Molecular and Virulence Analysis of Pseudomonas aeruginosa Isolated From Burn Infections Recovered From Duhok and Erbil Hospitals, Iraq

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ABSTRACT

In this study, 225 isolates of Pseudomonas aeruginosa were recovered from burn wounds in major hospitals in Duhok and Erbil, Iraq, between April 2015 and September 2015. A total of 136 of these isolates were from men, comprising 60.4% of the total, whereas 89 (39.6%) were recovered from women. One hundred of these isolates were selected (50 from each province of Erbil and Duhok) and subjected to 16 different antibiotics using the disc diffusion method. The isolates showed a high level of resistance to most of the tested antibiotics, with 90% of the isolates being multidrug resistant. Imipenem was considered as the most effective antibiotic against these isolates with a resistant rate of 47%. The genome of all of these isolates were successfully amplified and produced a single band for the 16S rDNA locus with a molecular weight of about 956 base pairs, which was used to confirm, at the molecular level, that all these isolates were indeed P. aeruginosa. The results of the detection of five virulence-related genes including opr1, toxA, exoS, lasB, and nan1 revealed that 10 of these isolates, accounting for 10%, lacked any of the tested virulence markers. The opr1 gene, as a marker for the presence of a pathogenicity island, was the most dominant marker among all the virulence markers and was detected in 90 isolates (90%), followed by the toxA and exoS genes, which were both observed in 86 (86%) isolates, whereas the lasB gene was found in 82 (82%) isolates and the nan1 gene in 35 (35%) of the isolates, respectively.

Keywords: Burn infection, P. Aeruginosa, PCR, 16s rDNA, Virulence genes

1. INTRODUCTION

Pseudomonas aeruginosa is an opportunistic pathogen that infects organisms and causes nosocomial infections (Vincent et al., 2004). It is one of the major causes of chronic lung infections in patients with cystic fibrosis (CF) and a major cause of hospital-acquired infections (Stover et al., 2000).

P. aeruginosa is well suited to survive in a wide variety of environments including water, soil, and animals, and it is prevalent in common, everyday surroundings (David et al., 2007). P. aeruginosa infections may occur in patients with cancer, patients suffering from urinary tract infections, and patients suffering from burn wounds (Bodey et al., 1983). Infections caused by P. aeruginosa are often difficult to treat because of the prominent resistance exhibited by the pathogen to antimicrobial agents (Hancock, 1998). In the context of a breakdown in host defenses, it is capable of infecting a plethora of tissue types, causing both acute and chronic infections. Burn victims as well as immunocompromised, mechanically ventilated, and patients with CF are particularly susceptible to P. aeruginosa infections (Sadikot et al.,...
2005). *P. aeruginosa* exhibits a variety of virulence factors to overcome the host defenses and establish an infection. These factors include the production of hemolysin, pyocyanin, gelatinase, and the formation of biofilms, which act by increasing tissue damage and helping the bacteria to evade the immune system and to avoid the action of antibiotics (Cevahir et al., 2008). The pathogenesis of the infections is multifactorial, as suggested by the number and broad range of virulence determinants expressed by the bacterium (Todar, 2009). *P. aeruginosa* is notorious for its multiple virulence factors such as adhesins, biofilm formation, elastase production, surface hemagglutinin, motility, synthesis and production of pyocyanin, rhamnolipid, type III secretion system, colonization pili, lipopolysaccharide, flagella, alkaline protease, siderophore uptake systems, and extracellular protein toxins (e.g., exoenzyme S and exotoxin A) (Gallagher and Manoil, 2001).

2. MATERIALS AND METHODS

A total of 225 clinical isolates of *P. aeruginosa* from infected burn wounds were collected from different patients attending major hospitals in Duhok and Erbil, Iraq. The patient population comprised both sexes, different ages, and different percentages of burn coverage during the period from April 2015 to September 2015. On the basis of the clinical judgment of the infection, swabs of pus from an infected burn wound were collected at the same time the dressings were changed. All of the clinical isolates, suspected to be *P. aeruginosa*, which were collected from the infected burn wounds were recultured onto various media including MacConkey agar, cetrimide agar, blood agar, and nutrient agar by the streak plate method and incubated at 37°C for 24 hours (Cheesbrough, 2006). The isolates were subjected to antibiotic sensitivity testing by the disc diffusion method on Mueller-Hinton agar according to the National Committee for Clinical Laboratory Standards and the Manual of Antimicrobial Susceptibility Testing (Cheesbrough, 2006; CLSI, 2007). Genomic DNA was extracted from 100 *P. aeruginosa* strains using a high yield DNA purification kit according to the manufacturer instructions (Bioneer, Daejeon, Republic of Korea).

The results of the DNA extraction were visualized using ultraviolet light after being electrophoresed on a 1% agarose gel (Maniatis et al., 1982). Table 1 shows the sequences of the primers and the amplification band sizes for the 16S rDNA, nan1, exoS, lasB, toxA, and opr1 genes, which were used for polymerase chain reaction (PCR) amplification by adding 12.5 µl of master mix (GeneDirex, USA), 1 µl of each primer including the forward and reverse primers (10 pmol/µl), 4 µl of genomic DNA (25–50 ng/µl), and 6.5 µl of sterile, deionized distilled water to each reaction. All of the prepared reaction tubes were placed in the thermal cycler to carry out the amplification.

The amplification conditions are illustrated in Table 2. The presence of the PCR product was confirmed electrophoretically using a 1.5% (w/v) agarose gel in tris-borate-ethelenediminetetraacetic acid buffer. A molecular marker of 1,500–100 base pairs (bp) was used to determine the molecular weights of the PCR products (Maniatis et al., 1982).

<table>
<thead>
<tr>
<th>Table 1: Molecular weights of the genes and sequences of the primers used</th>
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</thead>
<tbody>
<tr>
<td>Gene</td>
</tr>
<tr>
<td>16S rDNA</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Nan1</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>ExoS</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>LasB</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>ToxA</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
3. RESULTS

The purified isolates that grew on MacConkey and cetrimide agar confirmed that the isolates were indeed *P. aeruginosa* and that the tests were not contaminated during transport from the respective hospitals in Erbil and Duhok, Iraq. These isolates were found to be negative for lactose fermentation and formed pale yellow colonies on MacConkey agar and produced β-hemolytic colonies on blood agar. The colonies were surrounded by a bluish-green coloration on nutrient agar because of the production of soluble pyocyanin and pyoverdine, which is a water-soluble, yellow-green pigment. The pigments produced by the colonies on the selective cetrimide agar were more obvious (Prescott et al., 1993). The identity of the *P. aeruginosa* isolates from infected burn wounds were confirmed by biochemical tests such as the oxidase test, citrate utilization test, and the ability to grow at a temperature of 42°C (Cunliffe et al., 1995).

**Table 2:** PCR amplification conditions for the 16S rDNA, Nan1, ExoS, LasB, ToxA, and Opr1 genes of *Pseudomonas* spp.

<table>
<thead>
<tr>
<th>Gene</th>
<th>Initial denaturation</th>
<th>Denaturation</th>
<th>Annealing</th>
<th>Extension</th>
<th>Final extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>16S rDNA</td>
<td>95°C; 2min;</td>
<td>94°C; 20 s</td>
<td>54°C; 20 s;</td>
<td>72°C; 40 s</td>
<td>72°C; 5 min;</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>25 cycles</td>
<td></td>
<td>1 cycle</td>
</tr>
<tr>
<td>Nan1</td>
<td>94°C; 5 min</td>
<td>94°C; 20 s</td>
<td>54°C; 1 min</td>
<td>72°C; 1min</td>
<td>72°C; 90 s</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>36 cycles</td>
<td></td>
<td>1 cycle</td>
</tr>
<tr>
<td>ExoS</td>
<td>95°C; 2 min</td>
<td>94°C; 30 s</td>
<td>60°C; 1 min</td>
<td>72°C; 1 min</td>
<td>72°C; 5 min</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>35 cycle</td>
<td></td>
<td>1 cycle</td>
</tr>
<tr>
<td>LasB</td>
<td>94°C; 3 min</td>
<td>94°C; 30 s</td>
<td>60°C; 1 min</td>
<td>72°C; 90 s</td>
<td>72°C; 5 min;</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>30 cycle</td>
<td></td>
<td>1 cycle</td>
</tr>
<tr>
<td>ToxA</td>
<td>94°C; 2 min</td>
<td>94°C; 2 min</td>
<td>68°C; 1 min</td>
<td>72°C; 1 min</td>
<td>72°C; 7 min</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>30 cycle</td>
<td></td>
<td>1 cycle</td>
</tr>
<tr>
<td>Opr1</td>
<td>95°C; 2 min</td>
<td>94°C 40 s</td>
<td>57°C; 50 s</td>
<td>72°C; 20 s</td>
<td>72°C; 5 min</td>
</tr>
<tr>
<td>1 cycle</td>
<td></td>
<td></td>
<td>25 cycles</td>
<td></td>
<td>1 cycle</td>
</tr>
</tbody>
</table>

**Opr1**

F 5’ATGAACAACTGCTGAATTCTCTT3’

R 5’CTTGCGGCTGGCTTTTTCCAG3’

De Vos et al., 1993
Table 3: Samples of *P. aeruginosa* collected from 2 areas in Iraq and their prevalence among male and females patients

<table>
<thead>
<tr>
<th>Provinces</th>
<th>Number of patients</th>
<th>Male, n (%)</th>
<th>Female, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erbil</td>
<td>125</td>
<td>72 (57.6)</td>
<td>53 (42.4)</td>
</tr>
<tr>
<td>Duhok</td>
<td>100</td>
<td>64 (64)</td>
<td>36 (36)</td>
</tr>
<tr>
<td>Total</td>
<td>225</td>
<td>136 (60.4)</td>
<td>89 (39.6)</td>
</tr>
</tbody>
</table>

The patient demographics for the 225 patients from which the *P. aeruginosa* isolates were obtained are depicted in Table 4 and include the cause of the burn wounds, age, sex, and the total burn surface area (TBSA). Burns from a flame was the most common cause of the burn wounds, representing 125 (55.5%) of the patients, whereas scalding was the second most common cause of burn wounds, representing 85 (37.7%) of the patients. The remaining 15 patients (6.6%) had chemical (acid) burns. Forty two out of the 125 patients (33.6%) whose burn wounds were caused by fire were aged 12 years and below, while the remaining 83 (66.4%) patients were older than 12 years. Of those patients with burn wounds caused by fire, 88 (70.4%) were male and 37 (29.6%) were female. The TBSA for the patients with fire burns was less than 15% for 29 (23.2%) of the patients, whereas the remaining 96 (76.8%) patients had a TBSA of >15%.

A total of 33 of the 85 patients (38.8%) who obtained burn wounds from scalding were younger than 12 years, whereas the remaining 52 (61.1%) patients were older than 12 years. Of the patients with burn wounds from scalding, 43 (50.5%) were male and the remaining 42 (49.4%) patients were female. The TBSA for the patients with burn wounds from scalding were <15% for 13 (15.2%) of the patients and >15% for the remaining 72 (84.7%) patients. Of the 15 patients who had burn wounds from acid, 4 (26.6%) were younger than 12 years, whereas the remaining 11 (73.3%) patients were older than 12 years. The patients with acid burns were mostly male, representing 12 (80%) of the patients, whereas the remaining 3 (20%) patients were female. The TBSA was <15% for 5 (33.3%) of the 15 acid burn patients, whereas the remaining 10 (66.6%) patients had a TBSA of >15%.

The results of the antimicrobial sensitivity tests for the *P. aeruginosa* isolates, representing 50 of the isolates from each of the Duhok and Erbil territories, are shown in Table 5. It is clear that none of the isolates were sensitive to all the antimicrobials. Imipenem, an antimicrobial from the carbapenem class of antibiotics, was found to be the most powerful among all other antimicrobials with a combined resistance rate of 47% across the 2 districts.

Table 4: The cause of the burn wounds, age, sex, and the tbsa for the 225 patients from which the *P. aeruginosa* isolates were obtained

<table>
<thead>
<tr>
<th>Cause of burn</th>
<th>Patients, n (%)</th>
<th>&lt;12 years (n=79)</th>
<th>&gt;12 years (n=146)</th>
<th>Male (n=143)</th>
<th>Female (n=82)</th>
<th>&lt;15% (n=47)</th>
<th>&gt;15% (n=178)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame</td>
<td>125 (55.5)</td>
<td>42 (33.6)</td>
<td>83 (66.4)</td>
<td>88 (70.4)</td>
<td>37 (29.6)</td>
<td>29 (23.2)</td>
<td>96 (76.8)</td>
</tr>
<tr>
<td>Scald</td>
<td>85 (37.7)</td>
<td>33 (38.8)</td>
<td>52 (61.1)</td>
<td>43 (50.5)</td>
<td>42 (49.4)</td>
<td>13 (15.2)</td>
<td>72 (84.7)</td>
</tr>
<tr>
<td>Acid</td>
<td>15 (6.6)</td>
<td>4 (26.6)</td>
<td>11 (73.3)</td>
<td>12 (80)</td>
<td>3 (20)</td>
<td>5 (33.3)</td>
<td>10 (66.6)</td>
</tr>
</tbody>
</table>

Table 5: Resistance distribution against the tested antibiotic for the *P. aeruginosa* isolates from Duhok and Erbil

<table>
<thead>
<tr>
<th>Antibiotics</th>
<th>Class</th>
<th>Duhok Resistance, n (%)</th>
<th>Erbil Resistance, n (%)</th>
<th>Total Resistance, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Meropenem may be considered as the antibiotic with the highest resistance rate among the *P. aeruginosa* isolates, with 95 (95%) of the isolates across both territories displaying resistance. The *P. aeruginosa* isolates showed a high level resistant to most of the tested antimicrobials with the resistances rates for tobramycin, gentamicin, amikacin, and aztreonam being 94%, 93%, 91%, and 90%, respectively. Resistance against ampicillin and piperacillin, which are usually considered as first-line treatments for *P. aeruginosa* infections of burn wounds, seemed to be widespread with a total resistance rate for each of the antibiotics of 85% across the 2 territories. The resistance rates for the drug combinations ticarcillin-clavulanic acid and ampicillin-sulbactam was found to be in the range of 71% and 83%, respectively. The trimethoprim-sulfamethoxazole combination and ciprofloxacin seemed to have a relatively low resistance rate with 54% and 56% of the strains across both territories displaying resistance, respectively. There was a high level of resistance against the fourth generation cephalosporins with cefepime, ceftazidime, ceftriaxone, and cefuroxime having resistance rates of 93%, 91%, 90%, and 90%, respectively.

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th>Type</th>
<th>Resistant Rate Across Territories (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amikacin</td>
<td>Aminoglycoside</td>
<td>46 (92), 45 (90), 91 (91)</td>
</tr>
<tr>
<td>Tobramycin</td>
<td>Aminoglycoside</td>
<td>48 (96), 46 (92), 94 (94)</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>Aminoglycoside</td>
<td>46 (92), 47 (94), 93 (93)</td>
</tr>
<tr>
<td>Ticarcillin-clavulanic acid</td>
<td>Beta-lactam</td>
<td>35 (70), 36 (72), 71 (71)</td>
</tr>
<tr>
<td>Ampcillin-sulbactam</td>
<td>Beta-lactam</td>
<td>40 (80), 43 (86), 83 (83)</td>
</tr>
<tr>
<td>Ampcillin</td>
<td>Penicillin</td>
<td>43 (86), 42 (84), 85 (85)</td>
</tr>
<tr>
<td>Piperacillin</td>
<td>Penicillin</td>
<td>44 (88), 41 (82), 85 (85)</td>
</tr>
<tr>
<td>Meropenem</td>
<td>Carbapenem</td>
<td>47 (94), 48 (96), 95 (95)</td>
</tr>
<tr>
<td>Imipenem</td>
<td>Carbapenem</td>
<td>25 (50), 22 (44), 47 (47)</td>
</tr>
<tr>
<td>Cefepime</td>
<td>Cephalosporin</td>
<td>49 (98), 44 (88), 93 (93)</td>
</tr>
<tr>
<td>Ceftazidime</td>
<td>Cephalosporin</td>
<td>45 (90), 46 (92), 91 (91)</td>
</tr>
<tr>
<td>Ceftriaxone</td>
<td>Cephalosporin</td>
<td>45 (90), 45 (90), 90 (90)</td>
</tr>
<tr>
<td>Cefuroxime</td>
<td>Cephalosporin</td>
<td>46 (92), 44 (88), 90 (90)</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>Fluoroquinolone</td>
<td>27 (54), 29 (58), 56 (56)</td>
</tr>
<tr>
<td>Aztreonam</td>
<td>Monobactam</td>
<td>43 (86), 47 (94), 90 (90)</td>
</tr>
<tr>
<td>Trimethoprim-sulfamethoxazole</td>
<td>Folate pathway inhibitor</td>
<td>23 (46), 31 (62), 54 (54)</td>
</tr>
</tbody>
</table>
In the PCR tests, the 16S rDNA gene was successfully amplified for all of the 100 *P. aeruginosa* isolates, generating a single band at a molecular weight of around 956 bp, and providing further evidence that all of the strains that were isolated were indeed *P. aeruginosa*. These results are depicted in Fig. 1.

![PCR products](image1)

**Figure 1.** The PCR products, observed as bands, that correspond to amplification of the 16S rDNA gene of *P. aeruginosa* after electrophoresis on 1.5% agarose gels and run at 5 V/cm for 1.30 hour. Line M contained the DNA marker (1,500–100 bp).

The prevalence rates of the virulence-related genes *opr1*, *toxA*, *exoS*, *lasB*, and *nan1* in the *P. aeruginosa* isolates were investigated using PCR amplification and the results of these amplifications are displayed in Figs. 2, 3, 4, 5, and 6 and Table 6.

![PCR amplification of opr1 gene](image2)

**Figure 2.** PCR amplification of the *opr1* gene with a molecular weight of 249 bp following electrophoresis on a 1% agarose gel that was run at 5 V/cm for 1.30 hours. Line M contained the DNA molecular weight marker (1,500–100bp).

![PCR amplification of toxA gene](image3)

**Figure 3.** PCR amplification of the *toxA* gene with a molecular weight of 396 bp following electrophoresis on a 1% agarose gel that was run at 5 V/cm for 1.30 hours. Line M contained the DNA molecular weight marker (1,500–100bp).
4. DISCUSSION

From the results presented in Table 3 it can be seen that of the 225 isolates of *P. aeruginosa* that were collected from various hospital in 2 areas (Erbil and Duhok) in Iraq, 143 were isolated from men, accounting for 63.5% of the isolates, whereas 82 strains were isolated from women, accounting for 36.4% of the isolates. On the basis of the results obtained to create a better understanding of the patient demographics for comparison to other studies, presented in Table 4, it was observed that the most common cause of burn wounds in these regions was fire, with 25 (80.6 %) of the patients being burned with fire. Scalding and acid burns were the second and third most common causes of burns, respectively. The most common patient demographics associated with an increased rate of

<table>
<thead>
<tr>
<th>Table 6: Prevalence of the virulence markers among the <em>P. aeruginosa</em> isolates collected from the Erbil and Duhok provinces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Virulence markers</strong></td>
</tr>
<tr>
<td><strong>Province</strong></td>
</tr>
<tr>
<td>Erbil</td>
</tr>
<tr>
<td>Duhok</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
**P. aeruginosa** infection, irrespective of the cause of the burns, were male patients older than 12 years of age and a TBSA >15% (Naqvi et al., 2005). The TBSA was found to be the greatest risk factor for nosocomial infections (Oralancul et al., 2002). **P. aeruginosa** remains the most common pathogen associated with burn wound infections (Lari and Bahrami, 1998). It survives well in the clinic environment. Once **P. aeruginosa** colonization has been established, it can survive for months inside a unit and pose a threat as a multidrug resistant pathogen that can cause nosocomial infections in the patients being treated there. The hands of staff members can be contaminated with the bacteria, which can then be spread readily among patients (Edwards, 2003). In previous studies, the effectiveness of imipenem against **P. aeruginosa** was moderately greater, i.e., 86%, 78%, 88.6%, and 91.6%, respectively (Neely and Holder, 1999). The resistance of the **P. aeruginosa** isolates against imipenem was much higher in our study (48%) than that reported in a previous study conducted by Song et al. (2001) in Korea.

The rates of resistance against these drugs should be considered in the treatment of serious bacterial infections caused by β-lactam resistant bacteria (Paterson, 2006). The development of carbapenem resistance owing to the generation of carbapenemase compounds in Gram negative organisms is increasing universally. The discovery of carbapenem resistance in the hospital environment poses a great risk for infection that needs to be controlled (Hodiwala et al., 2013). Carbapenems are valuable in the treatment of a few cases of multidrug resistant strains of **P. aeruginosa** (Douglas, 2001).

Comparative studies about the use of antimicrobial agents in the treatment of patients with multidrug resistant infections are limited, but a few of these agents remain valuable in the treatment of specific patients (Nicolle, 2005). In another study comparing the effectiveness of a range of antimicrobial agents in the treatment of **P. aeruginosa** infections, 100% of the tested strains were resistant to amikacin, 95% were resistant to gentamicin, 94% were resistant to aztreonam, and 91% were resistant to tobramycin (Naqvi et al., 2005). In a comparative study conducted in Pakistan in which the effectiveness of ampicillin and piperacillin was also determined in the treatment against **P. aeruginosa**, it was found that 87% of the tested strains were resistant to ampicillin and piperacillin (Naqvi et al., 2005). The broad utilization of the fourth generation of cephalosporins is the driving force behind the rise in the extended-spectrum β-lactamase (ESBL)-generating organisms and has been the focus of numerous studies (Paterson, 2006). It has been found that the genes that encode the ESBLs are habitually found on the same plasmids as the genes that encode resistance to the aminoglycosides and trimethoprim-sulfamethoxazole (Yasufuku et al., 2011).

This implies that ESBL producing bacteria are commonly multidrug resistant, which poses a specific challenge in the treatment of nosocomial infections. Unsuccessful antimicrobial treatment of nosocomial- or community-acquired infections has been established to contribute to the mortality rates in intensive care units. Unsuccessful antimicrobial treatment of infections was the most important determinant of the mortality rates in hospitals (Paterson, 2006). Numerous previous studies have reported the successful amplification of the 16S rDNA gene as shown in Fig. 1, and this has been deemed a prerequisite for the molecular identification of **P. aeruginosa** (Theodore et al., 2004). The results obtained corresponded with those of a study conducted in the Baghdad Territory in which the same primers for the 16S rDNA gene were used for the identification of **P. aeruginosa** and in which the same molecular weight band was obtained. The results displayed in Figs. 2 to 6 appear to correlate with a number of related studies, for example, Khattab et al. (2015) found that 100% of their **P. aeruginosa** isolates possessed the oprl gene, whereas the nanl gene had the lowest prevalence.

