolidated.

3. THEORETICAL WORK (CASE STUDY – PIPELINE)

In this study, various components need to be considered when discussing matters related to corrosion. These components include factors such as aspect, rivers, rain, and the presence of minerals in the soil, such as clay, gossan, laterite, Fe^{2+}, and Ferrite–Martensite interphase (FMI). By taking into account factors like these, we can improve the accuracy of our predictions regarding the areas on the pipelines that are prone to corrosion reactions.

3.1. Aspect (The Direction of the Slope)

The alignment of the earth's surface with regard to the sun is referred to as an aspect [25]. It is typically represented as an angle in degrees from 0 to 360. ArcGIS calculates the aspect of every cell within the buffer in a DEM based on the slope and direction of the cell. The direction of the slope can affect the corrosion rate of metals. Water has the biggest impact on the corrosion of slope protection net, followed by anion content. While this study did not directly measure humidity, it was indirectly assessed through geographic direction. This relies on established geographic patterns, where Northern and Western Regions typically have cooler and more humid conditions than southern and eastern areas. Incorporating geographic direction data serves as a proxy for humidity, allowing us to infer these environmental factors without direct measurements.

Total soluble salt has a moderate impact on corrosion [26]. The effect of slope direction on steel depends on the application. It was discovered that distinct impact angles and velocities are determined by varied slope directions and that the peak impact velocity increases with increasing slope direction [27]. Hence, with increasing slope direction (aspect), the corrosion rate of steel will increase.

3.2. Rainfall

Chemicals or other airborne particles known as air pollution can hasten the rate of corrosion. Carbon monoxide (CO), nitrogen oxides (NO and NO_2), sulfur dioxide (SO_2), and last but not least lead (Pb) are examples of air pollutants [28]. When some impurities such as sulfur dissolve in rainwater, the corrosion rate will increase. The rain droplets will catch any pollutants from the air while it falls down and when it reaches the pipelines, the pollutants from the droplets cause the rate of corrosion to speed up rapidly. Rainwater can cause uniform corrosion in pipelines. One of the key elements that cause pipelines to corrode is the presence of moisture. Rainwater may increase the acidity of the soil near the pipeline, which could result in corrosion [29]. The amount of moisture in the soil also has an impact on the pace of corrosion [30]. Water, dirt, and other environmental variables can all cause pipelines to corrode. Where water is present as a distinct phase, pitting corrosion typically develops [31].

3.3. River

First, we should mention that there are two types of rivers (drainage networks): Perennial rivers and seasonal rivers. Rivers that have a continuous flow of water all year round are known as perennial rivers. However, seasonal rivers are ones that only flow during the rainy season at a specific time [32]. Rivers can have a variety of effects on pipeline corrosion. For instance, the dissolved oxygen and other compounds that may be present in river water could cause the pipeline to corrode. The erosion of the soil surrounding a pipeline due to river movement is another factor that may expose the pipeline to corrosive substances [33]. Rivers can influence the rate of corrosion in various ways, including dampness. The amount of water vapor in the air is gauged by the concept of humidity. Rivers and humidity are related in that rivers have an impact on the humidity of the places around them. For instance, the surrounding air becomes more humid when water evaporates from a river. On the other hand, water flowing downstream from a river can lower the relative humidity in the region [34]. Humidity directly influences how quickly metals corrode. Above a given relative humidity, the corrosion attack or rusting rate is noticeably higher. The rate of corrosion is minimal, however, below the crucial humidity level. The essential humidity is often around 45%; however, it can occasionally be even lower [35]. When the amount of moisture in the air approaches critical humidity – the point at which water no longer evaporates or is absorbed from the atmosphere – humidity can result in atmospheric corrosion. In general, metal components corrode more quickly the longer they are exposed to humid air [36]. When a chemical reaction affects a whole exposed surface, uniform corrosion ensues. Typically, it occurs when metals are exposed to open environments such as water, air, and soil [37]. Then, the rate of corrosion increases with how close the river is. If our pipeline is close to the rivers, the humidity, moisture, and flow rate of the river can affect the corrosion rate.

3.4. Minerals

In the present study, only five mineral types have been taken into account. This selection was made based on their availability within the region under investigation and their suitability for indexing using remote sensing techniques.

3.4.1. Clay

The Clay Minerals Index is a remote sensing index that can be used to map the distribution of clay minerals in soils and rocks. Clay has absorption features in the short-wave infrared spectral region, which can be used to distinguish them from other minerals [38]. All the components of soil, including minerals, living things, and animals, go toward its creation. The minerals, flora, and fauna remnants are ground into tiny particles over time by the pressure of the water [39]. These soils expand and soften during rainy seasons as they absorb more water whereas contracting and hardening during dry seasons as they lose water. Structures constructed on such soils as pipelines are predicted to suffer severe damage due to this behavior [40]. Clay soil can cause corrosion in steel pipes due to the presence of sulfate-reducing bacteria [41] and this will then cause some reactions that will lead to microbial-induced corrosion.

3.4.2. Fe2

Iron is an element that can be found in plants, animals, soil, and rocks [42], and it belongs to the first transition series and Group 8 of the periodic table. In the field of corrosion, it is commonly acknowledged that the corrosion products of metal ions significantly impact subsequent corrosion processes. For instance, the oxides and hydroxides formed by Fe^{2+}/Fe^{3+} play a crucial role in determining the density and structure of the rust layer on the steel's surface [43].

3.4.3. Gossan

Gossan is an iron oxide that forms on the top of sulfide deposits [44]. Its formation is attributed to the acidity of the environment. Steel is susceptible to corrosion when exposed to gossan, leading to general corrosion [44]. The presence of gossamer can serve as an indicator of the existence of sulfide minerals, which can contribute to corrosion in metals [44]. When gossan is present, it suggests the presence of sulfide minerals in the nearby rock, thereby increasing the corrosion rates in metals exposed to the environment. Steel can undergo homogeneous corrosion as a result of gossan [44].

3.4.4. FMI

In Dual-Phase (DP) steels, the area between ferrite and martensite is known as the FMI [39]. There are two stages to the early corrosion process of DP steel. Due to the subsequent appearance of cathodic TM and FM, the steel corrodes more quickly in the first stage than it does in the second stage due to the dissociation of martensite [45].

A particular kind of localized corrosion that affects steel is known as FMI corrosion. It results from the steel's microstructure's inclusion of the phases ferrite and martensite. Corrosion between these two phases occurs at their interface and is characterized by material loss there [46].

3.4.5. Laterite

The Laterite Index is a spectral index calculated from Landsat 8 satellite imagery using specific bands to identify and characterize areas with lateritic soils. The formula for the index is given by ((Band 6)/(Band 4) - 1) * ((Band 5)/(Band 7) - 1). In this equation, "Band 4" represents the red band, "Band 5" corresponds to the near-infrared band, "Band 6" is associated with the shortwave infrared band 1, and "Band 7" represents the shortwave infrared band 2 [47]. The index involves two ratios, (Band 6 / Band 4 - 1) and (Band 5 / Band 7 - 1), which are multiplied together. The resulting index values can be used to highlight areas with lateritic soils, as the combination of specific spectral bands helps accentuate the unique characteristics of these soils. This type of remote sensing analysis aids in the identification and mapping of lateritic regions, providing valuable information for geological, environmental, and land-use studies [48].

A particular kind of localized corrosion that affects steel is known as FMI corrosion. It results from the steel's microstructure's inclusion of the phases ferrite and martensite. Corrosion between these two phases occurs at their interface and is characterized by material loss there [49].

3.5. Case Study

The theory was applied to real data for the purpose of analysis and further investigation. The Kurdistan pipeline (Fig. 1) was used as a case study, which connects the North Iraqi oil fields from the Topkhana oil field to Turkey. This article paper primarily focuses on crude oil pipelines. The Kurdistan oil pipeline, which was completed by the Kurdistan Regional Government of Iraq in 2013 [44], serves as a central subject of discussion. This functioning oil pipeline connects the Taq Taq oil fields to the broader pipeline network linking Kirkuk to Khurmala. From Khurmala, the pipeline continues through Dohuk and terminates further North at Fishkabur on the Turkish border. At Fishkabur, it links up with the primary Kirkuk-Ceyhan pipeline [50].

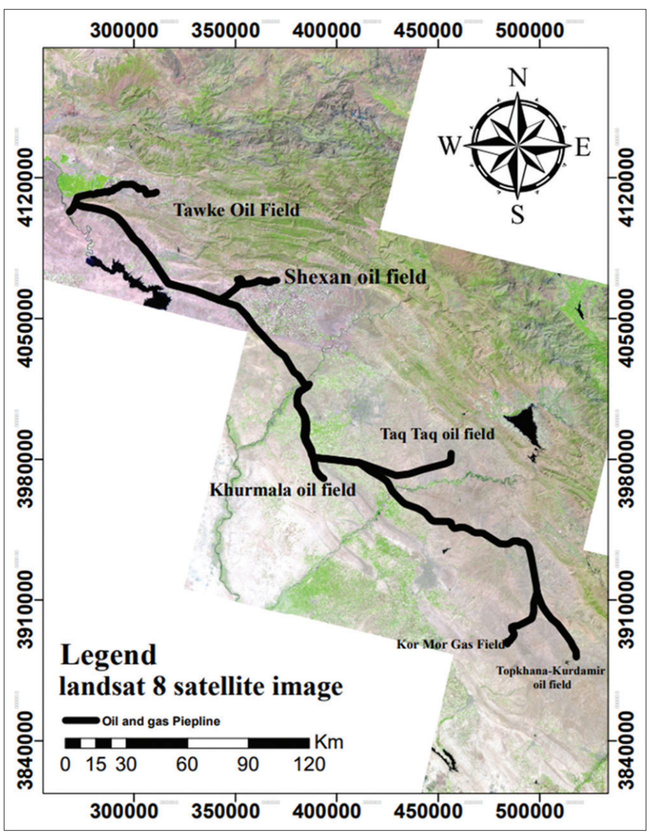

Fig. 1. Kurdistan oil pipeline.