In another study conducted in Poland by Wolska and Szweda (2009), it appeared that the most common virulence genes among **P. aeruginosa** isolates obtained from burn wound infections were lasB, toxA, and exoS, with prevalence rates of 96.8%, 88.7%, and 75.8%, respectively. Fazeli and Momtaz (2012) also determined the prevalence of the virulence factors of **P. aeruginosa** isolates from burn wound infections and found that the prevalence rates for exoS and toxA were 67.6% and 35.2%, respectively. The differences between the prevalence rates of **P. aeruginosa** virulence genes based on the geographic location were investigated in studies conducted by Rasol (2013) in the Duhok territory and by Karimian et al. (2012) in Iran who concluded that the climate of each location, their traditions, their foods, levels of open well-being, and hospital cleanliness may all contribute to the differences in the prevalence rates of
virulence genes among the P. aeruginosa strains from various districts.

5. CONCLUSION

It can be concluded that molecular methods are a fast and effective way of confirming the identity of P. aeruginosa isolates. It is important to determine if multidrug resistant isolates of P. aeruginosa are present and if they pose a risk of spreading widely and increasing their resistance rates over time.

REFERENCES


Synthesis of Zeolite A from Iraqi Natural Kaolin Using a Conventional Hydrothermal Synthesis Technique

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ABSTRACT

The synthesis of zeolite materials by hydrothermal transformation of kaolin using a conventional hydrothermal method was investigated. Different analytical techniques were used to characterize the starting kaolin and produced zeolite A samples, including scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), x-ray diffraction (XRD), x-ray fluorescence (XRF), thermogravimetric analysis (TGA), and Fourier transform infrared (FT-IR) spectroscopy. The synthetic zeolite type A was obtained after activation of kaolin and metakaolin followed by different thermal and chemical treatments. The metakaolinization phase was achieved by calcining the kaolin in air at 600°C for 3 hours, a much lower temperature than previously reported in the literature. Metakaolin was treated with 3 M sodium hydroxide solution at a ratio of 1:5 and, using stainless steel autoclaves with teflon liners, heated the mixture to 200°C in a microwave for 24 hours. The results from this synthesis route showed that zeolite A with a cubic crystal habit has been successfully synthesized.

Keywords: Zeolite A, Kaolin, Metakaolin, Hydrothermal synthesis

1. INTRODUCTION

Zeolites are well-known aluminosilicate that have been used widely as adsorbents in separation and purification processes and in the control of environmental pollution. Zeolites are used in various industrial applications owing to their high cation-exchange ability and molecular sieve and catalytic properties (Dyer and Zubair 1998; Ramos et al., 2004). Both natural zeolites and synthetic zeolites have important uses such as in petrochemical cracking, wastewater treatment, nuclear energy generation, as a landfill liner, in contaminated land remediation, and, more recently, in several emerging fields of health and medicine (Alvarez-Ayuso et al., 2003; Ackley et al., 2003). Furthermore, in comparison with the natural zeolites, synthetic zeolites have shown greater efficiency in the treatment of wastewater owing to their excellent adsorption capacities and high performances.

Previous studies have revealed that the preparation of synthetic zeolites from chemical sources of silica and alumina are more expensive when compared with the conversion of raw materials (i.e., natural sources of silica and alumina) into zeolitic materials using hydrothermal transformation (Querol et al., 1997; Tanaka et al., 2004; Adamczyk and Bialecka 2005; Walek et al., 2008; Kovo and Holmes 2010). Trials continued to improve the such as type A, mordenite, and X, Y, P zeolites, which are derived from cheaper raw materials, such as clay
Among these naturally available raw materials, kaolin, which has a silica to alumina ratio of nearly 1, similar to zeolite A, has been used as an alternative cheap raw material for the synthesis of zeolite A (Miao et al., 2009). Currently, synthetic zeolites are used more often in the commercial setting than natural zeolites owing to the homogeneity of their particle sizes and the purity of the crystalline products (Szotak, 1998).

Kaolin (Al₂O₃·2SiO₂·2H₂O) is a rock or sedimentary deposit rich in kaolinite and other very similar clay minerals, such as dickite, nacrite, and halloysite. Kaolin is also known as “China clay.” It was discovered in the year 1867 and the word “kaolin” is derived from the name of the Chinese town Kao-Ling located in the Jiangxi Province of southeast China (Paul, 2003; Pohl, 2011). The basic kaolin mineral structure comprises layers of a single tetrahedral silica (SiO₄) sheet and a single octahedral alumina [Al(O, OH)₆] sheet joined by sharing a common layer of oxygen and hydroxyl units (Deer et al., 1992). The low reactivity of kaolin is demonstrated in the difficulties that are encountered when it used in a chemical synthesis method (Murat et al., 1992), and accordingly, kaolin first needs to be decomposed by calcination at temperatures of between 550°C and 950°C to obtain the metakaolin phase formed following the loss of structural water and the subsequent reorganization of the structure (Lambert et al., 1989). Kaolin undergoes a series of phase transformations when thermally treated. The formation of metakaolin during thermal treatment is an essential step, which depends on the following 3 reactions (Scheme 1): destruction of the kaolin sheet structure, dehydroxylation and the recombination of silica and alumina to form the structure of metakaolin (Rios et al., 2007).

2. EXPERIMENTAL WORK

2.1. Synthetic zeolite procedure

The kaolin samples were crushed and milled into powder using a porcelain mortar before being sieved using laboratory soil sieves. The mesh sizes selected for the collection of the kaolin particles were 75 µm<dp<125 µm. Synthesis of zeolite A from kaolin involved the following 2 basic steps: the first step involved metakaolinization, which is the thermal treatment of the raw kaolin at a high temperature of 600°C for 3 hours, and the second step was the chemical treatment of the prepared metakaolin with 3 M sodium hydroxide (NaOH).

During the past decades, numerous studies have focused on minimizing the synthesis cost of good quality, pure zeolite A with a high crystallinity. Many studies have focused on the optimization of the main factors known to strongly effect the type and degree of crystallinity of the synthesized zeolite A, including the method of preparation, the type of mineralizer, concentration, and time (Rios et al., 2007; Ugal et al., 2010; Mousa and Buhl, 2014).

The concentration of the base is one of the most important parameters that control the crystallization of zeolites. The increase in alkalinity causes an increase in the crystallization rate via both nucleation and crystal growth (Wang et al., 2008).

In this study, local natural kaolin from Iraq was used as the starting material to produce zeolite A using a hydrothermal synthesis technique, enabling the exploitation of the large clay mineral deposits available, which is abandoned mainly as kaolin.
steel autoclaves with a teflon liner, heated the mixture to 200°C for 24 hours in order to insert the sodium ions into the metakaolin structure, as shown by the following reaction:

\[
6\text{Al}_2\text{Si}_2\text{O}_7\text{(metakaolin)} + 12\text{NaOH} \rightarrow 12\text{Na}(\text{AlO}_2)_{12}(\text{SiO}_2)_{12}\text{(zeolite A)} + 27\text{H}_2\text{O} + 6\text{H}_2\text{O} \quad (2)
\]

The treated kaolin clay was then washed 3 times with deionized water to remove the excess unreacted NaOH. It was subsequently filtered and dried in an oven at 100°C overnight as shown in Scheme 2. Various samples with different NaOH concentrations were prepared in order to study the optimum concentration required for the synthesis of zeolite A.

2.3. Characterization of the untreated and thermally treated kaolin

The physical and chemical characteristics of the samples were studied using the following analytical techniques:

2.3.1. Scanning electron microscopy

The surface morphology of the kaolin and zeolite A samples was determined using a ZEISS EVO50 scanning electron microscope (SEM) under the following analytical conditions: electron high tension (EHT) = 10.00 kV and 20.00 kV; signal A = secondary electron (SE) 1 and variable pressure secondary electron (VPSE); WD = 6.0, 6.5, 7.0, and 8.5 mm at different magnifications. The SEM micrographs in Figures 1 and 2 show the appearances of the kaolin products obtained before and after hydrothermal treatment of kaolin and metakaolin.

2.3.2. Energy-dispersive spectroscopy

The energy-dispersive spectroscopy (EDS) (Oxford INCA) analytical technique was used in this study for the analysis of the elemental composition or chemical characterization of the Iraqi kaolin and zeolite A samples. The main elements and their corresponding oxides were determined by EDS. The localizations of the 4 analyzed sites were designated by numbers and a typical EDS spectrum.

2.3.3. X-ray diffraction

X-ray diffraction (XRD) is an analytical technique used for the phase identification of natural kaolin and zeolite A materials and in this study, an Empyrean PANalytical x-ray diffractometer with copper K-alpha radiation at 40 mA and 40 kV and secondary monochromation was used. All of the data collection was obtained in the 2° 0 range at a starting position of 5° and an end position of 50° or 80°, with a scanning step of 0.02° 0. The results of the crystalline patterns were compared with the standard line pattern database supplied by the International Centre for Diffraction Data.

2.3.4. X-ray fluorescence spectroscopy

The analysis of the elemental composition of the raw Iraqi kaolin and the prepared zeolite was obtained using an LXE, PANalytical x-ray fluorescence (XRF) spectrometer with a 50 kV energy x-ray tube. The chemical analysis of the Iraqi kaolin in the “as received” form was studied.

2.3.5. Thermogravimetric analysis

The thermal stabilities of the raw Iraqi kaolin and the Iraqi metakaolin were obtained using thermogravimetric analysis (TGA) on a Perkin Elmer TGA7 thermobalance between 30°C and 1000°C. A heating rate of 20°C/min was applied under a nitrogen atmosphere. Thermal analysis methods were used to obtain information about the mass loss change and adsorption or crystallization. The transition of Iraqi kaolin to Iraqi metakaolin was observed at about 570°C.

2.3.6. Fourier transform infrared spectroscopy

An ALPHA (Brucker) Fourier transform infrared (FT-IR) spectrometer with a single platinum attenuated total reflectance (ATR) diamond module was used for the analysis of the materials in this study. The FT-IR spectra of the raw materials were recorded in the range of 400 to 4000 cm⁻¹. The FT-IR spectra of the original and thermally treated kaolin were investigated at 600°C, 950°C, and 1000°C.

3. RESULTS AND DISCUSSION

The micrographs of the “as received” Iraqi kaolin samples are presented in Figure 1. The images were obtained using SEM analysis under the following SEM analytical
conditions: EHT = 10.00 kV, Signal A = SE1, and WD 6.0 mm at a magnification of 20000x. The micrograph in Figure 1 shows that the crystals of the Iraqi kaolin is not well defined and that the crystallites are in a random orientation before any modification. Kaolin can be recognized by its platy morphology, which is composed of small, loosely packed hexagonal plates (Mousa and Buhl, 2014). In contrast, the micrographs of the Iraqi metakaolin samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 6.5 mm at a magnification of 20000x and 10000x. The samples were calcined at 600°C for 3 hours. The micrographs show the randomly oriented crystallites and, in particular, indicate the appearance of the hexagonal plates (Figure 2). The micrographs of the synthesized zeolite A samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 7 mm at magnifications of 5000x and 10000x. As shown in Figures 3 and 4, the micrographs indicate, in particular, the well-defined and that the crystallites are in a random orientation before any modification. Kaolin can be recognized by its platy morphology, which is composed of small, loosely packed hexagonal plates (Mousa and Buhl, 2014). In contrast, the micrographs of the Iraqi metakaolin samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 6.5 mm at a magnification of 20000x and 10000x. The samples were calcined at 600°C for 3 hours. The micrographs show the randomly oriented crystallites and, in particular, indicate the appearance of the hexagonal plates (Figure 2). The micrographs of the synthesized zeolite A samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 7 mm at magnifications of 5000x and 10000x. As shown in Figures 3 and 4, the micrographs indicate, in particular, the well-defined and that the crystallites are in a random orientation before any modification. Kaolin can be recognized by its platy morphology, which is composed of small, loosely packed hexagonal plates (Mousa and Buhl, 2014). In contrast, the micrographs of the Iraqi metakaolin samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 6.5 mm at a magnification of 20000x and 10000x. The samples were calcined at 600°C for 3 hours. The micrographs show the randomly oriented crystallites and, in particular, indicate the appearance of the hexagonal plates (Figure 2). The micrographs of the synthesized zeolite A samples were obtained under the following SEM analytical conditions: EHT = 10.00 kV, Signal A = SE1, and WD = 7 mm at magnifications of 5000x and 10000x. As shown in Figures 3 and 4, the micrographs indicate, in particular, the well-formed, typical cubic-shaped crystals of zeolite A with an average particle size of 3.1 µm.

The raw kaolin contained quartz as a major impurity. Kaolin can be identified by its characteristic XRD peaks at 12.23° and at 24.82° 2θ (Zhao et al., 2004; Gougazeh and Buhl, 2010). However, kaolin contains minor impurities of illite, muscovite, and halloysite. A variety of XRD patterns for the kaolin transformation phases at different temperatures are presented in Figure 6, including the untreated, “as received” kaolin and the thermally treated kaolin materials at 600°C, 950°C, and 1000°C. The XRD patterns for the treated kaolin show a significant difference in comparison with the untreated kaolin sample, which was characterized by the disappearance of the diffraction peaks of kaolin and the appearance of amorphous aluminosilicate patterns (Mousa and Buhl, 2014). Metakaolin is an amorphous material and the highest diffraction peaks correspond to the presence of quartz (SiO₂), which is the crystalline phase in metakaolin (Mousa and Buhl, 2014). The XRD pattern for zeolite type A, as prepared by the conventional hydrothermal synthesis method, is shown in Figure 7.

The XRD plot for the synthesized zeolite A, with both the “a” and “b” marked lines indicating a database match, indicates the presence of 2 difference phases. The “a” lines indicate the presence of zeolite A (73%), while the “b” lines represent the presence of sodalite (27%), as determined by phase quantification according to the Rietveld method. The effect of the NaOH concentration (2, 4, 5, and 6 M NaOH) is shown in Figure 8. Analyzing the XRD data of the prepared samples showed the appearance of the characteristic peaks of zeolite A occurring at 3 M NaOH; however, zeolite A did not form at 2, 4, 5, and 6 M NaOH. The optimum crystallinity is obtained with 3 M NaOH, concurring with similar data obtained by Ayele et al. (2015), who synthesized zeolite material from activated kaolin samples that were reacted with 3 M NaOH. Furthermore, Mousa and Buhl (2014) found that a concentration of 1.5 to 3.5 M of NaOH is ideal for the synthesis of zeolite A. In this study, a concentration of 3 M of NaOH was found to be ideal for the synthesis of zeolite A.

Information about the weight loss change and structural transformations of kaolin was obtained using DTA/TGA techniques at a temperature range of between 30°C and 1000°C (Figure 9). As expected, dehydration occurred during the first stage at temperatures below 400°C during which the weakest part of the chemical bond was broken or disturbed. Subsequently, dehydroxylation occurred in
the temperature range of 450°C and 600°C. During this stage of the transformation, the kaolin is transformed to the metakaolin phase with the loss of structural hydroxyl groups. At a temperature range of between 925°C and 950°C, a progressive decomposition occurs in which metakaolin converts to spinel. The DTG curve of the kaolin sample (Figure 9) shows a prominent peak at 570°C owing to dehydroxylation and at 980°C owing to the formation of a new solid phase. The total loss calculated from the thermogravimetric analysis was 23.5%.

Kaolin can be transformed into metakaolin at temperatures above 570°C. The dehydration of kaolin begins at between 550°C and 600°C during which disordered metakaolin is produced, with the continuous loss of hydroxyl ions up to a temperature of 900°C (Rios et al., 2007; Gougazeh and Buhl, 2010). According to Kakali, et al. (2001), kaolin dehydroxylation occurs at temperatures between 400°C and 650°C, which is the stage of transformation to metakaolin (Kakali, et al., 2001). Frost et al. (2003) determined that this kaolin dehydroxylation process occurs between 450°C and 550°C. However, in this study, the dehydroxylation process occurred between 450°C and 600°C.

During calcination of kaolin, the silicon atoms experience a range of reactions with different distortion owing to dehydroxylation (Bellotto, 1995). The aluminum atoms mostly transform from an octahedral to a tetrahedral geometry. As the calcination temperature increases, the structure becomes more distorted and amorphous silica is then formed (Bellotto, 1995). The dehydroxylation process might cause a disturbance of the Al(O,OH)₆ octahedral sheet at the outer hydroxyls, but it does not have much effect on the SiO₄ tetrahedral sheets owing to the more stable inner hydroxyl groups (Rios et al., 2007). The outer hydroxyls of the octahedral sheets may be removed more easily by heating than the inner hydroxyls, which will maintain a more ordered SiO₄ tetrahedral group in the structure during dehydroxylation (Rios et al., 2007). After heating at 950°C, the SiO₄ groups combine with the AlO₄ group to form the Al–Si spinel phase, which has a short-range ordered structure (Bellotto, 1995).

The results from the TGA/DTG analysis show that the zeolite A sample underwent continuous weight loss during the stepwise heating to 900°C owing to dehydration and dehydroxylation (Figure 10). According to Perraki and Orfanoudaki (2004), weight loss below 200°C is caused by losses of hygroscopic and loosely bonded water.

FT-IR spectra of the raw materials were recorded in the range of 400 to 4000 cm⁻¹. FT-IR spectra of the untreated and thermally treated kaolin were investigated at 600°C, 950°C, and 1000°C. Figure 11 shows the FT-IR spectra of the “as received” kaolin before calcination. The peaks at 3692 and 3620 cm⁻¹ can be attributed to the stretching vibration of the hydroxyl groups in the kaolin structure (Saikia et al., 2003; Perraki and Orfanoudaki, 2004; Zhao et al., 2004).

The peaks at 3620 cm⁻¹ were attributed to the stretching vibration modes of the inner hydroxyl groups, which are the OH groups located in the octahedral and tetrahedral sheets. The peaks at 3692 cm⁻¹ correspond to the stretching vibration modes of the inner surface OH groups, which are positioned at the surface of the octahedral sheets of the adjacent kaolin layer (Kristof, 1993).

The 1115 cm⁻¹ peak can be attributed to the stretching vibration of the Si–O bonds in the kaolin structure (Figure 11), whereas the peaks at 1034 cm⁻¹ and 1002 cm⁻¹ are caused by lattice vibrations of both the Si-O-Si and Si-O-Al bonds (Van der Marel and Beutelspacher, 1976). Frost et al. (2002) assigned the bending vibrations of the OH groups to the peaks at 910 cm⁻¹ and 942 cm⁻¹ corresponding to the “surface OH bends” and the “inner OH bends.” According to Van der Marel and Beutelspacher (1976), these bending vibrations of the OH groups are mainly caused by the bonds in the Al-OH groups (Sinha et al., 1995). The peaks at 795 cm⁻¹ and 749 cm⁻¹ were assigned to the Si-O-Si bonds and finally, the 456 cm⁻¹ and 522 cm⁻¹ peaks were assigned to deformation of the vibration of the Si–O bonds.

Figure 12 shows the transformation process of kaolin to metakaolin. The conversion of kaolin to metakaolin is revealed by the disappearance of these characteristic peaks. The peaks of metakaolin, located at 796 cm⁻¹ and 801 cm⁻¹, which are assigned to the Si-O-Al bonds, can be observed (Lambert et al., 1989). The vibration band at 1076 cm⁻¹ for metakaolin was assigned to the stretching of the Si-O-Si bonds, as reported in the previous studies (Sinha et al., 1995; Valcke et al., 1997; Qiu et al., 2004).
The presence of these bands confirmed the conversion of kaolin to the metakaolin phase, which was obtained from the calcined kaolin.

The 1034 cm\(^{-1}\) peak of metakaolin was shifted to 960 cm\(^{-1}\) (Fig. 12), which could be assigned to the antisymmetric stretching of the Si-O-Si or Si-O-Al bonds in the aluminosilicates with a zeolite structure (Nesse, 2000). A peak of weak intensity was observed around 549 cm\(^{-1}\), indicating the presence of zeolite A in the cubic prism form (Figure 13). It could represent the beginning of the crystallization of a zeolite with double rings (Alkan et al., 2005). The peaks at 456 cm\(^{-1}\) correspond to the internal linkage vibrations of the Si-O-Si or Si-O-Al tetrahedral structures and to the asymmetric stretching of zeolite A. The transformation of kaolin to zeolite A can be observed clearly in the FT-IR spectra in the lattice region 960 to 456 cm\(^{-1}\) (Fig. 13). The kaolin starting material gives well-defined FT-IR spectra bands in this region owing to the Si-O, Si-O-Al, and Al-OH vibrations.

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**Table 1. The chemical composition (% wt.) of the kaolin and zeolite type A using EDS and XRF analytical techniques**

<table>
<thead>
<tr>
<th>Element</th>
<th>Na(_2)O%</th>
<th>MgO%</th>
<th>Al(_2)O(_3)%</th>
<th>SiO(_2)%</th>
<th>K(_2)O%</th>
<th>CaO%</th>
<th>TiO(_2)%</th>
<th>FeO(_3)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolin</td>
<td>1.64</td>
<td>0.23</td>
<td>13.49</td>
<td>15.72</td>
<td>0.22</td>
<td>0.76</td>
<td>0.70</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>1.74</td>
<td>0.21</td>
<td>30.17</td>
<td>39.37</td>
<td>0.48</td>
<td>0.89</td>
<td>0.78</td>
<td>1.49</td>
</tr>
<tr>
<td>Zeolite A</td>
<td>4.624</td>
<td>0.104</td>
<td>17.47</td>
<td>25.95</td>
<td>0.159</td>
<td>0.79</td>
<td>0.56</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>4.744</td>
<td>0.114</td>
<td>16.47</td>
<td>23.95</td>
<td>0.179</td>
<td>0.69</td>
<td>0.66</td>
<td>1.26</td>
</tr>
</tbody>
</table>

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**Scheme 1.** Flow diagram to indicate the various steps in the process of transforming Iraqi kaolin to zeolite type A by thermal treatment
Scheme 2. A flowchart showing the conversion of the raw materials into zeolitic materials conducted by conventional hydrothermal synthesis.

Figure 1. SEM micrograph of kaolin showing the crystalline nature of kaolin at a magnification of 2000×.

Figure 2. SEM micrographs showing the crystalline nature of metakaolin at a magnification of (a) 20000× and (b) 10000×.
Figure 3. A SEM micrograph showing the orientation of the crystallites obtained using a conventional hydrothermal synthesis reaction at a magnification of 5000×.

Figure 4. A SEM micrograph showing the orientation of the crystallites obtained using a conventional hydrothermal synthesis reaction at a magnification of 10000×.

Figure 5. Spectral analysis showing the elemental composition of the kaolin sample.

Figure 6. XRD patterns of the untreated and calcined kaolin at different temperatures. Ill, illite; K, kaolin; Ms, muscovite; Mul, mullite.
Figure 7. XRD Graphic analysis showing the mineralogical XRD analysis of zeolite A and sodalite.

Figure 8. XRD graphic analysis showing the mineralogical XRD analysis on the effect of various NaOH concentrations (2, 4, 5, and 6 M NaOH).
Figure 9. Thermogravimetric analysis (TGA/DTG) of Iraqi kaolin showing the events between 30°C and 1000°C

Figure 10. The thermogravimetric analysis (TGA/DTG) of zeolite A prepared by conventional hydrothermal synthesis routes showing the curves between 20°C and 900°C

Figure 11. The FT-IR spectra obtained for the “as received” kaolin before calcinations
4. CONCLUSIONS

Following evaluation of the results obtained, the following conclusions can be drawn:

- Iraqi kaolin proved to be suitable for the production of zeolite type A following heating at 600°C for 3 hours, paving the way for the provision of local, low cost adsorbents that can be used in the removal of pollutants from wastewater and the reduction of material waste products.

- Applying both the EDS and XRF techniques revealed that SiO$_2$, Al$_2$O$_3$, Na$_2$O, and K$_2$O are the main components of kaolin and zeolite A. The analysis also showed that the predominant exchangeable cations in the kaolin and zeolite A structures are Na$^+$, Mg$^{2+}$, K$^+$, and Ca$^{2+}$, which remained unchanged during the dehydration and dehydroxylation transformations of kaolin.

- Optimization of the synthesis parameters for zeolite A from Iraqi kaolin was achieved for the first time. The parameters that were optimized are as follows: a base of 3 M NaOH, a crystallization time of 24 hours, a temperature of 200°C, and a 24-hour time interval for gel-formation conditions. By following these parameters, synthesis of zeolite A with a high crystallinity of about 90% in the cubic crystal form was achieved.

- The findings from the FT-IR spectra as well as the DTA/TGA measurements showed that the metakaolin phase can be obtained by heating the kaolin at 600°C for 3 hours.
• Finally, from the physicochemical characterization results, it can be concluded that the Iraqi kaolin used in this study has properties suitable for zeolite synthesis and could be, in principle, a useful source of silica and alumina.

REFERENCES


Comparative Study on Hydrocarbon Generation in Different Tectonic Zones: A Case Study from the Upper Jurassic Naokelekan Formation at the Imbricated and High Folded Zones, Kurdistan Region, Iraq

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1. INTRODUCTION

The Upper Jurassic Naokelekan Formation was selected as a potential source rock to address its petroleum generating potential within 2 different tectonic zones, and to discuss the reasons for the differences in the capacity of generating hydrocarbons within the studied sections. A source rock is defined as a rock that has the ability to generate or that has generated movable quantities of hydrocarbons (Law, 1999); thus, the quantity, quality, and thermal maturity of the organic matter (OM) have been documented as the 3 elements that a potential source rock should have. The quality and quantity of the OM are associated with the depositional environment. However, thermal maturity is related to the tectonic history and the geologic structure of the

ABSTRACT

The impact of tectonic activities from different tectonic zones on hydrocarbon generation in the Upper Jurassic Naokelekan Formation was addressed in this study. The Upper Jurassic Naokelekan Formation is an important potential of source rocks for hydrocarbon generation that charges most of the Cretaceous and younger reservoirs in the Kurdistan Region, Iraq. A total of 5 rock specimens from the Warte outcrop and 7 cutting samples from Well Bina Bawi-1 were collected for Rock-Eval pyrolysis to investigate the relationship between the ability of the formation to generate hydrocarbons and tectonic activities. The results of Rock-Eval analysis on the analyzed samples showed an average of 2.65 wt% and 0.9 wt% total organic carbon (TOC) for Warte and Well Bina Bawi-1, respectively. Based on the TOC data, the Naokelekan Formation, in general, has a good to very good source rock potential. The qualitative properties of the organic matter (OM) of the formation were inferred from the kerogen types. The Warte section mostly contains type III kerogen that is gas prone, whereas the Well Bina Bawi-1 section contains mixed type I-II kerogen that is oil prone. It should be taken into consideration that the values for the hydrogen index (HI) of the Warte section are unreliable for interpretation of the organic type, because the HI is considerably reduced owing to the high level of thermal maturity. The T_{max} values showed that the Warte section is thermally more mature than the Well Bina Bawi-1 section. The difference in the thermal maturity can likely be attributed to the differential effects of the tectonic activities on the studied areas. Depending on the proximity or distance of the area in relation to the subduction zone, the sediments in the Imbricated Zone were more affected by the tectonic activities than the sediments in the High Folded Zone. Accordingly, the main factors that might have caused a higher thermal maturity in the Imbricated Zone include a high paleo heat flow, overthrusting, and hydrothermal activities.

Keywords: Naokelekan, Imbricated Zone, High Folded Zone, Hydrocarbon generation, Heat flow, Hydrothermal
sedimentary basin (Law, 1999). Hydrocarbon generation occurs because of the chemical breakdown of kerogen with rising temperature. Thus, temperature and time represent the most significant factors that contribute to the breakdown of kerogen (Allen and Allen, 2013). The Naokelekan Formation is well known as an important source rock within the petroleum systems of the Kurdistan Region. Almost all the Cretaceous and Paleogene reservoirs of this region have been charged by the Sargaleu, Naokelekna, and Chia Gara source rocks (Aqrawi et al., 2010). Wetzel and Morton (1950) in Bellen et al. (1959) described the Naokelekan Formation for the first time from the Imbricated Zone of northeastern Iraq, near the Naokelekan village, Rowanduz district. Stratigraphically, it is overlain by the Barsarin Formation and underlain by the Sargelu Formation (Figure 1). Lithologically, the formation is divided into 3 parts (Bellen et al., 1959; Buday, 1980). The uppermost part is composed of laminated shaly limestones; however, this part is obscured in the type section.

The middle part of the formation comprises hard, dark gray or bluish thick-bedded dolomitic limestones with ammonite traces (it is called the Mottled unit). The lowermost division of the formation is mainly composed of thin beds of bituminous limestone with frequent intercalation between black bituminous and calcareous shales. Bellen et al. (1959) determined the age of the Naokelekan Formation to be Upper Oxfordian–Lower Kimmeridgian. However, Abdula (2016) believes that the age of the Naokelekan Formation should be placed between the Callovian and the Upper Oxfordian. Buday (1980) determined that the depositional environment of the formation is euxinic in a slow subsiding basin. The Naokelekan Formation has been proven to be a potential source rock. The thermal maturity of this formation increases from the west to the east of the Kurdistan Region, from 434°C $T_{\text{max}}$ in Amedi to 493°C $T_{\text{max}}$ in the Sargelu Village. Therefore, the Naokelekan can be considered as a potential source rock for the generation and extraction of hydrocarbons that have been charged by oil fields in the area (Abdula, 2017). Al-Ameri et al. (2013) believed that the Naokelekan Formation is a potential source rock because the values of TOC, $T_{\text{max}}$, and the hydrogen index (HI) range from 2.75 wt% to 34.92 wt% TOC, 434°C to 447°C, and 11 to 206 mg HC/g TOC, respectively. The best source rock intervals in Well Shorish-1 are Naokelekan (Sachsenhofer et al., 2015). In the Ajil and Balad Oilfields, Rock-Eval pyrolysis data on the Naokelekan samples indicated that it is good to excellent for source rock richness, the kerogen types are type II and mixed type II-III, and that it is thermally in the immature to mature stage (Al-Bayati et al., 2017). Odisho and Othman (1992) and Abdula (2017) concluded that the formation is in the postmature stage in Well Taq Taq-1.

The oil generation started before 134 MA from the Chia Gara, Naokelekan, and the Sargelu source rocks in the Duhok area (Awadh, 2010). The Naokelekan Formation contains a mixture of planktonic, bacterial, and algal OM with a marine origin and the formation is regarded as a very good to excellent source rock in the Ajil and Balad oil fields (El Diasty et al., 2018). Al-Badry (2012) studied the Jurassic formations in the Chia Gara anticline, and, based on his study, the Naokelekan Formation is considered to have a high value of OM content with type I-II kerogen and to be thermally mature and in the oil window.
2. GEOLOGICAL SETTING

In Iraq, the Late Toarcian-Early Tithonian (Mid-Late Jurassic) Megasequence AP7 is divided into 2 sequences. The lower sequence includes the Sargelu and Muhaiwir Formations, whereas the upper sequence includes the Najmah, Gotnia, Naokelekan, and Barsarin Formations (Jassim and Buday, 2006a). The Late Jurassic Megasequence AP7 of the Naokelekan successions were deposited during a period of isolation of the intrashelf basin of the Mesopotamia Foredeep from the Neo-Tethyan Ocean. It passes laterally toward the central and western parts of Iraq into the Najmah Formation. The Naokelekan Formation overlies the Kimmeridgian-Tithonian supersequence that consists of the evaporitic Gotnia Formation and the limestones and breccias of the Barsarin Formation (Jassim and Buday, 2006a). Regionally, the studied sections are part of the Zagros Fold-Thrust belt that formed during the Late Paleogene and Neogene tectonics (Beydoun, 1993). The Zagros Fold-Thrust Belt is characterized by a northwest-southeast trend that is 300 km wide and 1800 km in length (Alavi, 2004; Alavi, 2007; English et al., 2015). The plate tectonic setting of Iraq can be divided into the following 2 first order segments: the Arabian Plate platformal part and the Shalair terrane of the Sanandaj-Serjan Zone of the Eurasian Plate that is separated by the Zagros Main Thrust (Foud, 2015). Based on this tectonic division, the Warte section is located within the Imbricated Zone (Figure 2). The Imbricated Zone represents a narrow belt of 15 km in the north and 25 km in the northeast. It is extremely folded and thrust, Anticlines are displaced by thrusts into imbricates and override synclines (Jassim and Buday, 2006c). In contrast, the second section (Well Bina Bawi-1) is located within the High Folded Zone (Figure 2). The width of this zone is between 25 and 50 km. The folds are commonly asymmetrical and are oriented in a northwest-southeast trend in the northeast, and an east-west trend in the northwestern part of Iraq (Jassim and Buday, 2006c).
3. MATERIALS AND METHODS

The Rock-Eval technique is widely used to assess the hydrocarbon generation potential of a source rock (Espitalié et al., 1977). For this study, 5 outcrop samples and 7 subsurface rock samples were used for Rock-Eval pyrolysis. The examination of the samples was conducted at the Scientific Research Center of the Soran University, Kurdistan Region, Iraq. The samples were first carefully cleaned and crushed to a powder before Rock-Eval pyrolysis. The crushed samples were weighed to between 90 and 100 mg and were subjected to analysis using a Rock-Eval 6 apparatus to determine the amount of TOC, the kerogen type, and the thermal maturity of the OM for each sample. The Rock-Eval pyrolysis provides the S1, S2, S3, and Tmax values directly. By using these parameters, the type and maturity of the OM can be determined. In this study, the measured S1 (mg HC/g rock), S2 (mg HC/g rock), TOC (wt%), and Tmax (°C) parameters and the calculated HI (S2/TOCx100) and production index (PI) [(S1/(S1+S2)] parameters were used for interpretation of the data.

4. RESULTS

4.1 Quantity and Quality

The total OM is an indicator of the total amount of OM present in a rock sample. A source rock with a TOC value of >0.5 TOC wt% is regarded as a poor source rock. Values of 0.5 to 1.0, 1.0 to 2.0, 2.0 to 4.0, and >4.0 wt% are interpreted as fair, good, very good, and excellent for source rock richness, respectively (Peters and Cassa, 1994). As indicated in Table 1, the analyzed samples from the Warte section contained TOC values in a range of between 0.24 and 4.61 wt%, with an average value of 2.65 wt%. In Well Bina Bawi-1, the TOC values were in the range of 0.55 to 1.29 wt% (with an average of 0.90 wt%), and based on these values, the Naokelekan deposits can be interpreted as a very good source rock, with increasing values toward the Imbricated Zone.
The S1 value (mg HC/g rock) is the amount of hydrocarbon that has already been generated from a rock sample. It is used as a semiquantitative parameter of source richness (Dembicki, 2017). Values of 0.0 to 0.5, 0.5 to 1.0, 1.0 to 2.0, and >2.0 mg HC/g rock show poor, fair, good, and very good source rock potential, respectively (Peters, 1986). The values of S1 from the studied samples in the Warte section were in the range of 0.11 to 1.56 mg HC/g rock (Table 1). According to the previous S1 values, the analyzed samples indicated a poor quantity of source rock. In contrast, the values of S1 for the Well Bina Bawi-1 samples are in the range of 1.87 to 4.96 mg HC/g rock, representing a good to very good quantity for the source rock potential.

The genetic potential (GP) is the sum of the amount of free hydrocarbon and the quantity of the remaining OM that has not been converted to hydrocarbons (Tissot and Welte, 1984). GP values of <2, 2 to 5, 5 to 10, and >10 mg HC/g rock correspond to poor, fair, good, and very good, respectively, in terms of generation potential (Hunt, 1996). The cross plot between the GP and TOC shows that the samples of both sections have a good hydrocarbon generation potential (Figure 3a).

The S2 value (mg HC/g rock) refers to the amount of hydrocarbon that is produced during thermal cracking of the rock sample. It is commonly used to estimate the generation capacity of the remaining hydrocarbons in the rock sample (Peters and Cassa, 1994). S2 values of 0.0 to 2.5, 2.5 to 5.0, 5.0 to 10.0, and >10.0 mg HC/g rock indicate poor, fair, good, and very good source rock potential, respectively (Peters, 1986). In this study, the S2 values for the Warte section ranged from 3.09 to 13.60 mg HC/g rock, with an average of 6.5 mg HC/g rock, which indicate good to very good petroleum potential. The S2 values for the Well Bina Bawi-1 section were in the range of 3.74 to 9.20 mg HC/g rock, with an average of 6.25 mg HC/g rock, which indicates a good potential source rock (Table 1). The cross plot between the S2 values and TOC shows that the samples of both sections have good hydrocarbon generation potential (Figure 3b).

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample number</th>
<th>TOC (wt%)</th>
<th>S1 (mg HC/g rock)</th>
<th>S2 (mg HC/g rock)</th>
<th>HI (mg HC/g TOC)</th>
<th>PP (S1+S2)</th>
<th>T_max (°C)</th>
<th>Production index S1/(S1+S2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warte outcrop</td>
<td>NK3</td>
<td>4.60</td>
<td>1.56</td>
<td>10.38</td>
<td>260</td>
<td>11.94</td>
<td>497</td>
<td>0.13</td>
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<td></td>
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<td>2.80</td>
<td>0.67</td>
<td>5.17</td>
<td>185</td>
<td>5.84</td>
<td>506</td>
<td>0.12</td>
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<td></td>
<td>NK6</td>
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<td>215</td>
<td>3.33</td>
<td>494</td>
<td>0.07</td>
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<tr>
<td></td>
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<td>295</td>
<td>13.71</td>
<td>550</td>
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<tr>
<td></td>
<td>Average</td>
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<td>0.52</td>
<td>6.50</td>
<td>204</td>
<td>7.02</td>
<td>519</td>
<td>0.08</td>
</tr>
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<td>Well Bina Bawi-1</td>
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<td>3.21</td>
<td>6.23</td>
<td>708</td>
<td>9.44</td>
<td>432</td>
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<td>2.85</td>
<td>5.95</td>
<td>684</td>
<td>8.80</td>
<td>435</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
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<td>0.80</td>
<td>2.63</td>
<td>4.65</td>
<td>581</td>
<td>7.28</td>
<td>435</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
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<td>0.55</td>
<td>1.87</td>
<td>3.74</td>
<td>680</td>
<td>5.61</td>
<td>435</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Average</td>
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<td>3.12</td>
<td>6.27</td>
<td>692</td>
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<td>0.33</td>
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<td>68</td>
<td>0.29</td>
<td>547</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 1: Rock-Eval pyrolysis data for the samples from the Naokelekan formation (the samples’ names were given on the basis of the depth from which they were obtained in Well Bina Bawi-1)
The HI is the amount of hydrogen richness in the kerogen that can be generated relative to the amount of OM in the source rock (Dembicki, 2017). The HI value is important to differentiate between various OM source types and the main hydrocarbon products generated (Peters and Cassa, 1994). According to Peters and Cassa (1994), HI values of >600, 300 to 600, 200 to 300, 50 to 200, and values of <50 mg HC/g TOC refer to type I, type II, mixed type II-III, type III, and type IV kerogens, respectively. The analyzed samples from the Warte section indicate that the values for the HI were in the range of 68 to 295 mg HC/g TOC, with an average of 204 mg HC/g TOC, which mainly indicates type III kerogen that is gas prone (Table 1). However, the HI values for Well Bina Bawi-1 ranged from 581 to 756 mg HC/g TOC, with an average value of 692 mg HC/g TOC, suggesting mainly type I kerogen that is oil prone (Table 1). A plot of T<sub>max</sub> vs HI was also used to classify the type of kerogen of the OM in the sediments. As shown in Figure 4, the kerogen types for Well Bina Bawi-1 can be classified as mixed type I-II kerogen, and the samples of the Warte section are considered to be mixed type II-III kerogen. The values of HI for the Warte section cannot be reliably interpreted on the basis of the organic type because the HI value is significantly reduced by an increased thermal maturity (Dembicki, 2017). A cross plot of the remaining hydrocarbon (S<sub>2</sub>) vs TOC (wt%) can be used to determine the kerogen type (Dembicki, 2017). As shown in Figure 5, samples from Well Bina Bawi 1- are considered as type II kerogen, whereas those of the Warte section belong to type II-III and type III kerogens.

**Figure 3.** (a) A plot of the petroleum potential (or GP, S<sub>1</sub>+S<sub>2</sub>) vs TOC wt%, and (b) S<sub>2</sub> vs TOC wt% showing good petroleum potential of the Naokelekan Formation (adapted from Ghori, 2002 and Dembicki, 2017).

**Figure 4.** A plot of the HI vs T<sub>max</sub> showing that the samples from Well Bina Bawi-1 are less mature and belong to type II kerogen.
4.2. Kerogen maturity

\( T_{\text{max}} \) is the temperature at which the maximum rate of hydrocarbon generation takes place in a sample during Rock-Eval pyrolysis (Law, 1999). \( T_{\text{max}} \) indicates the level of thermal maturity of the OM (Peters, 1986). The amount of hydrocarbon within a source rock is strongly linked to the type of OM and its level of thermal maturity (Tissot and Welte, 1984). Based on the kerogen classification diagram constructed using \( T_{\text{max}} \) vs HI, it was determined that the samples from Well Bina Bawi-1 are in the immature to early mature stage, whereas the Warte samples are in the postmature stage (Figure 4). The PI (S1/(S1+S2)) is defined as the amount of hydrocarbon that was already generated relative to the total amount of hydrocarbon that could still be generated (Peters and Cassa, 1994). PI in conjunction with \( T_{\text{max}} \) is commonly used to indicate the type of hydrocarbon generated. As shown in Figure 6, the Warte samples are in the dry gas zone, but the samples from Well Bina Bawi-1 are just inside the early oil window.

Figure 5. A plot of the TOC (wt%) vs S2 as an indication of the source rock potential of the Naokelekan Formation

Figure 6. A \( T_{\text{max}} \) vs PI diagram of the Naokelekan. The samples from the Warte section in the Imbricated Zone seem to be more mature than the subsurface samples from the High Folded Zone.
5. DISCUSSION

The results of this study are not surprising considering that tectonic events could have played an essential role in the process of hydrocarbon maturation and generation. The simple example of the effect of tectonic events is illustrated in the Wells Shorish-1, and the Bina Bawi-1 fields. The Well Shorish-1 was drilled starting from the top of the Injana Formation, whereas the Well Bina Bawi-1 was drilled from the top of the of Upper Cretaceous Aqra Formation (Awdal et al., 2013; Sachsenhofer et al., 2015). As shown in Figure 7, almost all Cenozoic sediments have been eroded from the Bina Bawi anticline; however, the Low Folded Zone is still covered by a massive thickness of sediments. As mentioned earlier, based on the studies of Odisho and Othman (1992) and Abdula (2017), it was determined that the Naokelekan is in a thermally higher maturity level at Well Taq Taq-1, indicating that it has already generated liquid hydrocarbons. Likewise, based on the study of Sachsenhofer et al. (2015) on the well Shorish-1, the $T_{\text{max}}$ values for the Naokelekan Formation are in the range of 454°C to 463°C, which indicate a relatively high maturity. Accordingly, burial depth in Wells Taq Taq-1 and Well Shorish-1 is a significant variable that is affecting the maturity of the OM, but the overburden decreases toward the Bina Bawi anticline and thus a less mature source rock was detected. The top of the Naokelekan is 3067 m below the surface at Shorish-1, whereas the top of the Naokelekan Formation at Well Bina Bawi is less than 1200 m. The reason for a reduced overburden in the Bina Bawai anticline in comparison with the Shorish area can be attributed to the tectonic activities of the area. The northwest Zagros orogenic belt encountered the following 3 main deformation stages: (1) initial hinterland shortening by the Late Middle to Early Late Miocene (~12–10 Ma); (2) frontal Zagros thrust activation by the Latest Miocene (~8 Ma); and (3) Pliocene (~5 Ma) hinterland reactivation and potential out-of-sequence basement (Khoshnaw et al., 2017). Consequently, the Low Folded Zone (e.g., Well Shorish-1) received sediments from the High Folded, Imbricated, and Thrust zones (they were eroded); thus, the OM in the sediments of the Jurassic rocks remained as the underburden and became more mature. In contrast, owing to unroofing of the Bina Bawi area (Bina Bawi anticline), the chance of Jurassic sediments being more mature is less (maturation has possibly ceased since the Late Miocene). Moreover, overthrusting in the Imbricated Zone also may have affected the maturity of the OM in Jurassic source rocks. This is because temperature variations have a key role in influencing the progress of hydrocarbon generation (Barker, 1996). Overthrusting can display very complex temperature histories, because 1 thermal regime is superimposed on top of another. Likewise, the effects of local increases in the thermal maturity on sedimentary OM can be caused by hydrothermal fluids (Barker, 1983; Law et al., 1986).