In the subsequent sub-section, the theory will be applied to the pipeline to assess the impact of each factor on an individual map. The map data will then be standardized using Fuzzy logic, ensuring it falls within the range of 0–1, thus becoming dimensionless.

3.5.1. Aspect (Direction of the slope)

Aspect identifies the steepest downslope direction from each cell to its neighbors from the EM. It can be considered the slope direction or the compass direction of a hill face [19]. Regions that face more toward the North tend to have drier climates, resulting in lower humidity levels. Examples of such areas include Fish Khabur and the Tawke oil field. The higher values observed in the aspect map, as depicted in Fig. 2, are predominantly concentrated in these two regions.

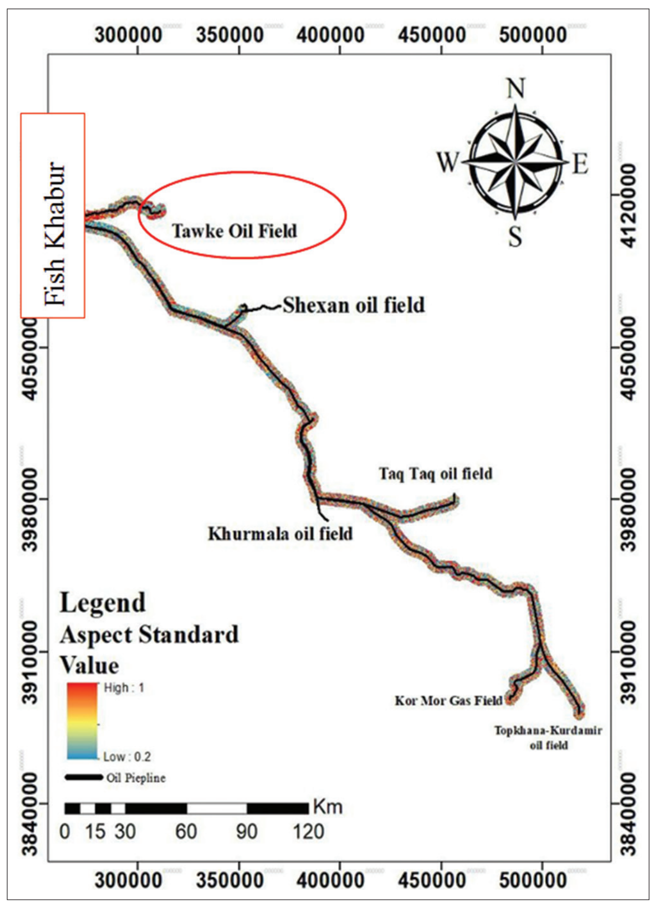

Fig. 2. Standardized aspect map depicting the intersection of oil transmission lines on the ground in different geographical directions

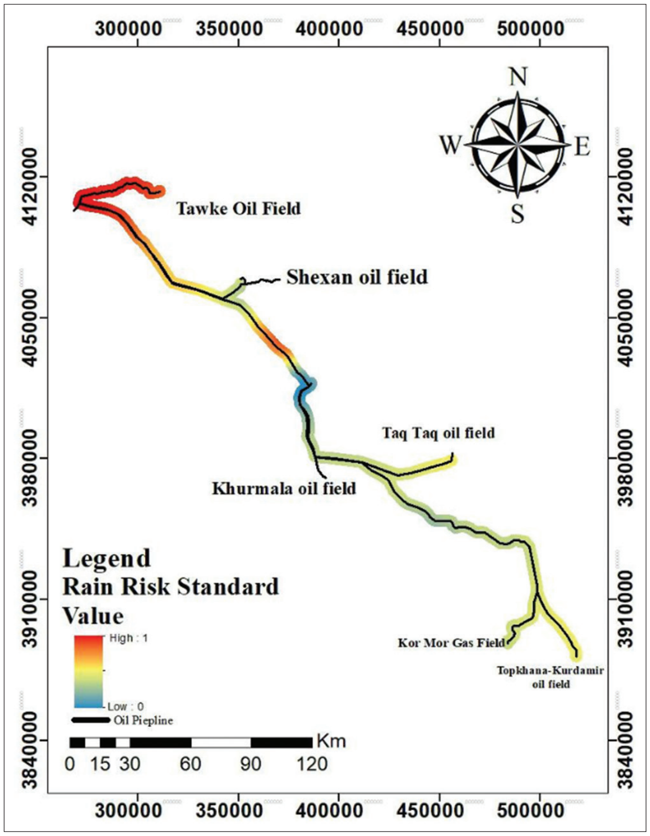

Fig. 3. Standardized spatial distribution map of rainfall.