It is clear that the $T_{\text{max}}$ values from the Imbricated Zone are higher than those from the Well Bina Bawi-1 in the High Folded Zone. The data also show that the Naokelekan source rock at the Imbricated Zone has entered into the oil window before the Zagros thrusting and uplifting. In addition to the overburden, heat flow can be regarded as a significant contributor to the maturation of the OM within a basin. Heat flow may affect the process of maturation of the kerogen in the sedimentary rocks over geological time (Barker, 1996). Allen and Allen (2013) believed that heat flow can be higher in geologically active areas such as active ocean ridges, rifts, and back-arc basins. Owing to the high tectonic activities at the boundary between the Arabian and Iranian Plate over geological time, a high paleo heat flow can be expected in the Zagros Suture in the study area. Pirouei et al. (2019) studied hydrothermal listvenitization and the associated mineralizations in the Zagros Ophiolites in the Rayat area close to Warte. They concluded that the process of listvenitization is related to the impact of the circulation of hydrothermal fluids upward along the fault zones in the Oligocene-Miocene period. Additional evidence is provided in the formation of gossanites, which are rich in sulfide minerals, owing to the hydrothermal activities in the area (Pirouei, 2020). Thus, the occurrence of hydrothermal activities in the area may increase the rate of OM maturation. Although the overthrusting and hydrothermal activities along the tectonic boundary between the Arabian and Iranian Plates are considered as important factors in the maturation of OM, the role of sedimentary overburden must be taken into consideration. On the basis of previous studies, it has been determined that the thermal maturity of OM increases from the east to west of the Kurdistan Region with the east area seemingly being overburdened by a huge amount of sediments compared with the west, and consequently, a higher maturity has been observed in the east of the
Kurdistan Region (English et al. 2015; Abdula, 2017; Edilbi, 2018; Abdula, 2019).

**6. CONCLUSION**

The results from the Rock-Eval pyrolysis of the Naokelakan sediments in the Warte outcrop and Well Bina Bawi-1 suggest a good quantity and quality of OM with relation to hydrocarbon generation. OM in the Imbricated Zone in the Warte area is thermally more mature than that in the High Folded Zone in which the Well Bina Bawi-1 exists. The disparity in thermal maturity level is more likely related to the tectonic setting, with the Imbricated Zone possibly having been influenced more by tectonic activities such as overthrusting, paleo heat flow, and hydrothermal processes. Furthermore, the effect of the tectonic activities can also be indicated by the relatively low thermal maturity of the formation in Well Bina Bawi-1 at the High Folded Zone, because the Bina Bawi anticline might have undergone unroofing and thus the OM ceased to mature further.

**ACKNOWLEDGMENTS**

The author gratefully acknowledges the Ministry of Natural Resources of the Iraqi Kurdistan Region for providing the subsurface samples. The author also expresses particular thanks to Dr Kamal Kolo, the dean of the Scientific Research Center at the Soran University, and to Mr Mohammad Pirouei, the head of the department of the petroleum geosciences at the Soran University, for facilitating Rock-Eval pyrolysis.
REFERENCES


1. INTRODUCTION

The Akri-Bijeel Block is 1 of 55 oil exploration blocks in the Kurdistan network Region of northern Iraq. The Bekhme-1 Well was drilled as an explorer or wildcat, and it is the second exploration well being drilled in the Akri-Bijeel Block, 20 km northeast of the Bijel-1 Discovery Well (the P50 operator estimates that there is a total 2.4 billion barrels of oil on site) (Csontos et al., 2011). The area of the Akri-Bijeel Block covers 889 km2 and the Bekhme-1 Well targets possible intervals in the Jurassic and Triassic periods with a predicted depth of 3000 m (Csontos et al., 2011). From a topographic point of view, the mountain mass is divided into the northern part, which is characterized by the E-W trend of the mountain range with heights up to 1500 m above sea level, and the southern part, a smooth and mountainous region 500 m above sea level on average (Csontos et al., 2011).

Abdula et al. (2017) used Rock-Eval pyrolysis to study the potential of generating oil from source rocks from the Bijeel 1 Well, Akri-Bijeel Block, in the Kurdistan Region of northern Iraq. The results showed that the Sargelu and Sehkaniyan configurations contain a marine type IIS kerogen and that the organic matter is thermally mature and in the oil window. In the samples studied, it was determined that the carbonates are richer in organic matter and more susceptible to oil generation than the shale, which seems to be potential sources of natural gas.

The samples from the Chia Gara, Naokelekan, Sargelu, and Sehkaniyan formations can be considered good source rocks with an average total organic carbon (TOC) content of 1.50, 2.86, 1.44, and 0.63 wt%, respectively, and they contain type II and III kerogens, indicating marine and nonmarine organic matter, which proposes oil
and gas prone sources (Ali, 2018). The petroleum system of Jabal Kand oil field (located SW of the study area) shows that formations such as the Kolosh (Palaeocene), the Shiranish (Upper Cretaceous), and the Sargelu (Middle Jurassic) are immature and have not generated any oil with Ro values of <0.55% (Abdula, 2017c). The main aim of this study was to determine the parameters of the petroleum system at Bekhme-1 Well to determine during which time the existing kerogen was changed to oil and became mature and to determine the time at which oil migrated into the reservoir.

The Bekhme-1 Well is located in the highland of the southern part of the Akri-Bijeel Block in the northern part of Iraq. Bekhme-1 Well is located about 10 km northwest of the city of Harir and 50 km north of the regional capital city, Erbil. It is situated at latitude 36° 40' 33.05” North and longitude 44° 17' 47.60” East (Figure 1).

Figure 1. Main map of Iraq showing the Kurdistan Region (A); Enlargement of the outlined area in A marked the Erbil Province (B); Enlargement of the area outlined in B showing the location of the studied well (C)

2. MATERIALS AND METHODS

In this study, 1-dimensional (1-D) basin modelling PetroMod 2011.1 software (Schlumberger, Houston, Texas, USA) was used to determine the burial and thermal history of Bekhme-1 Well. Data was obtained from the Ministry of Natural Resources, Erbil, on November 3, 2019, which included data about the top and base thickness, the lithology of the geological units, and the borehole temperature. The TOC wt%, hydrogen
index (HI), and $T_{\text{max}}$ of the organic matter from several formations were collected from the study by Ali (2018). The geothermal gradient value in the studied area was obtained from Abdula (2017a) and the sea levels during the deposition of the existing formations were obtained from Jassim et al. (2006). Adobe Illustrator CC 2019 was used to draw the geological column and Geological Information System software was used to draw a regional map of the region.

Formation names with their top and base boundaries, formations thickness, eroded amount, duration of none deposition, the main lithology of the geological units, the role of each formation in the petroleum system, TOC wt%, kinetics, and HI are presented in Table 1. The thermal conductivity and heat capacities are distinguished by the thermal properties of the different types of rocks by the user or programmed by default. The bottom well temperature was obtained from the well log header for the well that was used in the modelling (Figure 2). Mathematically calculated $T_{\text{max}}$ values and their equivalent %Ro values, as determined by Rock-Eval pyrolysis, were used for calibration. The $T_{\text{max}}$ values have been reported by Abdula (2015) and Abdula (2017b). It is reasonable to assume that the heat flow changed over time, but it has not been necessary to make assumptions about when the heat flow changed because the use of a constant heat flow over time has led to an appropriate context visualization of the %Ro value, as determined by EASY%Ro (Sweeney and Burnham, 1990).

The average surface temperature of all the burial history sites was estimated to be 21°C based on data recorded by the Iraqi Meteorological Organization and the Seismology-Kirkuk station for the years from 2010 to 2015 and from the results from this study. This means that the surface temperature is 4°C less than the data used by Pitman et al. (2004) for the southern part of Iraq.

![Figure 2. PetroMod software modelling of the temperature vs depth for the Bekhme-1 Well of the Akri-Bijel Oil Field](image-url)
Table 1: Formation names with their top and base boundaries, formation thickness, eroded amount, duration of none deposition, main lithology of geological units, the role of each formation in the petroleum system (PSE), TOC, kinetic, and HI values (data from Ali, 2018)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Top (m)</th>
<th>Base (m)</th>
<th>Thickness (m)</th>
<th>Eroded (m)</th>
<th>Depo. from (Ma)</th>
<th>Depo. to (Ma)</th>
<th>Lithology</th>
<th>PSE</th>
<th>TOC (wt.%</th>
<th>Kinetic (mg HC/g TOC)</th>
<th>HI (mg HC/g TOC)</th>
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<td>85</td>
<td>191</td>
<td>186</td>
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<tr>
<td>Sarki</td>
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<td>2015</td>
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<tr>
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<td>2397</td>
<td>382</td>
<td>202</td>
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<td>shale, limestone, dolomite</td>
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<tr>
<td>Kurra Chine Anhydrite</td>
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<td>218</td>
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<td>205</td>
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<td>202</td>
<td>anhydrite, dolomite</td>
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<tr>
<td>Kurra Chine-B</td>
<td>2723</td>
<td>2934</td>
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<td>214</td>
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<td>210</td>
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<td>Reservoir rock</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kurra Chine-C</td>
<td>2934</td>
<td>4625</td>
<td>1691</td>
<td>227</td>
<td>214</td>
<td>214</td>
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<td>Source rock</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Three members (A, B, and C) of the Kurra Chine Formation have been recognized.

They are characterized by 3 broad carbonate evaporation cycles.

3. GEOLOGICAL SETTING

Iraq is located in the northeastern part of the Arabian Plate and has been severely affected by its structural position in the major geological units of the Middle East (Jassim and Buday, 2006). The Akri-Bijeel Block is located in the northeast of Iraq on the border between the Arabian part of the African Platform (Nubia-Arabian) and the Asian branches of the Alps Tectonic Belt (Jassim and Buday, 2006) (Figure 3).

From Bijeel's counterline to Akri and Bakrman (Figure 4), it is very common to find very steep dipping layers in the area with Mesozoic units in the limb of the anticline. Many thrust exposures are found at the southern limb of the Aqra and Pirat anticlines and 1 at the northern limb within both existing anticlines (Figure 4) suggesting that thrusts are underlying the limbs of these major folds (Csontos et al., 2012; Abdula et al., 2017).
3.1. Stratigraphic Setting

At the southern shelf of the Tethys Ocean, the bulk of the Permian-Eocene sequence was deposited. The entire sedimentary succession may be more than 10 km thick and may begin with a ductile Late Precambrian series. It is crowned by a successive series of Palaeozoic with a thickness of several thousands of meters in which shallow-water carbonates in the Chia Zairi (Permian) and Kurra Chine (Triassic) formations form thicker and stiffer units with local anhydrite. The stratigraphy of the Bekhme-1 Well is shown in Figure 5.
**Figure 4.** The upper part is a map of Iraq showing the location of the studied well, the folded belt of Zagros, and the main oil and gas deposits of the region (according to Pitman et al., 2004). The lower part is a geological map of the area showing the 2 main anticlines and displaying the Mesozoic formations to the north that correspond to the Aqra anticline (west) and Bekhme (east) (according to Csontos et al., 2012).
<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Lithology</th>
<th>Description</th>
<th>PSE</th>
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<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Qamchaqa</td>
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<td>Barsarin</td>
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<tr>
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<td>Upper</td>
<td>Naokekekan</td>
<td>shale limestone, dolomite, limestone</td>
<td>Source Rock</td>
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<tr>
<td></td>
<td>Middle</td>
<td>ingléshow</td>
<td>limestone, shale</td>
<td>Source Rock</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Habtunayra</td>
<td>limestone, dolomitic limestone</td>
<td>Reservoir Rock</td>
</tr>
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<td></td>
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<td>Adalayah</td>
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<td>Seal Rock</td>
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<tr>
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<tr>
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<td>Karra Chino C</td>
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</tr>
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<td>Upper</td>
<td>Karra Chino E</td>
<td>dolomite, shale</td>
<td>Source Rock</td>
</tr>
</tbody>
</table>

**Figure 5.** Generalized stratigraphic column of the Triassic-Cretaceous sequences in the Akri-Bijeel oil field
3.2. Structural Setting

The oil exploration area is located at the front of the Zagros compression belt. The structural evolution of the area was affected by the collision of the Arabian Plate with the Eurasian Plate. The deformation can be divided into the following 2 phases: the northwesterly and southwesterly forwarded stress and the subsequent north-south strain (Csontos et al., 2012).

The most important structural elements of the oil exploration area include a considerable north and northeast thrust, the Bijeel anticline in the south of the thrust, and a raised, high anticline in the southern corner of the block, which is the Safeen Mountain. The northern thrust consists of 2 segments, namely the Aqra anticline and Pirat anticline. The larger Bijeel anticline is located between the Bekhme and Safeen structures and their axes cross in a southwestern-northwestern direction (Figure 6).

4. BASIN MODELLING PARAMETERS

Basin modelling allows calculation of the thermal history and retreat of the basin to predict the quantities and distribution of oil in a given area (Lerche, 1990a, b). Basin and petroleum systems modelling aim to predict the distribution and movement of petroleum within the basin and determine the generation, migration, and accumulation of hydrocarbon in addition to the temperature and pressure histories (Hantschel and Kauerauf, 2009). The following are the main parameters that were used for the modelling: borehole temperature, paleo water depth (PWD), heat flow, TOC, and other Rock-Eval pyrolysis parameters.

4.1. Borehole Temperature

Borehole temperature is the temperature measured in wells. Although the temperature of the Earth’s crust generally increases with depth, the relationship between the temperature and depth is not straight or linear because it changes according to the thermal conductivity of the geological units (Figure 7). The geothermal gradient values depend on thermal conductivity and are therefore linked to rock types that are generally not uniform across
the section. It can be determined by the following equation:

\[
\text{Geothermal gradient} = \frac{(\text{Formation temperature} - \text{mean surface temperature})}{\text{(formation depth)}}
\]

**Figure 7.** Borehole temperature vs depth for the Bekhme-1 Well

### 4.2. Paleo Water Depth

Sea level changes have occurred throughout Earth’s history. The timing and magnitudes of sea level changes are extremely variable. It offers a good overview of Earth’s tectonic and climatic history, but it is still difficult to pin down exactly. The ever-changing tidal currents are small when compared with the long-term fluctuations in Earth’s history. Sea levels can change if tectonic forces move the land up or down. A change in sea level must be caused by 1 of the following 2 events: (1) changes in the volume of water in the oceans, or (2) changes in the size of ocean basins. Figure 8 shows the PWD from the Triassic period to the Neogene in the Iraqi Kurdistan Region.

**Figure 8.** Sea level change from the Upper Triassic period to Neogene in Iraqi Kurdistan Region

### 4.3. Heat Flow

The heat flow is an important parameter in basin modelling, but it is difficult to define for previous geologic times. However, the palaeo-heat flow models are usually calibrated using thermal maturity measurements, such as the %Ro values and Rock-Eval pyrolysis T_max data (He and Middleton, 2002; Hakimi et al., 2010; Shalaby et al., 2011, 2012; Aldega et al., 2014; Mashhadi et al., 2015). In this study, the palaeo-heat flow for the study area was estimated by calibrating the models to the calculated vitrinite reflectance (%Ro) (from the T_max). The palaeo-heat flow is the result of the fit between the measured and modeled vitrinite reflectance profiles (He and Middleton, 2002; Hakimi et al., 2010; Shalaby et al., 2011, 2012; Aldega et al., 2014; Mashhadi et al., 2015). However, the palaeo-heat flow, together with the erosion periods, has a significant effect on the modeled maturity (Hakimi and Abdullah, 2015; Hadad et al., 2017; Makeen et al., 2016). The palaeo-heat flow modelling results for
the studied well indicate a warm history with a constant change in the heat flow rate during the Upper Triassic to Palaeocene (49–52 mW/m²), followed by a significant decrease during the Late Palaeocene to Miocene (48–23 mW/m²). The present-day heat flow values were also estimated and were inferred from obtaining a good fit between the modeled and measured bottom-hole temperatures.

4.4. Total Organic Carbon and Rock-Eval Pyrolysis Factors

Several representative samples from the Bekhme-1 Well were gathered and analyzed. The samples were from the Bekhme, Qamchuqa, Sarmord, Chia Gara, Barsarin, Naokelekan, Sargelu, Sehkaniyan, Adaiyah, Sarki, Baluti, and Kurra Chine formations. By using Rock-Eval pyrolysis, potential hydrocarbon parameters, which include the type and amount of kerogen and thermal maturity, were determined by analyzing the 15 collected samples. The average TOC wt% content of the samples from the Chia Gara, Naokelekan, and Sargelu formations was 1.47, 2.50, and 1.60 wt%, respectively. Consequently, they can be considered as good source rocks. The organic matter belongs to types II and III kerogens that were derived from marine and nonmarine organic materials, and is oil and gas prone. The values for $T_{\text{max}}$ range from 441°C to 450°C, averaging 446°C, and the calculated vitrinite reflectance ranges from 0.78 to 0.94 %Ro, with an average of 0.88 %Ro (Ali, 2018).

5. RESULTS AND DISCUSSION

The results of 1-D modelling show the burial history and tectonic subsidence (Figure 9). Based on the geologic model of depositional and erosional events, the burial and subsidence history of sedimentation can be evaluated in absolute time.

![Figure 9. Thermal, burial, and subsidence history curves at the Bekhme-1 Well](image)

The expelled and migrated oil was preserved in the Lower Cretaceous reservoirs (Figure 10). The source rock from the Sargelu Formation was formed by the Middle Jurassic time. The modeled burial and subsidence history curves in the Bekhme-1 Well show that the Triassic Period had a short burial history of approximately 227.76 to 199.60 Ma and is associated with relatively low subsidence rates and a thickness of about 2000 m. From the Jurassic to Lower Cretaceous time (~199.60–127.96 Ma), the subsidence rates and sedimentation rates increased and reached a thickness of 3400 m.
During the Upper Cretaceous to the end of the Miocene time (~100.5–5.333 Ma), there was a sharp change in the subsidence and sedimentation rates, which reached nearly 7100 m. The burial and subsidence history curves also indicate 3 main periods of unconformity and erosion events in the Kurdistan Region, namely the Upper Triassic–Lower Jurassic, Upper Cretaceous, and Pliocene. These events and the associated heat flows affected the rate of thermal maturity in the area (Makeen et al., 2016; Hadad et al., 2017).

In the basin modelling software program, the maturity simulation is a kinetic equation that shows the level of maturity. This equation is a function of time and temperature. The model has an average of 1000 m of erosion above the Bekhme Formation, implying that the underlying rocks were buried deeper than its present-day situation. The temperature was higher (50°C–60°C) and the rocks became more mature at that depth when compared with the erosion model. The Chia Gara Formation reached the early oil window at around 60 Ma in the Palaeocene, however, the Naokelekan and Sargelu formations entered the early oil window during the Lower Cretaceous at about 108 and 112 Ma, respectively.

Based on the 1-D basin model, the petroleum system of the Akri-Bijieel oil field shows that the Palaeogene formations, such as the Kolosh, is immature.

The Jurassic–Lower Cretaceous formations, such as the Chia Gara, Naokelekan, and Sargelu reached the late oil window during the Late Miocene (%Ro=0.84, 0.88, and 0.90, respectively). Because of uplifting, these source rocks have ceased to mature further in the Bekhme-1 Well (Figure 9 and Figure 11). The Triassic formations, such as the Geli Khana, are thought to have a high maturity, with %Ro values of ≥1.3%, and are thought to be in the wet and dry gases window. The older formations are in an area where hydrocarbons or fully dry gases are produced and depleted after the oil is expelled and carried over to the rock traps in the sedimentation structure.
6. CONCLUSIONS

Based on the history of the burial for oil production in the region, the Jurassic–Lower Cretaceous formations, such as the Chia Gara (%Ro=0.84), Naokelekan (%Ro=0.87), and Sargelu (%Ro=0.90) formations, are considered to be mature because of their %Ro values >0.55%. Other formations, such as the Geli Khana and other Triassic formations have a high maturity, with %Ro values ≥1.3%, and are in the wet and dry gases windows. The older formations are in an area where hydrocarbons or fully dry gases are produced and depleted after the oil is expelled and carried over to the rock traps in the sedimentation structure.

ACKNOWLEDGMENTS

The authors would like to thank Dr Ayad N. F. Edilbi for helping with the presentation of the enclosed figures.

REFERENCES


Figure 11. Time plot of the vitrinite reflectance (%Ro) at the Bekhme-1 Well. The data that were used to construct the curve were calculated mathematically from the \( T_{\text{max}} \) values.


Hydrocarbon Potential of the Middle–Late Jurassic Series of Northwestern Iraq: A Case Study in the Shaikhan Oil Field

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ABSTRACT

The Middle–Late Jurassic Sargelu, Naokelekan, and Barsarin formations of northwestern Iraq have been investigated in the Shaikhan oilfield (well Shaikhan-8) to assess their potential for hydrocarbon generation. The results of total organic carbon analysis and rock-eval pyrolysis revealed a good-to-excellent hydrocarbon content and suggest that the depositional conditions were suitable for the production and preservation of organic matter. The thermal maturity proxy indicates that the studied formations were at the start of the hydrocarbon generation period. Most of the samples from the Sargelu and Barsarin formations belong to kerogen type II, whereas those of the Naokelekan Formation belong to kerogen type II/III. The Pr/Ph, Pr/n-C17, and Ph/n-C18 ratios of the extracted bitumen indicated that the organic matter originated from marine sources under reducing conditions. The stable carbon isotope composition of the saturated and aromatic hydrocarbon fractions ranged from −28.3 to −27.7 ‰ and −28.0 to −27.7 ‰, respectively. The biomarker results show a high contribution of marine organic matter that was preserved under relatively anoxic conditions. The profiles of the burial and thermal maturity history show that the simulated generation zones, based on the calculated vitrinite reflectance, indicate immature (0.44%–0.6%) to early oil generating (0.6%–0.75%) source rock. The low thermal maturity of the studied formations relative to the depth may be attributed to the low geothermal gradient and heat flow.