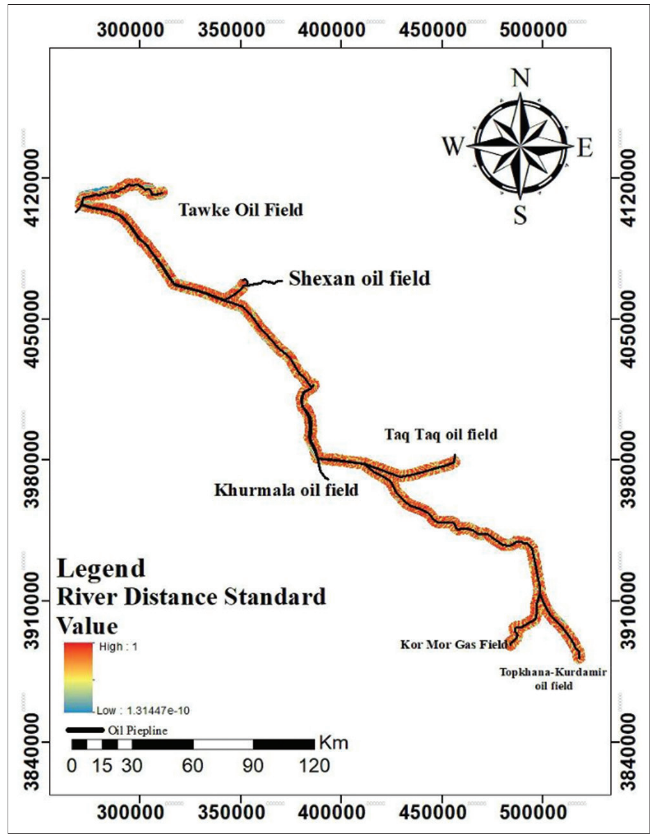

Fig. 4. River map (pipeline proximity to rivers).

3.5.2. Rain risk

According to the theory of corrosion, the increase in humidity resulting from rain and snow and the presence of impurities such as sulfur can lead to an increase in the rate of corrosion. When rain droplets collect pollutants from the air during their descent, these pollutants contribute to an accelerated corrosion process upon reaching the pipelines. The standardized spatial distribution map of rainfall depicted in Fig. 3 indicates that the corrosion rate is highest along the route from the Tawke oil field to Fish Khabur, with a ratio range of 0.844–0.990. On the other hand, the lowest corrosion rate is observed in the area between the Shekhan oil field and the Khurmala oil field (Kalak), where the ratio range is between 0.00056 and 0.2579.

3.5.3. River

Rivers can influence the corrosion rate through factors such as dampness. Humidity, which is a measure of water vapor in the air, is related to rivers as they affect the humidity levels of their surrounding areas. River water may contain dissolved oxygen and other compounds that can contribute to pipeline corrosion. Fig. 4 illustrates the river map, indicating the proximity of the pipeline to rivers. With the exception of the region between the Tawke oil field and Fish Khabur, where the ratio range is between 0.071 and 0.908, most regions exhibit similar ratios. This suggests that the corrosion rate remains relatively consistent across these areas, whereas the aforementioned region stands out with a comparatively lower ratio.

3.5.4. Minerals

3.5.4.1. *Laterite*

Minerals present in the soil have a significant impact on the corrosion rate. In particular, laterite and corrosion rate are closely related, as laterite can accelerate the corrosion of metals that come into contact with it. This is due to the significant presence of iron and aluminum in laterite, which can induce corrosion when in contact with metals [45]. The laterite map in Fig. 5 indicates the distribution of laterite in the region. The highest concentration of laterite is detected from Fish Khabur up until halfway toward the Tawke oil field. There is also a small area with high laterite in the North of the Khurmala oil field, although it is not as extensive as in Fish Khabur. The range of laterite in these

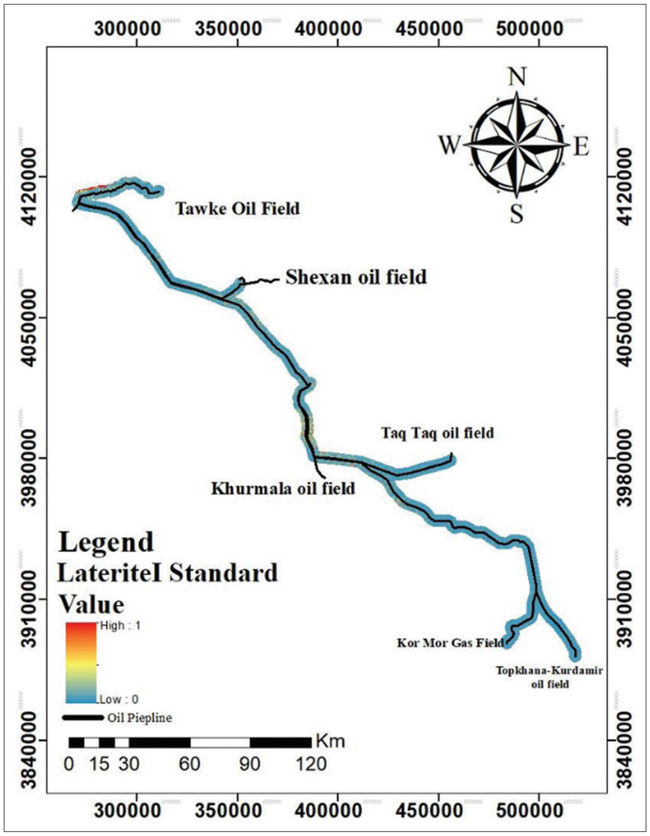

Fig. 5. Standardized laterite map illustrating the intersection of oil transmission lines on the ground.

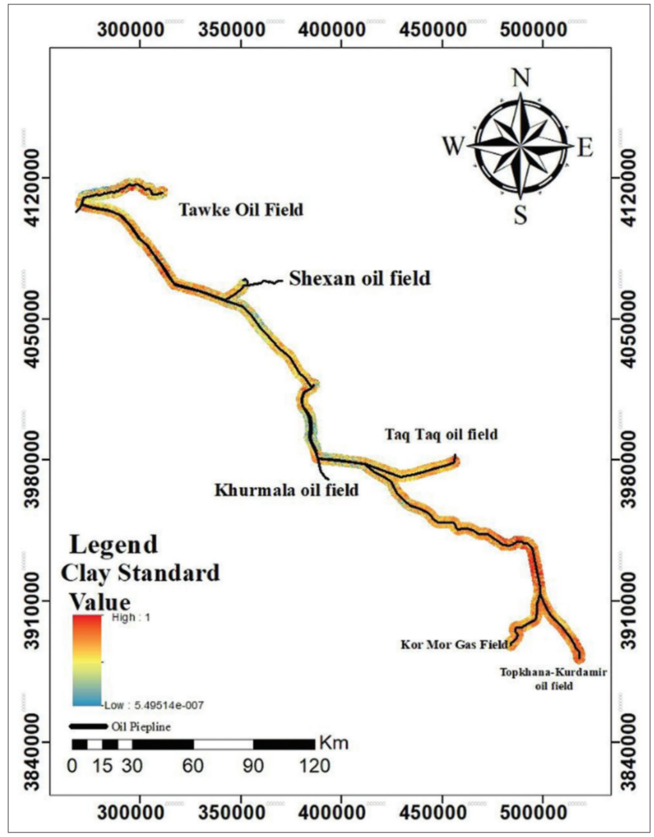

Fig. 6. Standardized clay map illustrating the intersection of oil transmission lines on the ground.

areas varies between 0.658 and 0.9114. The rest of the region exhibits a lower range of laterite, ranging between 0.595 and 0.658.

3.5.4.2. *Clay*

Clay can trap moisture and corrosive substances against the material of pipelines, because of the presence of clay in soil, these soils expand and soften during rainy seasons as they absorb more water, whereas contracting and hardening during dry seasons as they lose water and cause damages to pipelines. Microbial-induced corrosion also occurs due to the presence of sulfate-reducing bacteria in clay soil. The clay map is illustrated in Fig. 6, lowest value can be seen in the area between the Khurmla oil field and the Shekhar oil field and to be more exact from bina bawe to the Khurmala oil field, where it ranges (0.059–0.061). Most of the oil fields have similar high clay percentages. Except for the area between Shekhan and the Khurmala oil fields, more so starting near Khurmala and stretching southward until it reaches the joint that split into two branches (taq taq and chamchamal) with a range between 0.062 and 0.263.

3.5.4.3. *Fe^{2+}*

It is well established that the corrosion products of metal ions play a significant role in influencing subsequent corrosion processes. When iron (Fe2) reacts with water and oxygen, it generates these metal ions. The Fe^{2+} map, as presented in Fig. 7, highlights the areas with the highest concentration of Fe^{2+} from Fish Khabur up to halfway toward the Tawke oil field, with a range between 0.4341 and 0.5482. Conversely, the rest of the region, excluding the mentioned area, exhibits lower levels of Fe^{2+} with a range between 0.3145 and 0.3829.