Keywords: Middle-Late Jurassic, Rock-eval, Biomarker, Burial history, Shaikhan oilfield

1. INTRODUCTION

The majority of the discovered hydrocarbon reserves in northern Iraq are believed to be sourced from the Triassic and Jurassic rocks, and are trapped in the Jurassic, Cretaceous, and Tertiary reservoirs in the Zagros fold–thrust belt (Jassim and Goff, 2006; Aqrawi et al., 2010; Al-Ameri and Zumberge, 2012).

The Middle–Late Jurassic succession includes the most important source rocks across northern Iraq because of their high total organic carbon (TOC) content (Jassim and Al-Gailani, 2006; Al-Ameri et al., 2014).

A pioneering study on the stratigraphy of the Sargelu Formation in the Sargelu Anticline of the High Folded zone in the Sulaimani District of Iraqi Kurdistan, was presented by Wetzel (1948) (in Bellen et al., 1959). Wetzel and Morton (1950) (in Bellen et al., 1959) were the first to focus on the Late Jurassic stratigraphic units, namely the Naokelekan and Barsarin formations. They described the lithologies of these units at their type localities in the Naokelekan and Barsarin villages in northeastern Iraq.
The Bathonian–Bajocian, Callovian–Oxfordian, and Oxfordian–Kimmeridgian ages were suggested as the developmental time periods for the Sargelu, Naokelekan, and Barsarin formations, respectively (Al-Ameri and Zumberge, 2012; Al-Ameri and Al-Naqshbandi, 2015).

English et al. (2015) constructed a thermal maturity map of the Middle–Upper Jurassic areas of Iraqi Kurdistan Region. That map indicated a relatively low maturity across Mosul High where the source rock interval is overlain by a thin succession from the Cretaceous and Cenozoic periods. The maturity increases from the northwest to the southeast based on the thickness variations of the Cenozoic foredeep sediments within the Zagros foreland basin (Abdula, 2018).

2. GEOLOGICAL SETTING

Northern Iraq represents the northeastern boundary of the Arabian Plate (AP) and is a part of the Alpine Mountain belt. This belt has an E–W trend in the northern part and a NW–SE trend in the northeastern part (Jassim and Buday, 2006). The studied area (Fig. 1) is a part of the Zagros basin and represents the Zagros fold belt of northern Iraq. Based on folding intensity, the folded zone has been subdivided into 2 parts, namely the High Folded and the Foothill zones (Fig. 2) (Jassim and Goff, 2006).

Figure 1. A Landsat image showing the location of Well Shaikhan-8 (Sh-8)
The Shaikhan oilfield is located in the High Folded zone about 60 km north of Erbil city. This oilfield is a recent oil discovery in the Kurdistan Region of Iraq. The Shaikhan anticline is a WNW–ESE trending, doubly-plunging, asymmetrical anticline with a gentle southwestern limb and a steeper back limb. The attitude of the fold axis is $275^\circ/5^\circ$. This fold is considered as an open structure because of its interlimb angle of $120^\circ$ (Al-Azzawi and Hamdoon, 2008).

The stratigraphic succession, exposed within well Shaikhan-8 (Sh-8), includes the following (from the oldest to youngest): The Jurassic Alan, Sargelu, Naokelekan, and Barsarin formations. Younger Cretaceous units are composed of the Chia Gara, Garagu, Sarmord, Qamchuqa, Kometan, Wajna (informal name), and Aqra formations. These were further overlain by a Tertiary succession comprising the Kolosh, Gercus, and Pila Spi formations (Fig. 3).

The lithology of the Sargelu Formation in the studied well consists of the following (from bottom to top):

1. limestone, which is light gray, gray, dark brown, occasionally pale, yellowish brown, firm to slightly hard, soft in part, commonly opaque, finely crystalline, and slightly argillaceous with poor porosity;
2. shale, which is dark gray to gray, slightly firm, fissile, and slightly calcareous; and
3. anhydrite, which is white, soft, pasty, occasionally firm to slightly hard, opaque, and interbedded with limestone (Fig. 4).
Figure 3. Stratigraphic column of well Sh-8 (Al-Atroshi et al., 2019)
The Naokelekan Formation has conformable contacts with the overlying Barsarin and the underlying Sargelu formations.

The Naokelekan Formation’s lithology consists of the following (from bottom to top):

1. argillaceous limestone, which is light to dark gray, occasionally brownish gray, firmly blocky, hard in part, microcrystalline, and slightly dolomitic;

2. limestone, which is predominantly pale gray to brown, hard, sub-blocky to angular, microcrystalline, argillaceous in part, and slightly dolomitic; and

3. calcareous claystone, which is very dark gray to brownish gray, moderately hard, sub-blocky to angular, and carbonaceous.

The lithologic composition of the Barsarin Formation consists of the following (from bottom to top):
3. MATERIALS AND METHODS

A total of 9 well cutting samples were collected from the shaly limestone and limestone units within the Sargelu, Naokelekan, and Barsarin formations. All samples were analyzed by facilities available at the Geological Survey Repository in Erbil, Iraq. The TOC (wt.%) was determined using a Buchner funnel and LECO C230 analyzer (Leco Corporation, St Joseph, MI, US). The studied rocks were analyzed by rock-eval pyrolysis, which estimates the genetic potential (GP) of rock samples, using a Rock Eval 6 apparatus (Vinci Technologies, Nanterre, France) that operates according to a programmed temperature pattern. Results of pyrolysis are represented by the $S_1$, $S_2$, and $S_3$ peaks and $T_{\text{max}}$. The $T_{\text{max}}$ can also be used to calculate the vitrinite reflectance ($R_o$) using the following mathematical formula introduced by Peters et al. (2005):

$$R_o(\text{calculated}) = (0.018 \times T_{\text{max}}) - 7.16$$

Other diagnostic ratios were calculated from the $S_1$, $S_2$, and $S_3$ peaks and TOC values, such as the production index (PI), hydrogen index (HI), and the oxygen index (OI). Pyrolysis data were recorded with the aim of characterizing the organic richness, kerogen type, petroleum generation potential, and the thermal maturity (Espitalie et al., 1977; Espitalie et al., 1980; Espitalie et al., 1985; Peters and Cassa, 1994).

Gas chromatography (GC) was introduced to measure the abundance of alkane peaks. Four rock extracts were fractionated and analyzed in a fashion similar to that for oil using a Hewlett Packard HP 6890 Series II GC system (Agilent Technologies, Wilmington, DE, US). The stable carbon isotopes of the saturated and aromatic hydrocarbon fractions were also determined.

The studied well was modelled using Schlumberger's PetroMod 1-dimensional (1-D) modelling software (IES, 2007). The 1-D burial history model, one of the common commercial modelling software tools, was used in this study for the reconstruction of the burial and temperature history of well Sh-8. Accordingly, source rock maturation and the timing of hydrocarbon generation and expulsion could be modelled (El Nady and Hakimi, 2016).

The samples of the Sargelu, Naokelekan, and Barsarin formations from the studied well were processed at StratoChem Services, Cairo, Egypt.

4. RESULTS AND DISCUSSION

4.1. Hydrocarbon Potential

The hydrocarbon potential of the Sargelu, Naokelekan, and Barsarin formations in well Sh-8 was determined from rock-eval data (Table 1). Several parameters were examined to determine the thermal maturity of the source rocks. The quality of the OM defines whether the kerogen is oil prone (type I and II) or gas prone (type III) (Peters and Cassa, 1994).

TOC, total organic carbon (wt.%); $S_1$, free hydrocarbon (HC) content (mg HC/g rock); $S_2$, remaining hydrocarbon generative potential (mg HC/g rock); $S_3$, carbon dioxide yield (mg CO$_2$/g rock); $T_{\text{max}}$, temperature at maximum of $S_2$ peak; HI, hydrogen index = $S_2 \times 100/\text{TOC}$ (mg HC/g TOC); OI, oxygen index = $S_3 \times 100/\text{TOC}$ (mg CO$_2$/g TOC); PI, production index = $S_1/(S_1+S_2)$; GP, genetic potential = $(S_1+S_2)$ (kg HC/ton rock); $R_o$, calculated vitrinite reflectance.
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The plot of TOC vs. $S_1$ provides conclusive evidence about the source of the hydrocarbon present, namely if it is indigenous (autochthonous) or non-indigenous (allochthonous) (Hunt, 1996). All the analyzed samples from well Sh-8 lay below the inclined line (not migrated), and most of them have a high TOC content relative to the low $S_1$ values, which indicate their indigenous origin and contamination-free nature (Fig. 5).

The TOC content ranges from 1.16 to 11.6 wt%, 0.9 to 1.24 wt%, and 1.22 to 1.33 wt% for the Sargelu, Naokelekan, and Barsarin formations, respectively, indicating good-to-excellent organic richness (Table 1). The variations in the TOC content of these formations are

### Table 1: Details of the cutting samples collected for pyrolysis from the studied formations from Well Sh-8

<table>
<thead>
<tr>
<th>Formation</th>
<th>Depth (m)</th>
<th>TOC</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
<th>$T_{\text{max}}$ (°C)</th>
<th>HI</th>
<th>OI</th>
<th>PI</th>
<th>GP</th>
<th>R₆ %</th>
</tr>
</thead>
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<td>1495</td>
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<td>534</td>
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<td>434</td>
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<td>14.32</td>
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</tr>
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<td>427</td>
<td>232</td>
<td>116</td>
<td>0.11</td>
<td>2.33</td>
<td>0.53</td>
</tr>
<tr>
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<td>1.18</td>
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<td>0.91</td>
<td>429</td>
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<td>1569</td>
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<td>0.36</td>
<td>3.89</td>
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<td>314</td>
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<td>0.08</td>
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</tr>
<tr>
<td>Naokelekan</td>
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<td>1.16</td>
<td>0.49</td>
<td>4.97</td>
<td>0.82</td>
<td>422</td>
<td>428</td>
<td>71</td>
<td>0.09</td>
<td>5.46</td>
<td>0.44</td>
</tr>
<tr>
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<td>4.16</td>
<td>1.89</td>
<td>18.88</td>
<td>0.72</td>
<td>436</td>
<td>454</td>
<td>17</td>
<td>0.09</td>
<td>20.77</td>
<td>0.69</td>
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<td>Sargelu</td>
<td>1659</td>
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<td>63.75</td>
<td>0.90</td>
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<td>550</td>
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<td>0.04</td>
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</tr>
<tr>
<td>Sargelu</td>
<td>1664</td>
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<td>1.43</td>
<td>23.95</td>
<td>0.72</td>
<td>436</td>
<td>535</td>
<td>16</td>
<td>0.06</td>
<td>25.38</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Figure 5. Plot of TOC versus $S_1$ for the identification of migrated hydrocarbons in the studied samples
because of the changes in the environmental conditions, which caused the formation of different lithologies. The measured Tmax values ranged between 427°C and 442°C, which indicate that all the samples were in the early maturation stage (Moldovan et al., 1985). Similarly, the OI values ranged from 6 to 166 mg CO2/g rock, being <200 mg CO2/g rock, which indicates an absence of intensive weathering or mineral decomposition (Jarvie and Tobey, 1999). The calculated Ro values ranged between 0.53% and 0.80%, corresponding to the onset of oil generation (Table 1). The pyrolysis data (Tmax vs. HI) suggest that most of the analyzed samples from the Sargelu and Barsarin formations are limited to the mature and immature zones of kerogen type II, whereas most of samples from the Naokelekan Formation fall within the zone of mixed type II/III kerogen (Fig. 6). This also corresponds with their HI and Tmax values, which range from 245 to 550 mg HC/g TOC and 427°C to 442°C, respectively (Table 1). This suggests that the Sargelu and Barsarin formations have a limited capacity to generate liquid hydrocarbons, and the Naokelekan Formation is more likely to be gas prone.

4.2. Gas Chromatographic Analysis
Four cutting samples from the studied formations were selected to determine the ratios of isoprenoid hydrocarbons, namely pristane (Pr) and phytane (Ph), which act as indicators of the depositional environments (Table 2). Carbonate source rocks that were deposited in

![Figure 6. Plot of HI vs. Tmax for the analysis of the samples from the studied formations](image)
an anoxic depositional environment have a Pr/Ph value of <2 (Peters et al., 2005). A higher Ph content and lower Pr/Ph ratio can be attributed to the presence of a reducing environment at the time of deposition of the source rock (Ten Haven et al., 1987).

The carbon preference index (CPI) is used as an indicator of maturity (Peters et al., 2005). Early researches concluded that immature source rocks frequently show high CPI values of >1.5, whereas the CPI values for mature rocks are always <1.2 (Jalees et al., 2010). Moldowan (1985) believes that mature source rocks have CPI values of between 0.8 and 1.2.

The Sargelu, Naokelekan, and Barsarin formations have low Pr/Ph values of between 0.58 and 0.62, 1.04, and 0.44, respectively, indicating an anoxic, reduced marine carbonate depositional environment (Tissot and Welte, 1984) (Fig. 7).

This conclusion was drawn by Mohialdeen et al. (2018) at the Miran oilfield, northeastern Iraq. Pr/Ph values of less than 0.8 with CPI values of less than 1.0 indicate saline to hypersaline conditions that are associated with carbonate and evaporate deposition. In contrast, Pr/Ph values greater than 3.0 indicate terrigenous plant input deposited under oxic to suboxic conditions (Peters et al., 2005; Hakimi et al., 2018).

The relatively low CPI values of less than 1.0 that were obtained in well Sh-8 suggest that the analyzed extract samples of the studied formations were generated from marine source rocks (Fig. 8).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Depth (m)</th>
<th>Lithology</th>
<th>Pr/Ph</th>
<th>Pr/n- C17</th>
<th>Ph/n- C18</th>
<th>CPI</th>
<th>δ13C Sat (%)</th>
<th>δ13C Aro (%)</th>
<th>CV</th>
<th>SAT wt%</th>
<th>ARO wt%</th>
<th>NSO wt%</th>
<th>ASPH wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barsarin</td>
<td>1509</td>
<td>LST</td>
<td>0.44</td>
<td>0.33</td>
<td>0.56</td>
<td>1.04</td>
<td>-28.3</td>
<td>-28.0</td>
<td>2.21</td>
<td>11.70</td>
<td>12.90</td>
<td>33.06</td>
<td>42.34</td>
</tr>
<tr>
<td>Naokelekan</td>
<td>1569</td>
<td>LST</td>
<td>1.04</td>
<td>0.32</td>
<td>0.36</td>
<td>1.28</td>
<td>-27.7</td>
<td>-27.7</td>
<td>3.06</td>
<td>42.62</td>
<td>21.02</td>
<td>20.45</td>
<td>15.91</td>
</tr>
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<td>Sargelu</td>
<td>1629</td>
<td>Shaly LST</td>
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<td>0.53</td>
<td>0.94</td>
<td>-28.2</td>
<td>-28.1</td>
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<td>16.40</td>
<td>6.67</td>
<td>12.31</td>
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<tr>
<td>Sargelu</td>
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<td>LST</td>
<td>0.62</td>
<td>0.32</td>
<td>0.46</td>
<td>0.93</td>
<td>-28.2</td>
<td>-28.1</td>
<td>2.68</td>
<td>16.40</td>
<td>6.67</td>
<td>12.31</td>
<td>64.62</td>
</tr>
</tbody>
</table>
Figure 7. Gas chromatographs of the extracted rock samples from the studied formations in well Sh-8

Figure 8. A plot of the CPI values vs. the Pr/Ph ratios (Hakimi et al., 2018)
The Pr/n-C17 ratio is helpful for discriminating between OM that formed in a marine environment (when the ratio is <0.5) and OM that formed in a swamp environment (when the ratio is >1.0) (Osuji and Antia, 2005). Lower values of Ph/n-C17 and Pr/n-C18 indicate a marine source rock bearing type II kerogen (Obermajer, 1999). The Pr/n-C17 and Ph/n-C18 ratios of the 4 extract samples for the Sargelu (0.32–0.34; 0.46–0.53), Naokelekan (0.32; 0.36), and Barsarin (0.33; 0.56) formations (Table 2), indicate that the extracted bitumen was derived from a carbonate-rich source rock and deposited in a reduced marine environment with low to medium biodegradation (Fig. 9). The CPI values of the extracts of the studied formations are between 0.80 and 1.20, indicating a marine source at the maturation stage, with an exception in a sample from the Naokelekan Formation that scored a CPI of 1.28, indicating an immature stage (Table 2).

**Figure 9.** Ph/n-C17 vs. Pr/n-C18 for the bitumen extracts from the studied formations in well Sh-8 (Shanmugam, 1985)

### 4.3. Carbon Isotopes (δ¹³C ‰)

The isotope composition of the extracted bitumen (saturates and aromatics) is employed to discriminate between marine and terrigenous depositional environments by applying a mathematical relation known as the canonical variable (CV) introduced by Sofer (1984). A CV value of <0.47 mostly indicates marine OM, whereas values of >0.47 indicate that the OM is mostly terrigenous (Sofer, 1984). The calculated CV values for the studied extracts range from −3.06 to −2.21 indicating a predominantly marine environment (Table 2).

The values for the carbon isotopes measured for the saturates (δ¹³CSat) and aromatics (δ¹³CAro) for 3 rock extract samples from the studied formations, ranged from −28.3‰ to −27.7‰ and −28.2‰ to −27.7‰, respectively (Table 2). These values point out a slight variation in the isotopic composition of the samples owing to the different maturation levels among them (Demaison and Huizinga, 1991), therefore indicating that the OM of the 3 studied formations was mainly derived from a marine source (Fig. 10).
4.4. Modeling Source Rock Maturation

The input data for the source rock maturation modeling include formation depths (in meters), related lithologies, ages (Ma), well temperatures (°C), erosional time (Ma), petroleum system element (as source, reservoir, or seal), TOC (wt.%), source rock kinetics, and HI (mg HC/g TOC). The erosional events and ages of deposition were used according to the geologic time scale of Sharland et al. (2001) (Table 3).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (m)</th>
<th>Eroded (m)</th>
<th>Deposited from (Ma)</th>
<th>Deposited to (Ma)</th>
<th>Eroded from (Ma)</th>
<th>Eroded to (Ma)</th>
<th>Lithology</th>
</tr>
</thead>
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<tr>
<td>Pila Spi</td>
<td>64</td>
<td>1666</td>
<td>39.1</td>
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<td>33</td>
<td>0.1</td>
<td>Limestone, dolomite</td>
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<tr>
<td>Gercus</td>
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<td>64</td>
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<td>40.4</td>
<td>40.4</td>
<td>39.1</td>
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<tr>
<td>Kolosh</td>
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<td>62</td>
<td>54.9</td>
<td>54.9</td>
<td>54.9</td>
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<td>220</td>
<td>80.5</td>
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<td>75</td>
<td>62</td>
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<td>80.5</td>
<td></td>
<td></td>
<td></td>
<td>Limestone, marl</td>
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<tr>
<td>Kometan</td>
<td>72</td>
<td>90.6</td>
<td>83.5</td>
<td></td>
<td></td>
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<td>241</td>
<td>116.2</td>
<td>99.6</td>
<td>99.6</td>
<td>90.6</td>
<td>Limestone, dolomite</td>
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<td>112.5</td>
<td>199</td>
<td>133.9</td>
<td>128.7</td>
<td>128.7</td>
<td>116.2</td>
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<tr>
<td>Garagu</td>
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<td>140.2</td>
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<td>Chia Gara</td>
<td>165</td>
<td>148.1</td>
<td>142.8</td>
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<td>Shale, limestone, marl</td>
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<tr>
<td>Barsarin</td>
<td>51</td>
<td>153.2</td>
<td>148.1</td>
<td></td>
<td></td>
<td></td>
<td>Limestone, anhydrite</td>
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<td>Naokelekan</td>
<td>34</td>
<td>164.7</td>
<td>153.2</td>
<td></td>
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<td>177.2</td>
<td>164.7</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

The 1-D PetroMod program requires correction of the thermal regime (Fig. 11) based on the calculated thermal conductivities of the rock succession, heat flow parameters, burial history linked to the present-day surface, and bottom hole temperature (BHT) (Pitman et al., 2004).
The present-day geothermal gradient for well Sh-8 was calculated using BHT and subsequently corrected for the drilling mud circulation. The kinetics for a type IIS kerogen were used for source rock maturation considering the high sulfur contents (nitrogen, sulfur and oxygen $[\text{NSO}] = 12.31\%$ to $33.06\%$) in the analyzed samples (Table 2).

Several erosion events have been recognized in the studied well (Table 3). The burial history of well Sh-8 (Fig. 12) shows that during the Middle–Late Jurassic period, the sedimentation was characterized by relatively low subsidence rates leading to the present thickness of about 346 m.
Subsidence and sedimentation continued in the Cretaceous period when the rate of the former increased, leading to the present thickness of about 1015 m. The overlying Tertiary units were characterized by a relatively low subsidence rate and a total thickness of 305 m of sediments accumulated during the Tertiary Period.

The burial and thermal maturity history profiles for the studied well (Fig. 13) show that the generation zones that were simulated based on the calculated Ro (Table 1) for the Sargelu, Naokelekan, and Barsarin formations are immature (0.25% – 0.55%) and in the early oil generation stage (0.55% – 0.70%).

The thermal maturation of the Jurassic source rocks in Mosul High is relatively low and less than that of the Kirkuk Embayment because of the thinning of the overlying Cretaceous section and a thinning or missing Cenozoic section (English et al., 2015). The presence of thick layers of high thermal conductivity carbonates in the
Cretaceous formations and the absence of the younger Tertiary formations caused a reduction in the geothermal gradient toward the northwest of the Kurdistan Region (Abdula, 2018). However, the low thermal maturity of the studied source rocks relative to the depth in well Sh-8 may be attributed to the lower geothermal gradient and heat flow.

The onset of oil generation can be expected with a transformation ratio (TR) of 0.1, whereas a TR greater than 0.5 offers an estimate of the peak oil generation stage (Hantschel and Kauerauf, 2009). The modelled generation mass of the Middle–Late Jurassic formations and their TRs associated with the geologic time of the studied well (Fig. 14) indicated that all studied formations did not reach the early phase of oil generation (TR < 0.1). This is because of the shallower burial depths and low geothermal gradients of the studied well.