3.5.4.4. *Gossan*

The presence of gossan can indicate that there is sulfide which can trap moisture and corrosive substances against metal surfaces in the surrounding rock, which can lead to increased corrosion rates in metals exposed to the environment. Fig. 8 presents a gossan map, it can be seen that the highest gossan amount in the area from the Tawke oil field moves southward until it reaches the pipeline that feeds into the Shekhan oil field and from the Shekhan oil field pipeline moves 37.357828 km South with ranges between

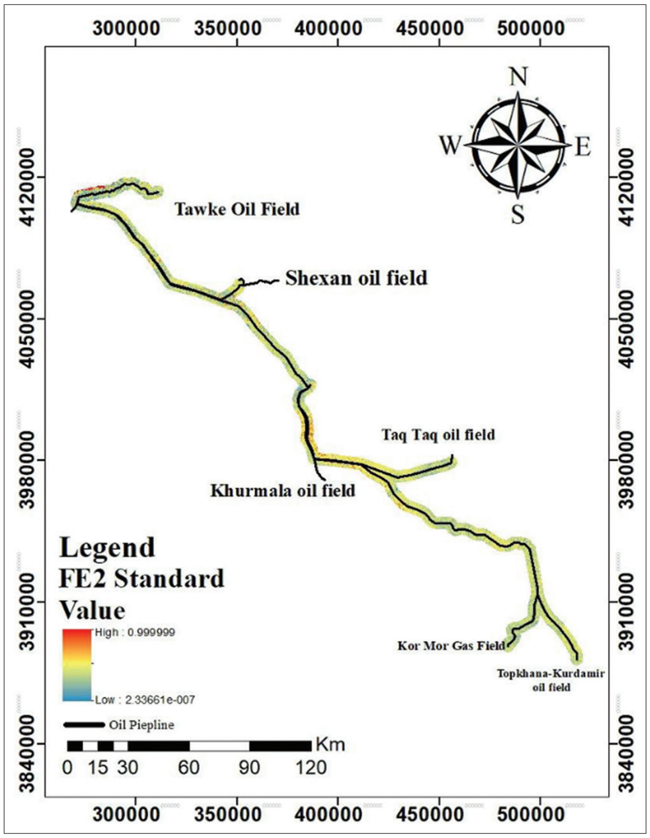

Fig. 7. Standardized Fe^{2+} map illustrating the intersection of oil transmission lines on the ground.

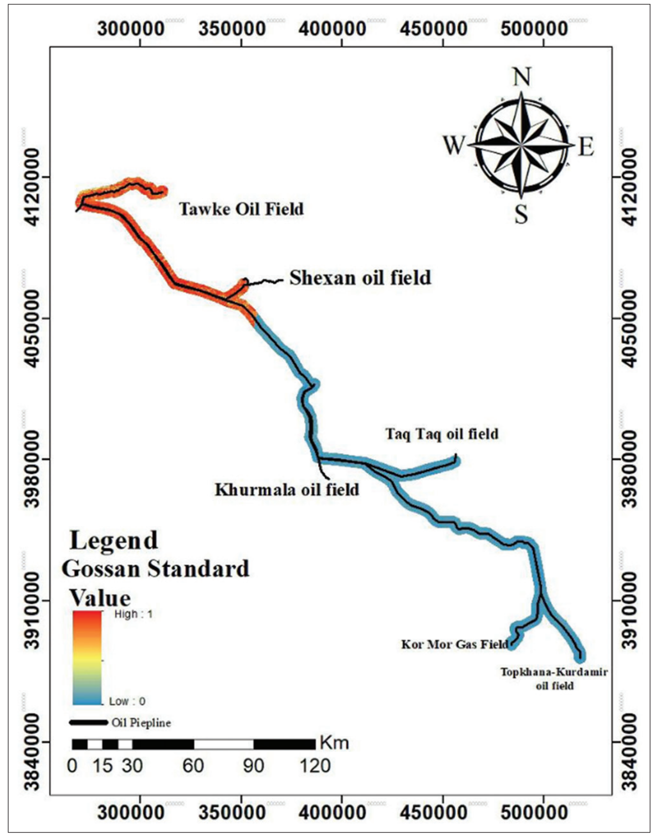

Fig. 8. Standardized Gossan map illustrating the intersection of oil transmission lines on the ground.

0.309 and 0.380. While the lowest gossan rate starts from 37.357828 km down from the Shekhan oil field pipeline and moves southward covering the areas: Khurmala, Taq Taq oil fields, and Kor Mor gas field, until it reaches the Topkhana oil field with a range between 0.168 and 0.226.

3.5.4.5. *Ferric minerals index FMI*

A particular kind of localized corrosion that affects steel is known as FMI corrosion. It results from the steel's microstructure's inclusion of the phases ferrite and martensite. Corrosion between these two phases occurs at their interface and is characterized by material loss [11]. The standard FMI map is illustrated in Fig. 9, and the highest FMI area exists from Fish Khabur to the Tawke oil field with ranges between 0.3538 and 0.5180 whereas the lowest FMI values are in the rest of the region (largest area) ranging between 0.3291 and 0.4191.

4. RESULTS AND DISCUSSION

Corrosion is a complex process that can be influenced by a wide range of factors. However, not all factors have the same impact on corrosion rates, and it is, therefore, necessary to assign appropriate weights to each factor to accurately assess the overall risk of corrosion. Failure to properly weigh each factor can result in inaccurate and erroneous assessments of corrosion risk. To address this issue, we have conducted a study of various criteria that can impact corrosion rates. Our analysis involves assigning weights to each criterion based on its relative contribution and significance in accelerating the corrosion process. By considering the unique characteristics of each criterion, we can develop a more comprehensive and accurate understanding of the overall risk of corrosion. It is important to note that the weighting process is not arbitrary but is based on scientific and engineering principles. By leveraging our collective expertise and experience, we have developed a rigorous and systematic approach to assigning weights which ensures that the assessments are both reliable and consistent in Table 1. With this approach, it can help ensure the safe and effective operation of engineering systems and structures by identifying and mitigating corrosion risk.

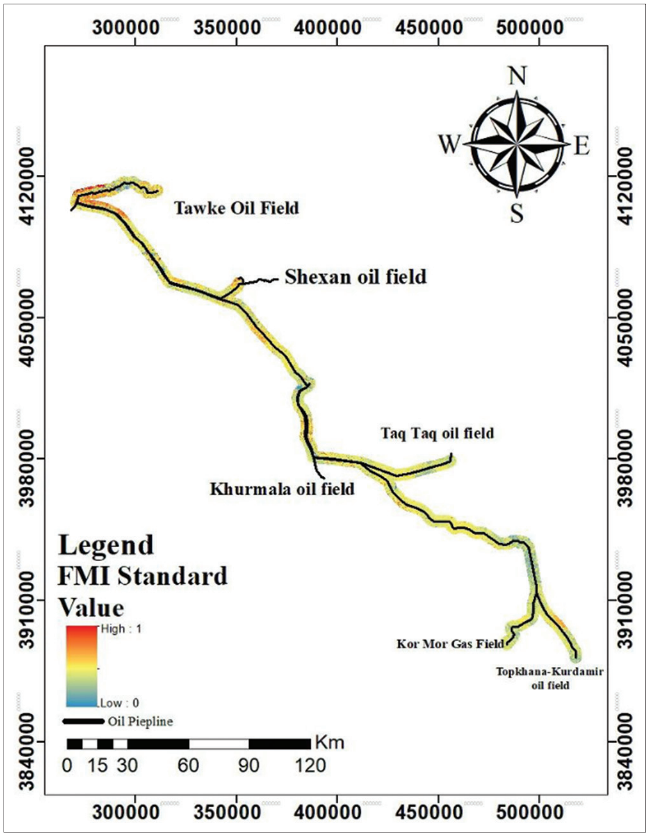

Fig. 9. Standardized Ferrite–Martensite Interphase map illustrating the intersection of oil transmission lines on the ground.

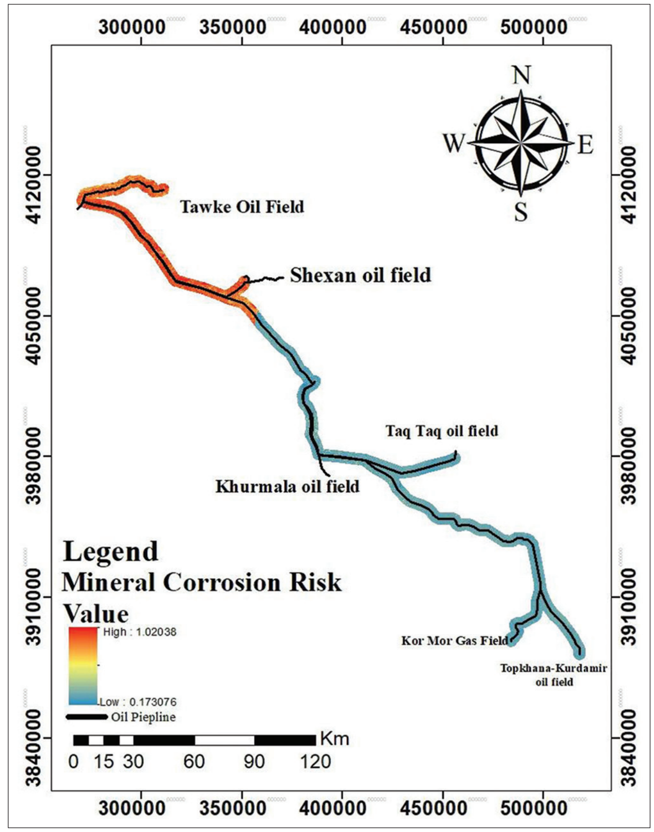

Fig. 10. Minerals corrosion risk map.