5. CONCLUSIONS

The study of the organic geochemical parameters, biomarker analyses, and burial history of the Sargelu, Naokelekan, and Barsarin formations in the Sh-8 well in the northwestern Iraqi Kurdistan Region have led to the following conclusions:

![Figure 14. Generation mass and TR ratio vs. time for the Middle–Late Jurassic source rocks in the studied well (Sh-8)](image)
The OM in the Naokelekan Formation is mainly of type II/III, whereas that of the Sargelu and Barsarin formations is predominantly type II.

The TOC contents ranged from 1.16 to 11.60 wt.% (with an average of 5.35 wt.%), 0.90 to 1.24 wt% (with an average of 1.11 wt%), and 2.36 to 3.13 wt% (with an average of 2.75 wt%) for the Sargelu, Naokelekan, and Barsarin formations, respectively; these figures indicate the good potential of the source rock.

The OM in the rocks of these formations were deposited in an anoxic environment, as revealed by the Pr/Ph, Pr/n-C17, and Ph/n-C18 ratios, and they also appear to be biodegraded to a medium to low extent.

The stable carbon isotope composition of the saturates and aromatics, and the CV values indicate that the OM of the Sargelu, Naokelekan, and Barsarin formations were mainly derived from marine sources.

The applied PetroMod 1-D models indicated that all the studied formations did not reach the early phase of oil generation owing to their shallow burial depths (1570 m, 1536 m, and 1465 m for the Sargelu, Naokelekan and Barsarin formations, respectively) and the low geothermal gradients of the Sh-8 well.

ACKNOWLEDGMENTS

The authors express their gratitude to the Ministry of Natural Resources – Geological Survey in Erbil for providing the cutting samples. We extend our gratitude to StratoChem Laboratories, Cairo, Egypt, for their technical support.

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Alterations in the Serum Trace Element Levels in Women Infected with Chlamydia Trachomatis

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1. INTRODUCTION

Chlamydia trachomatis is an obligate intracellular bacterium that causes several severe and debilitating diseases in humans. C. trachomatis is responsible for a variety of genitourinary tract infections in both men and women, but as observed in general for other sexually transmitted infections (STIs), it is primarily a woman’s healthcare issue because the clinical picture of the infection and outcomes are more damaging to the reproductive health of women than that of men (Paavonen and Eggert-Kruse, 1995). Trace elements such as iron (Fe), copper (Cu), and zinc (Zn) play an essential role in the metabolic activities of both prokaryotic and eukaryotic cells. During infection, serum trace element levels are known to be altered in response to the infection process. An alteration in trace element levels during an infection may occur to deprive the pathogens of these elements (Pekarek and Engelhardt, 1981).

There is a fine balance between the infected host and the microorganism with regard to nutritional needs, with competition for various nutrients between them. The human body requires a number of minerals in trace (milligram) amounts, whereas other minerals are needed in ultratrace (microgram) quantities. Usually, a mineral deficiency involves more than one element, and these combined deficiencies have a serious effect on human health (Halme et al., 2000).

ABSTRACT

Most infectious diseases are accompanied by changes in the levels of several trace elements in the blood. A total of 88 female patients referred to the Nawroz Private Laboratory in the Duhok province, Kurdistan Region, Iraq, were enrolled in this study. The enrolled patients were sent to the laboratory for investigation of their hormone levels because they were suffering from various gynecologic abnormalities. The serum levels of anti-chlamydia immunoglobulin (Ig) G and IgM antibodies were estimated using enzyme-linked immunosorbent assay (ELISA) tests, and the serum trace element levels were evaluated by atomic absorption spectroscopy. The results showed that 10 (11.4 %) of the samples tested positive for the presence of anti-chlamydia IgG antibodies, whereas none of the samples tested positive for anti-chlamydia IgM antibodies. Furthermore, a significant reduction in the serum potassium levels was observed in response to the chlamydia infection, whereas no significant changes were observed in any of the other elements.

Keywords: Chlamydia Trachomatis, Trace Elements, Infectious Diseases

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This study aimed to detect the incidence of the *C. trachomatis* infection in women and to study the effect of the infection on serum trace elements.

### 2. MATERIALS AND METHODS

A total of 88 female patients referred to the Nawroz Private Laboratory in Duhok province, Kurdistan Region, Iraq, were enrolled in this study. The patients were sent to have their reproductive hormone serum levels analyzed. Blood was collected from each individual patient and the hormone(s) of interest was investigated according to the referral report.

The serum samples were divided into 2 aliquots. One aliquot was used for ELISA analysis to investigate the presence of anti-chlamydia IgG and IgM antibodies. For this purpose, 2 kits, namely the NovaLisa *Chlamydia trachomatis* IgG-ELISA kit (Nova Tec Immunodagnostica GmBH, Dietzenbach, Germany) and the NovaLisa *Chlamydia trachomatis* IgM-ELISA kit (Nova Tec Immunodagnostica GmBH) were used. Both kits were used according to the manufacturer’s instructions. The samples were considered positive if the absorbance was at least 10% above the cutoff and negative if the absorbance was at least 10% below the cutoff. The remaining serum aliquots were used for the detection of serum trace elements (Zn, Cu, Na, K, Fe, and Ca) using atomic absorption spectrophotometry (PG instruments AA500 Atomic Absorption Spectrophotometer, Leicestershire, United Kingdom). The slit width was 0.4 nm, lamp flow was 5.0 mA, and the wavelengths were 213.9, 589.0 nm (width 0.2 nm), 766.5 nm, 248.3 (width 0.2 nm) and 422.7 nm, respectively.

### 3. RESULTS

The results of the ELISA measurements revealed that all the samples were negative for the anti-chlamydia IgM antibodies. Five samples (5.7%) were positive for the anti-chlamydia IgG antibodies, whereas 7 samples (7.9%) were indeterminant or in the gray zone. ELISA testing was repeated for the indeterminant samples after one month, following which 5 of the 7 patients tested positive for anti-chlamydia IgG antibodies, and the other two remained indeterminant and were thus considered to be negative. Collectively, 10 samples (11.4%) tested positive for anti-chlamydia IgG, whereas 78 samples (88.6%) were negative (Table 1).

<table>
<thead>
<tr>
<th>ELISA</th>
<th>Indeterminant</th>
<th>Negative</th>
<th>Positive</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-chlamydia IgM</td>
<td>0</td>
<td>88</td>
<td>0</td>
<td>88</td>
</tr>
<tr>
<td>Anti-chlamydia IgG</td>
<td>7</td>
<td>76</td>
<td>5</td>
<td>88</td>
</tr>
<tr>
<td>Repeat for indeterminant</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

The results showed that only the K levels were affected by the chlamydia infection. In individuals without the chlamydia infection, the mean serum K level was 4.6 mmol/L, whereas in the women with the chlamydia infection, the mean level was reduced to 3.9 mmol/L. This reduction in the K level was statistically significant ($p = 0.019$; 99% confidence interval, 0.016–0.023). No significant changes were observed in the other elements related to the chlamydia infection.

### 4. DISCUSSION

Several trace elements are important co-factors of multiple enzymes and are important for immune cell production, activation, and function. Most infections are accompanied by an alteration in the trace element levels, which is reflected in serum measurements. A well-documented and common response to infection is a reduction in the levels of Zn and Fe in the serum with a concomitant increase in Cu levels (Beisel et al., 1974).

Trace elements play an important role in immune response (Deveci and Ilhan, 2003; Kassu et al., 2006; Mohan et al., 2006). Fe is a component of enzymes critical for the functioning of immune cells and is involved in the regulation of cytokine production and action. Cu is involved in the maintenance of the intracellular antioxidant balance, suggesting an important role in the immune response.
role of Cu in inflammatory response. Zn is essential for highly proliferating cells, especially in the immune system, and is involved in the protection against oxidative stress (De Moraes et al., 2011).

It is well known that an infection may cause micronutrient deficiencies and these deficiencies may alter the risk of infectious disease morbidity (Scrimshaw et al., 1968; Tomkins and Watson, 1989). The effects of an infection are mediated through the acute response phase and localized lesions, leading to decreased intake and absorption of micronutrients, in addition to the increased utilization and loss of micronutrients. A micronutrient deficiency may affect the risk of infection by a specific infectious agent and also the severity of the disease morbidity. These effects are mediated via the pathogenicity of the infectious agent, host risk behavior, or the host defense, and may be either synergistic or antagonistic (Friis, 2001). A synergistic relationship exists when a specific micronutrient deficiency increases the infectious disease morbidity, in which case either improved micronutrient intake or treatment of the infection will break the vicious circle. An antagonistic relationship exists when a specific micronutrient deficiency reduces or increased intake increases the infectious disease morbidity (Scrimshaw et al., 1968). In fact, a micronutrient may act synergistically in moderate doses but antagonistically in high doses. For example, Zn, although essential for the optimal functioning of the immune system (Shankar and Prasad, 1998), is immunosuppressive at high doses (Chandra, 1984).

The results of the current study were inconsistent with those of others who stated that changes in serum trace element levels had also been noted in individuals with different infectious diseases. Lower respiratory tract infections and diarrhea among Indian infants were associated with low plasma Zn levels (Bahl et al., 1988). Increased Cu levels along with reduced Zn levels were recorded in patients diagnosed with *Plasmodium vivax* malaria (Seyrek et al., 2005). Patients with pulmonary tuberculosis showed an increase in serum Cu levels (Ciftci et al., 2003). Such changes could be the direct or indirect effect of the defense strategies employed by the host system to prevent growth or adhesion of the pathogen, or to improve the host immune defense mechanism.

Finally, we should emphasize that serum K levels reflect the general condition of the body and should not be considered as a specific diagnostic parameter for genital chlamydia infection in these women. This reduction could also be attributed to other co-existent conditions in the body. The resampling technique proved useful in circumventing the issue of small sample size in our study; however, more readings will provide better inferential power. It should also be emphasized that within the infected group, there were only 11 readings and that two of them were outliers as determined by boxplots, which could have introduced some variation in the permutation test. Collectively, these results should encourage future studies with larger sample sizes to support the current findings and also to investigate in more depth the mechanism(s) by which the chlamydia infection could affect serum K levels in humans.

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The Role of Elementary Dimensions in the Creation of the Source of Elementary Particles

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ABSTRACT

It is agreed that before the creation of particles, space was completely devoid of matter and radiation. In this study, we assume that the absolute void comprises 4 dimensions, namely 3 spatial dimensions and a force equivalent representing the factor of change among the elementary dimensions. Our hypothesis is based on the expansion of the spatial dimensions and the subsequent space instability. We demonstrated that when the equivalent outward force strength exceeds a critical limit, it collapses inwardly to restore the equilibrium of the system. Subsequently, the void inside the collapsed force equivalent acts as a void in a confined system, and the energy of the system remains conserved at all stages. With the decrease in the spatial dimensions owing to the collapse, the energy density increases, and at the final stage, the energy in the confined system becomes concentrated, thereby forming a solid state of energy. In this solid state of energy, a particle becomes the source of the elementary particles. The created high-energy sources are controlled by the internal and external forces of the source and all the entities in its external force field until equilibrium is reached. This article gives a summary of the Big Bang theory and its problems, which are further discussed in detail. This article will help in understanding how elementary dimensions play a role in the formation of elementary particles. Quark-gluon plasma, inflation, gravitational collapse, and gravitational lensing provide evidence that supports the elementary dimensions theory presented in this paper.

Keywords: Elementary particles, Elementary dimensions, Space, Force, Gravitational force, Quark-gluon plasma, Gravitational lensing

1. INTRODUCTION

At present, Astrophysics claims that our universe was formed as a result of the “Big Bang.” It was confirmed by the astronomical observations of distant galaxies and the observation of a large redshift in the wavelength of the light coming from these galaxies to the observer on Earth.

According to Hubble’s law, the wavelength of light increases as the distance between the observer and galaxies increases. Doppler’s law linked the cosmological redshift in the spectra of distant galaxies to their active expansion away from each other, including from the observer on Earth. The detection of relic radiation and gravitational waves have also confirmed that there was a Big Bang in the past.

There are 2 points of views on what constituted the Big Bang. According to the first one, known as the Gamow Big Bang theory, an ultra-dense elementary particle exploded about 15 billion years ago. Because of this explosion, our universe was formed. Following the explosion, the universe has been continuously expanding, and because of this, the galaxies scattered and they indicate this with a redshift in their spectra. Over time, as
the distance from the observer on Earth increases, the expansion rate increases. As the galaxies approach the edge of the visible universe, the wavelength of light increases much faster than that predicted by Hubble’s law. The researchers who discovered the expansion of universe were awarded with a Noble Prize.

The second point of view arose from the insolvency of ideas about the explosion of a kind of "cosmic egg," which was the explosion of the largest nuclear bomb. Astrophysics today views space as empty and at best filled with electromagnetic radiation. Within the space available for observations, astronomers observe the explosions of stars but do not observe explosions of space between the stars. According to the second point of view, the expanding space entrains the galaxies. Because of this, galaxies disperse and, in accordance with the Doppler law, indicate this by extending the wavelength of the light. At the same time, the mechanism of interaction of material objects with space has not been defined. Previously, authors and supporters of space expansion agreed on the fantastic idea that space expands and that the galaxies remain in place and do not scatter. They argued that the cosmological redshift is in no way connected with the Doppler effect, but they do not offer an alternative explanation for this redshift in the spectra of distant galaxies. Therefore, the second point of view is no better than the first (Alice Collaboration, 2014; Burago Sergey Georgievich, 2017).

According to the current theories, the universe was created by the Big Bang, during which there was a stage in which matter existed as a sort of extremely hot, dense soup called quark-gluon plasma, which was composed of the elementary building blocks of matter. As the time passed, the universe cooled down and the quarks became trapped in composite particles such as protons and neutrons. This process or phenomena is called the confinement of quarks. The Large Hadron collider (LHC) is a machine that is able to produce quark-gluon plasma by accelerating and colliding 2 beams of heavy ions. In the collisions, the temperature exceeds that of the center of the Sun by 100,000 times. Under these conditions, the quarks are free and detectors, which are attached to the LHC, can observe and study the primordial soup, thus probing the basic properties of the particles and how they aggregate to form ordinary matter. It is also used for finding extra dimensions and providing information about the origin and expansion of the universe and the mass of stars or matter (Adolphi, 2008).

Observations undeniably suggest that the universe is expanding. Therefore, it might be difficult to debate that the space-time continuum did not start with the Big Bang. Before the creation of particles (before the Big Bang, if there was a Big Bang), it is agreed upon that space was devoid of matter and radiation (electromagnetic, heat, etc.), meaning that the absolute zero temperature was reached naturally. Hereafter, we call this kind of space absolute void (AV); in contrast, space devoid of matter but containing electromagnetic and heat radiation is simply referred as void.

The absolute zero temperature is reached naturally when all the sources of heat are nonexistent. Therefore, before the Big Bang, the absolute zero temperature was reached naturally because there were no particles or radiation as a source of heat.

Briefly, the differences between AV and void only are as follows:

- An AV exists in the spaces where the particles have not been created and radiation has not reached them yet. In this space, all sorts of heat sources are nonexistent, which allowed these spaces to reach the absolute zero temperature naturally. It is very challenging to create an AV in the laboratory because the removal of all sorts of matter and radiation for the creation of absolute zero temperature in a volume of space is very difficult.

- A void exists in the spaces where the particles have not been created but where radiation has reached them. In these spaces, electromagnetic and heat radiation are present, which causes the temperature of these spaces to be above absolute zero temperature. A void can be created by removing all sorts of particles (including radiation particles, such as alpha particles) from a volume of space.

Both the void and AV are 3-dimensional (space dimensions in the x, y, and z axis). However, if they only consisted of spatial dimensions, no change would occur, and the void would remain the only entity, and, therefore, particles would not be created. However, a fourth
dimension would lead to the creation of matter or particles. The question is if time is the fourth dimension.

Time is a hypothetical concept (McTaggart, 1908; Craig, 2010) that corresponds to changes during certain events, which can be compared with a constant rate of change event. Accordingly, time is a human defined concept used to organize our lives and history. Although time does not really exist, living beings can sense its effects. Therefore, time itself cannot be the fourth dimension, but the factor of change that time represents can be the fourth dimension.

To identify the factor of change, we need to study the properties of the void and AV using experiments. Creating a volume of AV is challenging. Creating a space void totally devoid of particles is also challenging; however, our experiment will allow us to identify the fourth dimension, which corresponds to the factor of change.

2. IDENTIFICATION OF THE FOURTH DIMENSION EXPERIMENT

Fig. 1 shows the creation of void by using a closed head syringe.
Owing to lack of resources, a 10 ml syringe was used to identify the elementary dimensions of the void. The syringe head was closed, and the bottom part was pulled out by using weights to create the void in the syringe.

Through classical physics, the summation of the forces on the vertical axes equals zero, which is illustrated as follows:

\[ F_y = 0, \quad F_v + F_{\text{downward}} = 0, \]

where \( F_{\text{downward}} \) is the force needed to pull the matter downward to create an \( xyz \ m^3 \) of void, and \( F_v \) is the equivalent force sourced from the void to resist the lack of matter. If,

\[ F_v + F_{\text{downward}} = 0, \]

then, \( F_v = F_{\text{downward}} \)

Therefore, the force \( F_v \) corresponds to the factor of change, which means that the \( F \) equivalent is the fourth dimension in voids and AVs.

We can conclude from this simple syringe experiment that when a volume of void is existent, the following 2 forces are present in the system:

- \( F_v \): represents the equivalent force that developed internally from the void to resist the lack of matter. Its direction is inward. It is the internal force \( F_i \).
- \( F_{\text{downward}} \): represents the external equivalent force needed to create the void. Its direction is outward. It is the external force \( F_e \).

As already mentioned, the \( F \) equivalent identified in this experiment corresponds to the void. The \( F \) equivalent created in an AV space is significantly stronger.

It is well know that the 7 dimensions in physical quantity are:

1. Time (second)
2. Length (meter)
3. Mass (kilogram)
4. Electric current (ampere)
5. Thermodynamic temperature (Kelvin)
6. Amount of substance (mole)
7. Luminous intensity (candela)

However, force is not among those 7 dimensions, which leads us to emphasize the importance of the \( F \) equivalent. The equivalent force, which is mentioned above as the fourth dimension, is not the force that we are fond of in physics. The force that we are accustomed to is defined as any interaction that changes the motion of an object. In addition, in physics, force is defined as mass times acceleration. It means that a particle should exist for a defining force.

Following the discussions above, void and AV spaces are 4-dimensional and include \( x, y, \) and \( z \) axes, and the force.

### 3. FORCE PATTERNS

Figs. 2 and 3 show the force pattern direction of an absolute void and a void (AV&V) space in a confined and an open system, respectively.
Similar to the experiment conducted in Fig. 1, the force acts to prevent the formation of the void by trying to crush the parameter of the surroundings toward the center in Fig. 2, and therefore, the direction of $F$ is pointed toward the center of the void.

**Figure 2.** Forces sourced from the AV&V in a confined system

**Figure 3.** Forces sourced from the AV&V in an open system
However, the AV&V is considered an open system, in other words, the AV&V exists in a free form. At any point of the AV&V, the force is pointing outward as depicted in Fig. 3. Consequently, any point of the AV&V in a confined system acts as an AV&V in an open system, which means that the force is pointing outward (Fig. 4).

![Figure 4](image1)

**Figure 4.** Any point of the AV&V in a confined system acts as the AV&V in an open system

### 4. CREATION OF THE SOURCE OF ELEMENTARY PARTICLES THROUGH ELEMENTARY DIMENSIONS

When the volume of the AV increases, the outward force subsequently increases, causing the space to become unstable and lose its equilibrium. When the outward force exceeds a critical limit, the system reaches the highest level of instability. To restore equilibrium in the system, the outward force collapses inward (Fig. 5).

![Figure 5](image2)

**Figure 5.** The transformation of AV in an open system to AV in a confined system or the birth of a source of elementary particles

Consequently, the AV transformed from an open system to a confined system, and the energy of the system remained conserved during all stages. However, with a decrease in the spatial dimensions, the energy density increases (Fig. 6).
At the final stage, the energy in the confined system is concentrated and forms a solid state of energy. Within this solid state of energy, a particle is present, and from this particle, the elementary particles originate. Therefore, the created particle from the increased energy density is the source of elementary particles (hereafter, referred to as source for simplification). The source is created to absorb the surplus force and to decrease the level of instability in the system, thereby achieving equilibrium in space. At this stage, the source is controlled by the following 2 forces:

Internal force $F_i$, which originates from the void inside the particle, just like a void in a confined system, and is directed toward the center.

External force $F_e$, which originates from the void outside the born particle.

The force $F_i$ causes the source to shrink or collapse, whereas the force $F_e$ is the resisting force. Therefore, the source will collapse unless equilibrium is achieved between the internal and external forces. In the case, when more than 1 source-like entity exist relatively close together, the equilibrium process exists among all of them.

The source is a high-energy and an absolute zero temperature entity (the energy calculation is below in the gravitational collapse topic).

Before the creation of particles, infinite space of AV existed. Therefore, when unlimited numbers of the source-like entities were created, this was the first step toward the creation of the universe and before the occurrence of the Big Bang. However, deciphering the processes that took place after the source was created is based on a theory. Theoretically, the interactions and collisions among the created sources led to the increase in the temperature of the universe as explained below. This explains how the increase in temperature led to destruction of the sources, which caused the creation of elementary particles and the expansion of the universe.

5. THEORETICAL EVIDENCE

In this section, we discuss 4 phenomena that support the above mentioned elementary dimensions (EDs) theory.

5.1. Gravitational Force and Collapse

The process of gravitational collapse is similar to the process in which a void in an open system becomes a void in a confined system or the force changes from outward-directed to inward-directed. The force equivalent (the fourth dimension), mentioned in the illustrations above, corresponds to the gravitational force.

Demonstrated by observations (Bedran et al., 1996; Glavan and Lin, 2020), gravitational collapse occurs in the universe. Although the observable products of gravitational collapses (e.g., black holes) are not the sources themselves, both the product and the sources are created by the same process (Hacar et al., 2017).

The fact that black holes are also high-energy entities further proves their similarity to the sources. Specifically:

1. The source in equilibrium state

Figure 6. Increased energy density inside the collapse system
As already mentioned, the internal force causes the source to shrink or collapse, whereas the external force is the resisting component. The source collapses unless equilibrium is achieved between the internal and external forces, as shown in Fig. 7.

The equilibrium of the source is affected by external entities (other sources, stars, planets, etc.) present in its field of impact (Fig. 9). Because those entities have their own external and internal forces, equilibrium must be reached among all the forces of all entities, including the source.
Figure 9. A source in a state of equilibrium with all the entities in its field of impact in which $F_{\text{in,total}} = F_{\text{ex,total}}$

The system in Fig. 9 is in equilibrium when the summation of the internal equivalent forces equals the external ones and is indicated by the following equation:

$$\sum_{n=1}^{n} F_{\text{in}}^n = F_1 + F_2 + \cdots + F_n$$

The same applies to the external forces:

$$\sum_{n=1}^{n} F_{\text{ex}}^n = F_1 + F_2 + \cdots + F_n$$

The vector sum of each component along the x, y, and z coordinates for the internal forces can be calculated as follows:

$$\sum_{n=1}^{n} F_x = F_{1x} + F_{2x} + \cdots + F_{nx}$$
$$\sum_{n=1}^{n} F_y = F_{1y} + F_{2y} + \cdots + F_{ny}$$
$$\sum_{n=1}^{n} F_z = F_{1z} + F_{2z} + \cdots + F_{nz}$$

The vector sum of each component along the x, y, and z coordinates for the external forces can be calculated as follows:

$$\sum_{n=1}^{n} F_x = F_{1x} + F_{2x} + \cdots + F_{nx}$$
$$\sum_{n=1}^{n} F_y = F_{1y} + F_{2y} + \cdots + F_{ny}$$
5.1.1. The black hole in equilibrium state

Before a star dies, the space affected by the star is in equilibrium because the external and the internal forces of all the entities in the field are balanced. The stars and any other forms of particle clusters exert internal and external forces; however, the force impact is much lower than that of a black hole because such entities are low-energy entities (Fig. 10).

A star is made up of a cluster of particles. It is already in equilibrium with all of its own particles’ internal and external forces balanced. However, the space region of the star is dependent on the star’s forces, implying that a star can have forces bigger than the forces of the total entities in its external force field.

Figure 10. A star in a state of equilibrium indicating all the entities in its field of impact (not in scale), with \( F_{\text{star}} \gg F_{\text{entities}} \)

For larger stars above the Landau or Tolman–Oppenheimer–Volkoff limit (Pooley et al., 2018) (corresponding to approximately 2 solar masses), known forms of matter cannot provide the force required to balance gravity when the star dies. Therefore, there is nothing to stop the collapse.

When a particle collapses to its Schwarzschild radius (Schwarzschild, 1916; Ghez, 2008), it forms a black hole, a space-time region in which even light cannot escape. Following the theorem of Roger Penrose (Penrose, 1965) and general relativity, the formation of singularity is inevitable. According to Penrose’s cosmic censorship hypothesis, the singularity is limited to the event horizon bounding the black hole, and therefore the encompassing space-time district maintains a usual geometry with a solid and limited bend. It is normal (Carter, 1971) to develop toward a fairly straightforward structure that can be described by the Schwarzschild metric in as far as possible and by the later Kerr metric if angular momentum is present. Therefore, a black hole is formed to restore equilibrium in the system.

According to the EDs analysis, a massive star dominates space. This star has the largest amount of internal force among all entities, meaning that the equilibrium of that region of space is mostly dependent on the internal force of the star. When the star dies, the system loses its equilibrium. Based on relative spatial dimensions, a star is not a high-energy entity, regardless of its mass. Therefore, a much smaller, high-energy entity is needed to substitute the star in the equilibrium process. For
instance, a black hole is a high-energy entity. The size of a black hole needed to substitute a star will be much smaller, smaller than the limit of the Schwartzchild radius of the star.

By using the Schwartzchild radius’s equation, we can determine that the radius of a black hole needed to substitute a star is as follows:

\[ r_s = \frac{2GM}{c^2} \]

where \( r_s \) is the black hole radius, \( G \) is the gravitational constant, \( M \) is the mass of the star, and \( c \) is the speed of light in vacuum.

![Figure 11. The formed black hole in a state of equilibrium with all the entities in the field of impact of the dead star (not in scale), in which \( F_{\text{total}} = F_{\text{e, total}} \)](image)

We deduce that the source is formed to create equilibrium in space, because before the creation of the sources, only external forces existed. The sources collapse until equilibrium is achieved, and a black hole is formed in place of the dead star to restore equilibrium (Fig. 11).

5.1.2. Mass, energy, internal, and external force calculation for source-like entities

Through the same equation, we can calculate the mass-radius equivalent for source-like entities as follows:

\[ M = \frac{r_s \times c^2}{2G} \]

Because we have mass, using the energy-momentum relation (Forshaw et al., 2009), we can determine the energy \( E \) as follows:

\[ E^2 = (pc)^2 + (Mc^2)^2 \]

where, \( P \) is the momentum and \( M \) and \( c \) are the same as mentioned above.

Also (McGill and King 1995):

\[ P = Mv \]

where, \( v \) is the velocity of the entity
Fin $\alpha E$

Fex $\alpha E$ and Fex $\frac{1}{R}$

Therefore, Fex $\alpha E$ in joule/meter = newton, $R_n = \sqrt{x_n^2 + y_n^2 + z_n^2}$

F1 and F2 are the external force effects of the dominant entity, which shift the axis to the center of the smaller entity. The smaller entity also has an external force F3 and F4 effect on the dominant entity.

5.1.3. Thermal equilibrium

The source-like entities are absolute zero-temperature entities unlike stars, which are high-temperature entities. Hypothetically, the absolute zero entities have the ability to devour the high-temperature entities because of their temperature nature and enormous mass through thermal equilibrium (Lieb and Yngvason, 1999; Völkel et al., 2019).

$[m\Delta T]\text{Source} + [m\Delta T]\text{ Star} = 0$

Here, msource = source’s mass; mstar = star’s mass; C = specific heat capacity

$\Delta T$ = the difference in temperature

5.2. Quark-gluon Plasma

In theoretical physics, the Hagedorn temperature (Gaździcki & Gorenstein, 2016), TH, corresponds to the temperature where the hadron is no longer stable and must either evaporate or convert to quark matter. Therefore, TH can be considered to be the boiling point of the hadron (Rafelski, 2020).

Quark-gluon plasma (QGP) (Bhalerao, 2014) is an interacting localized assembly of quarks and gluons at thermal (kinetic) equilibrium and close to chemical abundance equilibrium. The temperature of the QGP is above the Hagedorn temperature. QGP emerges as the new phase of strongly interacting matter manifesting its physical properties in terms of nearly free dynamics and quarks and gluons practically without mass (Rafelski, 2015; Koch et al., 2017).

The following procedure is considered when taking a random atom as a sample:

At medium (273–360 Kelvin) temperature, the structure of atoms is in a solid state.

By increasing the temperature, the degrees of freedom in atoms are increased, which changes their structure to a liquid state.
By increasing the temperature further, the increase in the degrees of freedom changes the atom structure to a gas state.

Excessively increasing the temperature to Hagedorn temperature causes the formation of the QGP state (as defined earlier).

This procedure differs from the method mentioned in EDs theory, in which it is stated that before the creation of particles, the universe was at an absolute zero temperature.

In fact, when temperature decreases to the absolute zero, the process occurs in reverse, implying that before the creation of particles when all types of heat sources were nonexistent and when the absolute zero temperature was reached naturally in a volume of space, all the components of the atom were merged. This means that fermions and bosons were compressed together at the same point to form a singularity (Shapiro and Teukolsky, 1991).

According to the EDs theory, singularity is a characteristic of the source of particles, and it is the state at which the absolute zero temperature is reached and all particle components (fermions and bosons) are in the same location. In the singularity state, the source of particles is at its maximum mass level in relation to the spatial dimensions.

With an increase in temperature, the source (singularity) decomposes to the elementary particles. However, once the elementary particles are created, the process cannot be reversed, meaning that achieving absolute zero temperature will not create singularity again. In this case, the elementary particles will be at ground state or vacuum state (Astrid Lambrech 2002). However, singularity can be created through gravitational collapse.

The sources of elementary particles created from elementary dimensions are, therefore, at the singularity state and at the maximum mass level, which occupies a very small scale of the spatial dimensions.

5.3. Inflation

According to Overbye (2017), Whiting (2004), and Borağan Aruoba (2020), the Big Bang theory gives a lot of information about the origin of universe and explains why the universe is expanding as discovered by the Hubble Space Telescope. However, the Big Bang model was not complete because it had 3 problems: (1) horizon, (2) flatness, and (3) monopole. All of these problems were solved by using an inflammatory model of the universe, which assumes that from 10^{-36} to 10^{-33} or 10^{-32} seconds after the Big Bang occurred, the universe expanded by a factor of 1050 (Sapkota and Adhikari, 2017). The basics of inflation cosmology is explained below.

The source or the singularity is a high-energy entity, and when it decomposes into elementary particles, a tremendous amount of energy is released in different forms (electromagnetic and heat radiations, etc.). The temperature increases tremendously and the spatial dimensions consequently expand, leading to the expansion of the universe in every direction (the energy calculation for this is explained in the section of gravitational collapse).

The source may decompose because of the increase in the temperature, the interactions, or because of the collisions among the unlimited sources created in the infinite AV of the early universe.

The universe will keep expanding as long as there is a source of heat radiation that increases the temperature. When all sources of heat radiation are consumed, the expansion will stop.

When the expansion stops, because of the consumption of all the sources of heat, the universe will be at absolute zero temperature and infinite spatial dimensions, thereby bringing the universe back to the first stage before the creation of particles. From there, the system will collapse again, and thereby form the source of elementary particles.

The process above indicates that the universe is in a cycle.
5.4. Gravitational Lensing

Gravitational lensing (Einstein, 1936) emerged as an observational field following the 1979 discovery of a quasar with a double image that was lensed in a foreground galaxy. Following that discovery, many advanced imaging systems have been developed. Lensing is currently one of the most effective methods used for the determination and mapping of dark matter over a wide range of scales and also to find the nature of energy. One of the most effective lensing methods is microlensing, which is effectively used to determine the mass of planets (Jain, 2007; Mukherjee et al., 2020). The basic process of the gravitational mechanism is explained below.

A distribution of matter (e.g., galaxy clusters) between a distant light source and an observer can bend the light of the source as it travels toward the observer (Sauer, 2008). Gravitational lensing fits perfectly in the EDs theory, as shown in Fig. 13.

When a beam of light approaches a black hole or star, it is affected by the external force field of the system. Although the beam of light tends to travel straight toward the system, the force $F_e$ prevents it from falling into the system, causing what is known as gravitational lensing (Mauro Sereno, 2018).

The same well-known equations can be used to measure the angle of deflection.

5.5. Particle Creation

Particles cannot materialize out of space to create the universe. In contrast, they must be created from the void and its dimensions, because the void is the predecessor of particles.

6. CONCLUSION

In this study, we hypothesized that there is a limit to the level of instability of the AV at absolute zero temperature, at which point the external force is huge. When the external force exceeds this limit, the force collapses inward, creating the source of elementary particles. Furthermore, we discussed that the source is governed by 2 forces, namely the internal force that leads to the collapse of the source and the resistant external force. The source is in a state of equilibrium when the external force equals the internal force. According to EDs theory, the source is a high-energy entity that exists at absolute zero temperature, meaning that all particle components are merged together into a singularity. Finally, we concluded that an AV consists of 4 dimensions, 3 of which are spatial dimensions and the fourth is a factor of change.
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REFERENCES


Determining the Tectonic Origin of the Gara and Mateen Anticlines Using Geomorphological and Structural Forms, Iraqi Kurdistan Region

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ABSTRACT

Gara and Mateen are 2 major anticlines in the northern part of the Iraqi Kurdistan Region, located in the vicinity of the town Amadiyah. Both anticlines are oriented in an almost east–west (E–W) trend with a steep southern limb. The length and width of the Gara and Mateen anticlines are 87 km and 63 km, and 11 km and 9.5 km, respectively. The 2 anticlines are separated by a wide and shallow syncline filled by the Tertiary rocks of the Pliocene–Pleistocene age. The oldest exposed rocks in the Gara and Mateen anticlines are from the Triassic age. The carapace of both anticlines is built up by the Bekhme and Qamchuqa formations. The geomorphological and structural features were studied through satellite images and geological maps. Based on these studies, it was found that both anticlines show clear geomorphological and structural features that indicate their lateral growth. Among those features are water and wind gaps, different shapes of valleys that indicate lateral growth, abandoned alluvial fans, whale-back shapes, en-echelon plunges, and multiple dome anticlines. Furthermore, the rate of upward movements was calculated using neotectonic data. In addition, the rate of river and stream incisions was calculated on the basis of the height of the river terrace levels.

Keywords: Lateral growth, Water and wind gaps, Fork-shaped valleys, Abandoned alluvial fans, En-echelon plunges

1. INTRODUCTION

In tectonically active areas, the lateral growth of anticlines is a very common phenomenon (Blanc et al., 2003; Bennett et al., 2005; Ramsey et al., 2008).

The Iraqi Kurdistan territory, which forms the northeastern part of the Arabian Plate, is a good example of a tectonically active area. The Arabian Plate collides with the Iranian Plate with a convergent tectonic plate
boundary (Alavi, 2004; Allen et al., 2004; Fouad, 2012). Because of the compressional forces exerted by the collision, many anticlines and their associated main faults developed. Mountain building and landscape evolution are controlled by the interactions between river dynamics and tectonic forces. The landscape geomorphology and the drainage patterns provide indirect information about the tectonic activity of the drainage basins and included folds (Oberlander, 1985; Burbank and Pinter, 1999; Keller et al., 1999; Tomkin and Braun, 1999; Burbank and Anderson, 2001; Castelltort and Simpson, 2006; Bretis et al., 2011; Graseman and Schmalholz, 2012; Colligon, et al., 2016). Keller et al. (1999) evaluated fold growth using the following geomorphic criteria: the deformation of progressively younger deposits or landforms, the development of characteristic asymmetric drainage patterns, and the occurrence of a series of wind gaps with decreasing elevation in the propagation direction. The Gara and Mateen anticlines exhibit lateral growth with clear indications of interaction between the existing rivers and tectonic forces, which are indicated by the different geomorphological and structural features that are evaluated in this study. The studied area includes the Gara and Mateen anticlines, which are located north and south of the town of Amadiya, respectively, and about 85 km north of the city of Erbil in the Iraqi Kurdistan Region (Fig. 1).

The aim of this study was to determine the origin of the Gara and Mateen anticlines and identify how they developed to their present morphology. The data were acquired using the geomorphological and structural features that are present in both anticlines. Identification of the features was achieved by the interpretation of high-quality satellite images.

1.1. Previous Studies

Tectonic-geomorphological studies are not common in the Iraqi Kurdistan Region, including the studied area. These types of studies are very rare, although a few studies have been conducted and are described in the following section.

Sissakian (2010) attributed the development of the Derbendi Bazian gorge to neotectonic activity based on a tectonic-geomorphological study in which he confirmed that it was a wind gap. Sissakian and Abdul Jabbar (2010) concluded that the Basara gorge was a water gap that developed because of neotectonic activity based on a study of the transversal gorges in the Iraqi Kurdistan Region. Sissakian et al. (2014) conducted a geomorphological study of the High Folded zone and concluded that the developed gorges in the Handreen, Zozik, and Tanoun anticlines were caused by lateral propagation (growth) of the anticlines. Al-Kubaisi and Abdul Jabbar (2015) indicated a high level of tectonic activity and low maturity of the drainage basins in 3 anticlines in the Kurdistan Region, as determined by a morphotectonic study of 3 folds and presented their effects on the drainage systems. Sissakian et al. (2018) determined the lateral growth of the Qara Dagh anticline by conducting a tectono-geomorphological study. They used the same geomorphological and structural forms that have been used in this study. Ghafur et al. (2019) conducted a tectonic-geomorphological study on the Agra anticline, confirming its lateral growth using geomorphological and structural forms. Finally, in the latest study conducted by Sissakian et al. (2020), the authors studied the lateral growth of the Handreen, Zozik, and Tanoun anticlines in the Kurdistan Region of Iraq, relying on geomorphological features.

Internationally, several studies have been conducted including the study by Cartwright et al. (1995) who identified fault growth by segment linkage at Canyonlands’ Grabens in southeast Utah, United States, by conducting a geomorphological study. Bennett et al. (2005) identified the lateral growth of a ridge along a blind fault in a geomorphological study in South Rough Ridge, Central Otago, New Zealand. They used geomorphological data to confirm the lateral growth. Some of the data of the previous studies have been used in this study. Mumipour and Najad (2011) and Mousavi and Arian (2015) conducted tectonic-geomorphological studies in the Zagros belt, Iran, using geomorphological features to determine the growth of anticlines. Data from these studies have been used in this study to indicate the origin of the Gara and Mateen anticlines.
2. MATERIALS AND METHODS

To conduct this study and to determine the origins of the Gara and Mateen anticlines, the following materials were used: geological maps at a scale of 1:100,000 and 1:250,000, topographical maps at a scale of 1:100,000, and high resolution satellite images.

The opinions of different researchers were considered in recognizing the geomorphological and structural features, which indicate the origin of the Gara and Mateen anticlines in the study area, including the studies by Keller et al. (1999), Ramsey et al. (2008), Grasemann and Schmalholz (2012), and Collignon et al. (2016). Using available topographical and geological maps of 1:100,000 and 1:250,000 scales with the help of Flash Earth, Global Mapper, a digital elevation model, and other satellite images, different geomorphological and structural features and forms were identified to determine the origin of the Gara and Mateen anticlines. Geomorphological and structural features and forms such as wind and water (river) gaps (or transverse streams), en-echelon plunges, multiple dome folds, and different shapes of valleys like radial, axial, curved, and fork-shaped have been extensively used to define the style of deformation and to quantify both the rate and the direction of propagation (or the lateral growth) of the fault and fold segments (Burbank and Pinter, 1999; Keller et al., 1999; Décallau et al., 2006; Ramsey et al., 2008; Bretis et al., 2011; Grasemann and Schmalholz, 2012). Water gaps represent valleys that were developed by the carving of exposed rocks during fold growth and still host a flowing stream, whereas wind gaps represent similar valleys that are presently dry, but previously hosted water, indicating that the rate of lateral growth of the folds is higher than the rate of stream incision (Ramsey et al., 2008).
In regions affected by low or moderate tectonic deformation rates (as seen in the study area), geomorphological and geological data provide some of the best approaches to detect and characterize active tectonics (Molin et al., 2004; Dumont et al., 2005; Necea et al., 2005).

The rate of upward movement in the Gara and Mateen anticlines was calculated using neotectonic data. The elevation of the contact between the Fatha Formation (Middle Miocene, marine sediments) and the Injana Formation (Upper Miocene, continental sediments) indicates the amount of upward movement since the Upper Miocene, which was during 11.62 Ma (International Commission on Stratigraphy [ICS], 2012). The amount of upward movement at each of the recorded locations could be calculated from the development of the present relief which started from the Pleistocene Epoch (2.588 Ma; ICS, 2012). Accordingly, the rate of the upward movement during the Pleistocene Epoch was calculated. Moreover, the stream rate of river and stream incisions was calculated based on the height difference between the river and/or the stream levels and the base of the terrace levels.

3. GEOLOGICAL SETTING

The geological setting of the study area, including the geomorphology, tectonics, and stratigraphy, is briefly reviewed based on the findings of Sissakian and Fouad (2012, 2014), Fouad (2012), Sissakian and Al-Jiburi (2014), and Sissakian et al. (2014).

3.1. Geomorphology

The following are the main geomorphological units identified in the study area:

1. Structural units, indicated by anticlinal ridges, are well-developed in both the Gara and Mateen anticlines.

2. Structural–denudational units are represented by the flat iron topography, cuestas, and hogbacks and are all well-developed in both the Gara and Mateen anticlines.

3. Fluvial units are represented by valley fillings, flood plains, terraces, and alluvial fans. Many abandoned alluvial fans were recognized, indicating lateral growth of both anticlines.

The geomorphological features that are indicators of lateral growth of the folds include the following: water gaps, wind gaps, axial valleys, curved valleys, radial valleys, inclined valleys, crossed valleys, and fork-shaped valleys. All of these features were recognized in the Gara and Mateen anticlines. The presence of a whale-back shaped anticline is also a good indication of the lateral growth of folds. This was recognized only in the Mateen anticline.

3.2. Tectonics and Structural Geology

The study area is located within the High Folded zone of the Outer Platform, which belongs to the Arabian Plate and is part of the Zagros fold–thrust belt. Both the Gara and Mateen anticlines are double plunging, NW–SE trending, but they change to an E–W trend. Both anticlines exhibit en-echelon plunging and multiple dome folds. It is recognized that both anticlines consist of 2 anticlines. In this study, the authors refer to them as Gara East (with the G1 and G2 domes) and Gara West (with the G3, G4, and G5 domes), and Mateen East (with the M1, M2, and M3 domes) and Mateen West (with the M4, M5, and M6 domes) (Fig. 1). The multiple dome folds and en-echelon plunging are good indicators of the lateral growth of the folds (Cartwright et al., 1995; Dawers and Anders, 1995; Cowie, 1998; Blanc et al., 2003; Bennett et al., 2005) and (Keller and Pinter, 2002; Ramsey et al., 2008), respectively. A long and narrow syncline lies between the 2 anticlines and becomes wider
westward where the Bai Hassan Formation of Pliocene–Pleistocene age is exposed in the trough. Many thrust faults run through both anticlines.

3.3. Stratigraphy
The exposed geological formations in the Gara and Mateen anticlines are briefly described in order, from the oldest to the youngest. The exposed formations are presented in the geological map (Fig. 2).

(1) Baluti and Kura China formations (Upper Triassic): both formations are exposed at the core of both anticlines as very narrow strips. The formations consist of black shale, limestone, and dolomite.

(2) Sehkanian and Sarki formations (Lower Jurassic): both formations are exposed at the core of both anticlines. Both formations consist of limestone, dolomite, and black shale.

(3) Chia Gara, Barsarin, Naokelekan, and Sargelu formations (Upper Jurassic): these formations are exposed at the core of both anticlines. The formations consist of limestone, dolomite, and marl.

(4) Qamchuqa Formation (Lower Cretaceous): it forms the carapace of both anticlines and consists of massive limestone and dolomite deposits.