In this study, we employed the Delphi method for weighting the criteria. The Delphi method is a structured and iterative communication technique that involves a panel of experts. Through a series of rounds, these experts anonymously share their opinions and insights, and the process continues until a consensus is reached or a pre-defined level of agreement is achieved. The Delphi method helps aggregate the diverse perspectives of experts and is particularly useful in situations where there may be uncertainties or varying opinions regarding the importance of different factors.

The rainfall rate has the highest weight of (22%) since it can contribute most toward corrosion and since there was a high rate of precipitation for the data used during (2019–2020). Fe^{2+} minerals (21%) have a lot of contribution toward corrosion. The river weight is (14%) since it is considered a flow accumulation of greater than 500 ml; the rivers can be seasonal and might not be around all year round. While the weight for the clay is given (13%) since at times can contribute toward corrosion whereas at other times, it can act as a protective barrier from outside sources. The rest of the minerals are given (8%–7%–7%) for FMI, gossan, and laterite, respectively, since they seem to be less abundant as visible from the mapping of these minerals, and without the presence of moisture or water these minerals cannot contribute much toward corrosion. The process of giving weights is done by multiplying each corrosion factor by its corresponding weights and then overlaying them. Fig. 10 is the overlay map for the minerals only, and Fig. 11 is the overlay map for all the

TABLE 1: Factors weights

Factors	Weights (%)
Aspect	8
River	14
Rain	22
Clay	13
Fe^{+2}	21
FMI	8
Gossan	7
Laterite	7

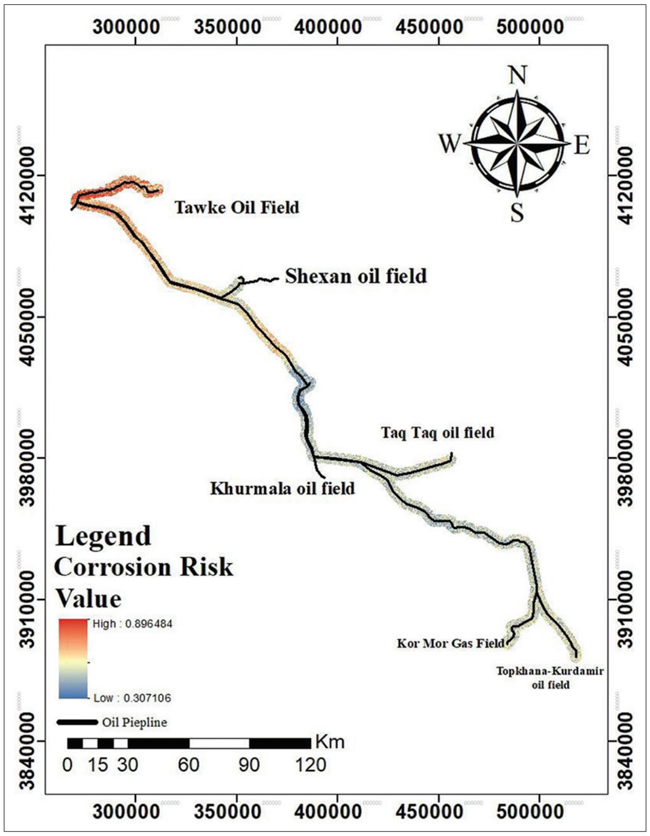

Fig. 11. Corrosion risk map.

factors including minerals with the weights that are given in Table 1. It appears that corrosion is more prevalent in the Northern regions as compared to the Southern regions. This can be attributed to the fact that the areas in the North experience higher levels of precipitation, therefore, are more exposed to moisture and humidity. In addition, the level of minerals is high in that region. Corrosion is strongly influenced by the presence of water and oxygen. As a result, regions with high levels of moisture and humidity, such as those found in the northern areas, are more prone to corrosion than those with lower levels, such as the southern areas.

5. CONCLUSION

This paper demonstrates how GIS technology can be utilized to identify areas at higher risk of corrosion. The data on environmental factors were analyzed to generate maps that could visually display the distribution of these factors. By overlaying these maps, regions that are more susceptible to corrosion were identified. The use of GIS and remote sensing technologies in identifying areas of higher risk emphasizes the significance of corrosion risk assessment. The findings of the current study are based on the principles of corrosion science and materials engineering. Corrosion occurs due to the interaction between metal structures and their environment. By utilizing GIS technology to identify areas at higher risk of corrosion, industries can take a proactive approach to prevent or mitigate the corrosion process, ultimately ensuring the safe and sustainable operation of critical infrastructure.

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