(5) Bekhme Formation (Upper Cretaceous): it forms the outermost part of the carapace of both anticlines and consists of thickly and thinly bedded limestone and dolomite.

(6) Shiranish Formation (Upper Cretaceous): it consists of 2 parts. The lower part consists of white well-bedded marly limestone, whereas the upper part consists of dark blue and olive-green marl. The formation is exposed as a continuous belt surrounding both anticlines.

(7) Tanjero Formation (Upper Cretaceous): it consists of dark olive-green sandstone, shale, and marl. The formation is exposed as a continuous belt surrounding both anticlines in the form of dissected slopes.
Figure 2. Geological map of the Gara and Mateen anticlines, imposed over the DTM (modified from Sissakian and Fouad, 2012)

(8) Kolosh Formation (Paleocene): it consists of black fine clastics. The formation is exposed as a continuous belt surrounding both anticlines in the form of dissected slopes.

(9) Gercus Formation (Eocene): it consists of reddish brown fine clastics. The formation is exposed as a continuous belt surrounding both anticlines in the form of dissected slopes.

(10) Pila Spi Formation (Upper Eocene): it consists of well-bedded, pale white limestone and dolostone. The formation is exposed as a continuous belt surrounding both anticlines in the form of continuous anticlinal ridges with common flat irons of different sizes.

(11) Fatha Formation (Middle Miocene): it consists of reddish brown fine clastics. The formation is exposed as a continuous belt surrounding both anticlines in the form of anticlinal ridges and dissected slopes.

(12) Injana Formation (Upper Miocene): it consists of reddish brown fine clastics. The formation is exposed as a continuous belt surrounding both anticlines in the form of anticlinal ridges, questas, hogbacks, and dissected slopes.

(13) Mukdadiya Formation (Upper Miocene–Pliocene): it consists of gray fine clastics, and some of the sandstone beds are pebbly. The formation is exposed as a continuous belt surrounding both anticlines in the form of anticlinal ridges, questas, hogbacks, and dissected slopes.

(14) Bia Hassan Formation (Pliocene–Pleistocene): it consists of coarse conglomerate alternated with reddish brown claystone. The formation is exposed as a continuous belt surrounding both anticlines.
in the form of anticlinal ridges, questas, hogbacks, and dissected slopes.

Quaternary sediments are represented by terraces, alluvial fans, slope sediments, valley fill sediments, and flood plain sediments.

4. RESULTS

The recognized structural and geomorphological features in the Gara and Mateen anticlines are summarized in Table 1. The geomorphological and structural features that were recognized and interpreted from satellite images with the aid of topographical and geological maps, are briefly mentioned below. The rates of upward movements were calculated in the Gara and Mateen anticlines using neotectonic data. Moreover, the rates of river incisions were calculated based on the height differences between the levels of the rivers and terraces at different locations in both anticlines.

| Table 1: The recognized geomorphological features in the Gara and Mateen anticlines |
|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Anticline                      | Structural and Geomorphological Features | Inclined | Fork-shaped | Axial | Cross-shaped | Radial | Asymmetrical |
|--------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Gara                           | En-echelon plunges               | Yes             | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Multiple dome folds              | Yes             | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Water gap                        | No              | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Wind gap                         | No              | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Abandoned alluvial fans           | Yes             | Yes            | Yes            | Yes             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Whaleback shaped anticline        | No              | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
| Mateen                         | En-echelon plunges               | Yes             | Yes            | Yes            | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Multiple dome folds              | Yes             | Yes            | Yes            | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Water gap                        | Yes             | Yes            | Yes            | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Wind gap                         | No              | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Abandoned alluvial fans           | Yes             | Yes            | Yes            | Yes             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             |
|                                | Whaleback shaped anticline        | No              | No             | No             | Yes             | No             | Yes             | Yes             | Yes             | Yes             | Yes             | Yes             |

(1) **En-echelon plunges:** The presence of en-echelon plunges in a fold is an indication of the lateral growth of the fold (Keller and Pinter, 2002; Ramsey et al., 2008). En-echelon plunges can be recognized easily from the existing geological maps and by interpretation of satellite images. The Gara East and Gara West anticlines form an en-echelon plunge (Fig. 1). There is an en-echelon plunge between the Mateen East and Mateen West anticlines (Fig. 1). Moreover, the Gara and Mateen anticlines show en-echelon plunges with the Chinara and Shireen anticlines, respectively (Fig. 1). The northwestern plunges of both the Gara and Mateen anticlines have narrow and long shapes (Figs. 1 and 2).

(2) **Multiple dome folds:** The presence of multiple domes in folds is another indication of the lateral growth of folds (Cartwright et al., 1995; Dawers and Anders, 1995; Cowie, 1998; Blanc et al., 2003; Bennett et al., 2005). Multiple dome folds can be identified by using available geological maps and through the interpretation of satellite images; however, the available geological maps are at a scale of 1:250,000 and therefore not all of the existing domes are present on the geological maps. Moreover, Grasemann and Schmalholz (2012) have mentioned that multiple domes in a fold can join together to form 1 single fold. In the Gara anticline, 5 domes (G1, G2, G3, G4, and G5) have developed but not along a straight line, with an extensive lineament separating domes G2 and G3 (Fig. 1). In the Mateen anticline, 6 domes (M1, M2, M3, M4, M5, and M6) have developed but they are not aligned in a straight line, and the same extensive lineament, which runs through the Gara anticlines, extends to the Mateen anticlines and cuts through dome M2 (Fig. 1).

(3) **Abandoned alluvial fans:** The presence of an abandoned alluvial fan along a fold is an indication of the lateral growth of the fold (Keller and Pinter, 2002; Ramsey et al., 2008). The alluvial fans can be easily interpreted from satellite images; moreover, some of them are also present on the geological maps. Abandoned alluvial fans can be seen along the Gara
anticline (Fig. 3-3) and the Mateen anticline (Fig. 4-3). In both anticlines, the alluvial fans are very old and inactive. In the Mateen anticline, they are capped by calcrete (Fig. 4-3).

(4) **Whale-back shaped anticline:** when an anticline exhibits a whale-back outer shape or part of it, it is an indication that the anticline is experiencing lateral growth (Keller and Pinter, 2002 and Ramsey et al., 2008). The whale-back shape can be easily interpreted from satellite images and even from detailed topographical maps. Only in the northwestern part of the Mateen West anticline can the whale-back shape be seen (Fig. 4-4), whereas in the remaining parts of the anticline, the whale-back shape has vanished because of extensive erosion and the exposure of the soft-to-fairly-hard rocks of the Triassic age. However, along both limbs of the anticline, the remnants of the whale-back shape can still be seen (Figs. 4-4 and 5). In the Gara anticline, the whale-back shape was not recognized (Fig. 3-2), although the exposed rocks on both limbs of the anticline are the same as those in the Mateen anticline. This can be attributed to the widely exposed soft-to-fairly-hard rocks of the Triassic age in the core of the anticline.

(5) **Different valley shapes:** the presence of different valley shapes in a fold such as axial, curved, inclined, cross-shaped, or radial, is a good indication that the fold exhibits lateral growth (Keller and Pinter, 2002; Ramsey et al., 2008). In the Gara and Mateen anticlines, all types of valleys can be seen (Figs. 3 and 4) such as fork-shaped valleys, crossed valleys, inclined valleys, axial valleys, and radial valleys. However, a radial valley did not develop in the Mateen anticline. Accordingly, the presence of such valleys is a good indication of the lateral growth of the Gara and Mateen anticlines. It is worth mentioning that

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**Figure 3.** Satellite images of the Gara anticline indicating the (1) inclined and fork-shaped valleys, (2) radial valleys, (3) abandoned alluvial fan (the blue dashed line represents the abandoned feeder channel), and (4) cross-shaped and fork-shaped valleys. For locations, refer to Figure 1.
asymmetrical valleys are recognized in both anticlines, however, they are not present in the interpreted satellite images.

(6) **Water gaps:** the presence of water gaps in folds is a good indication of the lateral growth of the anticlines (Ramsey et al., 2008). In the Mateen anticline, 4 water gaps have developed (Fig. 1) because the anticline is crossed by the Al-Khabour, Greater Zab, and Shamdinan rivers. No streams and/or valleys cross the anticline to form more water gaps. This is attributed to the exposure of very hard and thick carbonate rocks of the Bekhme and Qamchuqa formations along both limbs of the anticline. A longitudinal cross section along the anticline shows that the depth of the water gaps increases to the southeast (Fig. 6, bottom), indicating the direction of the lateral growth. No water gap developed in the Gara anticline (Fig. 1). This can be attributed to the same reasons as mentioned for the Mateen anticline.

(7) **Wind gaps:** the presence of wind gaps in folds is a good indication of the lateral growth of the anticlines (Ramsey et al., 2008). No wind gap was recognized in the Gara or Mateen anticlines. However, in the Mateen anticline (Fig. 4-4), 2 valleys show the same alignment, crossing the anticline in opposite sides as a single valley, and possibly indicate the existence of a previous wind gap that is no longer present because of the upward growth of the anticline. Nevertheless, the position of both valleys at the highest part of the anticline decreases the possibility of the existence of a wind gap. The absence of wind gaps is attributed to the absence of water gaps apart from the 3 main rivers (Al-Khabour, Greater Zab and Shamdinan) that cross the Mateen anticline.

(8) **Rates of upward movements:** using neotectonic data, the rates of upward movements along the Gara and Mateen anticlines were calculated in certain areas where the Fatha and Injana formations are exposed; the elevation of the contact point represents the amount of uplift (when exposed) or downward movements (when in the subsurface) from the Miocene sea level. The calculated rates during the Pleistocene Epoch are presented as mm/100 years in Table 2.

(9) **Stream incisions:** through careful inspection of satellite images, with the help of geological maps at a scale of 1:100,000, the river terrace of the Greater Zab and Al-Khabour rivers were recognized. Locally, 3 levels were preserved, and the height differences between the river and terrace levels are indicated on Google Earth images. Accordingly, the incision rates were calculated during the Lower, Middle, and Upper Pleistocene periods.
Figure 4. Satellite images of the Mateen anticline indicating (1) an axial valley, (2) 2 water gaps, (3) 2 abandoned alluvial fans, and (4) an eroded whale-back shape. For locations, refer to Figure 1; C, calcrete; FCh, new feeder channel.

Figure 5. Satellite image showing the en-echelon plunge between the East and West Mateen anticlines (on the left and right of the image, respectively); Ax, axial valley; Cr, cross-shaped valleys; In, inclined valleys; Fr, fork-shape valleys.
5. DISCUSSION

The results obtained from the interpretation of satellite images clearly show that both the Gara and Mateen anticlines are exhibiting lateral growth (Figs. 3, 4, and 5). The presence of the various structural and geomorphological forms (Table 1) is a good indication of the lateral growth of both anticlines. However, the rate of growth and the incision of the streams in both anticlines are not the same. In the Gara anticline where no wind gaps and/or water gaps have developed (Figs. 1, 3 and 6), it is clear that the rate of uplift is greater than the rate of incision of streams and valleys (Ramsey et al., 2008). In contrast, in the Mateen anticline, the presence of many water gaps and the absence of any wind gap (Figs. 1 and 4) is a good indication that the rate of stream incision is higher than the rate of uplift, otherwise some wind gaps would be present, which is a good indication that the original water gaps changed to wind gaps because of a higher rate of uplift.

The presence of domes (Cartwright et al., 1995; Dawers and Anders, 1995; Cowie, 1998; Blanc et al., 2003 and Bennett et al., 2005) and en-echelon plunges (Keller and Pinter, 2002; Ramsey et al., 2008) are good indications of the lateral growth of both anticlines. Both the Gara and Mateen anticlines (Figs. 1, 2, 3, and 5) have domes and en-echelon plunges, implying that they are growing laterally (Campbell, 1958). Moreover, the continuous growth of a fold that includes many domes may lead to the merging of the domes and the formation of 1 large fold (Grasemann and Schmalholz, 2012). In both the Gara and Mateen anticlines, it is clearly observed that some of the domes do not show clear closures in their plunges (Figs. 1 and 5). This is another indication that the folds are growing and that the domes will merge together over time.

It is well-studied and well-known that the intensity of folding and deformation decreases to the southwest because of the continuous collision of the Arabian and Iranian plates (Alavi, 1994; Berberian, 1995; Jassim and Goff, 2006; Burberry, 2015; Obaid and Allen, 2017). However, the Gara anticline shows a higher rate of uplift than that of the Mateen anticline, although the Mateen anticline is closer to the deformational front compared with the Gara anticline and it shows a higher peak of 2294 m (above sea level) (Fig. 6, bottom). In contrast, the highest peak in the Gara anticline is 1942 m (above sea level) (Fig. 6, top). This can be attributed to 4 factors. The first factor is the...
presence of a large lineament in the middle part of the Mateen anticline (Fig. 1 and 4-1), which forms a water gap to allow the passage of the Greater Zab river. This lineament has contributed and facilitated the crossing of the Greater Zab river to the Mateen anticline. In addition, it has accelerated the rate of incision because of the weakness zone initiated by the lineament. Second, the big difference in the thickness of the Qamchuqa Formation in the Gara and Mateen anticlines (Fig. 7), where it is thicker in the Gara anticline, has played an important role in resisting the incision of the streams at the anticline.

Third, the steepness of the dip in the beds of the Qamchuqa Formation in the Gara anticline when compared with those in the Mateen anticline (Fig. 7) indicates that in the Gara anticline, the upward movement is greater than in the Mateen anticline. Finally, the Mateen anticline is the last fold within the High Folded zone, which faces the Imbricate Zone (Fouad, 2012), and therefore it has received more pressure from the imbrication and accordingly, there is a decreased rate of upward warping and lateral growth.

Apart from the presence of multiple domes in both the Mateen and Gara anticlines, the presence of sharp en-echelon plunges in both is a good indication that both anticlines originally consisted of many domes that were all aligned at each anticline in a single axial line (Campbell, 1958; Fossen, 2010). However, because of the continuous lateral growth of the folds, the domes at each anticline started losing their separate dome shapes. Moreover, both folds started exhibiting en-echelon plunges, especially the Mateen anticline (Figs. 4-2 and 5), with different indications being present in the plunge area as the different shapes of the valleys developed, accompanied by the en-echelon plunges (Fig. 5).

The presence of abandoned alluvial fans in both the Gara and Mateen anticlines (Figs. 3-3 and 4-3, respectively) is a good indication of the lateral growth of both anticlines.

This means that the gradients at different places in both anticlines have changed and accordingly, the sediment supply for the development of the alluvial fans has changed too. However, climatic change during the Holocene period and its role in the abandoning of the alluvial fans cannot be ignored.

The constructed longitudinal topographical cross sections along both the Gara and Mateen anticlines (Fig. 6) indicate that the lateral growth of both anticlines is toward the southeast. This is confirmed by the depth of the water gaps in the Mateen anticline, which is deeper at the southeast, and in the southeastern plunge of the Gara anticline, which is deeper than the northwestern plunge. The rates of upward growth at both the Gara and Mateen anticlines have been estimated using neotectonic data. The Neotectonic period started in Iraq during the Upper Miocene period (Atomenergeoexport, 1985). Sissakian and Diekran (1998) adopted this idea and constructed the neotectonic map of Iraq based on the elevations of the contact between the Fatha Formation (Middle Miocene, marine sediments) and the Injana Formation (Upper Miocene, continental sediments). The elevation of the mentioned contact was recorded at different locations along both the Gara and Mateen anticlines (Table 2).
Figure 7. Satellite images of the northwestern plunges of the (left) Gara anticline, and (right) Mateen anticline. Note the differences in thickness and steepness of the beds of the Qamchuqa Formation (Q) in both anticlines.

Table 2: Recorded elevations of the contact between the Fatha and Injana formations

<table>
<thead>
<tr>
<th>Anticline</th>
<th>Geographic Location</th>
<th>Elevation of the contact between the Fatha and Injana Formations (m, a.s.l.)</th>
<th>Amount of upward movement during the Pleistocene (2.588 Ma) (m)</th>
<th>Rate of upward movement during the Pleistocene (mm/100 year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gara</td>
<td>Near Sarsang town</td>
<td>NE Limb 1035</td>
<td>230.51</td>
<td>8.907</td>
</tr>
<tr>
<td></td>
<td>NE of Chamange village</td>
<td>SW Limb 1028</td>
<td>228.96</td>
<td>8.847</td>
</tr>
<tr>
<td></td>
<td>South of Al-Khabour river</td>
<td>NW Plunge 910</td>
<td>202.68</td>
<td>7.832</td>
</tr>
<tr>
<td></td>
<td>NE Limb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SW Limb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NW Plunge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SE Plunge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>8.529</td>
</tr>
<tr>
<td>Mateen</td>
<td>Near Khash’khashe village (25 km NW Amadiya town)</td>
<td>NE Limb 1352</td>
<td>301.12</td>
<td>11.635</td>
</tr>
<tr>
<td></td>
<td>Near Amadiya town</td>
<td>SW Limb 1048</td>
<td>233.41</td>
<td>9.019</td>
</tr>
<tr>
<td></td>
<td>Near Al-Khabour river</td>
<td>NW Plunge 926</td>
<td>206.24</td>
<td>7.969</td>
</tr>
<tr>
<td></td>
<td>SE Plunge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>9.541</td>
</tr>
</tbody>
</table>

--------- Means not present

The recorded elevation of the contact between the Fatha and Injana formations, represents the amount of upward movement since the Upper Miocene period at the recorded location along both the Gara and Mateen anticlines. The amount of the upward movement at each of the recorded locations could be calculated (Table 2) because the present relief developed from the Pleistocene Epoch (2.588 Ma, ICS, 2012). Subsequently, the rate of the upward movement during the Pleistocene Epoch was calculated (Table 2). The maximum rate of upward movement (11.635 mm/100 year) was recorded along the northeastern limb of the Mateen anticline, near Khash’khashe village (25 km NW of Amadiya town), whereas the minimum rate of upward movement (7.832 mm/100 year) was recorded along the northwestern plunge of the Gara anticline near the Al-Khabour river (Table 2). It
is clear that the rate of the upward movement decreases southward, as recorded along the northeastern and southwestern limbs of both the Mateen and Gara anticlines (Table 2). The same decrease in the rate was recorded in the northwestern plunges of the Mateen and Gara anticlines, respectively (Table 2). The average rate of upward movement at both anticlines is 8.529 and 9.541 mm/100 years, respectively.

The rate of river incision is also calculated along the courses of the Greater Zab and Al-Khabour rivers. Locally, 3 levels of terraces were recognized. These are dated as Lower, Middle, and Upper Pleistocene as determined by Sissakian et al. (2014) and by using an exposure dating method (Keller and Pinter, 2002). Terraces were recognized at 10 different locations, with 8 along the Greater Zab river and 2 along the Al-Khabour river, each with 3 levels of terraces; however, at some locations only 1 or 2 levels of terraces were recognized (Table 3).

<table>
<thead>
<tr>
<th>River</th>
<th>Location</th>
<th>Terrace level</th>
<th>Age</th>
<th>Height difference between the terrace and river level (m, a.s.l.)</th>
<th>Rate of incision (mm/100 years)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Zab</td>
<td>Iraqi – Turkish borders North of Mateen anticline</td>
<td>1 L</td>
<td></td>
<td>164</td>
<td>6.337</td>
<td>There may be an older terrace level than Level 1</td>
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<tr>
<td></td>
<td></td>
<td>2 M</td>
<td></td>
<td>92</td>
<td>11.779</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 U</td>
<td></td>
<td>13</td>
<td>11.111</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 U</td>
<td></td>
<td>18</td>
<td>15.385</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>3 U</td>
<td></td>
<td>15</td>
<td>12.821</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deralok</td>
<td>1 L</td>
<td></td>
<td>67</td>
<td>8.579</td>
<td>These are along the syncline between the 2 anticlines</td>
</tr>
<tr>
<td></td>
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<td>151</td>
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<td></td>
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<td></td>
<td>97</td>
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<td></td>
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<td></td>
<td>Balinda</td>
<td>2 M</td>
<td></td>
<td>148</td>
<td>5.719</td>
<td>Southeast of the Gara and Mateen anticlines</td>
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<td>3 U</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td>8.265</td>
<td>Average of 3 levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 U</td>
<td></td>
<td>23</td>
<td>19.658</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barzan</td>
<td>1 L</td>
<td></td>
<td>117</td>
<td>4.521</td>
<td>Crossing of Al-Khabour river to the plunge area of the Mateen anticline</td>
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<td></td>
<td></td>
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<td></td>
<td>67</td>
<td>8.579</td>
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<tr>
<td></td>
<td></td>
<td>3 U</td>
<td></td>
<td>22</td>
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<td></td>
</tr>
<tr>
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<td></td>
<td>Average</td>
<td></td>
<td>10.312</td>
<td>Average of 3 levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greater Zab NW Plunge Area (East of Batifa)</td>
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<td></td>
<td>117</td>
<td>4.521</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 M</td>
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<td>67</td>
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<td></td>
<td></td>
<td>3 U</td>
<td></td>
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<td>18.803</td>
<td></td>
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<td></td>
<td>Al-Khabour Mateen Anticline</td>
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<td>Average</td>
<td></td>
<td>10.312</td>
<td>Average of 3 levels</td>
<td></td>
</tr>
</tbody>
</table>

Pleistocene, L, Lower = 2.588 Ma; M, Middle =0.781 Ma; U, Upper = 0.0117 Ma.

The height differences between the river level and the terrace level at each of the recognized 10 points were calculated using Google Earth images. The time spans of the 3 parts of the Pleistocene Epoch were used to calculate the incision rates. For the Lower, Middle, and Upper Pleistocene periods, the following time spans were used: 2.588 Ma, 0.781 Ma, and 0.126 Ma, respectively.

The minimum rates of the upper, middle, and lower levels along the Greater Zab river are: 4.521, 6.914, and 11.111 mm/100 year,
respectively, whereas the maximum rates of the upper, middle, and lower levels are 6.337, 12.419, and 17.949 mm/100 years, respectively (Table 3). However, the average rates of incision of the 3 levels along the Greater Zab river are 5.964, 9.398, 14.359 mm/100 years, respectively. Moreover, the average rate of the 3 levels along the Greater Zab river is 8.265 mm/100 years, whereas the average rate of the 3 levels along the Al-Khabour river is 10.312/100 years.

6. CONCLUSIONS

The Gara and Mateen anticlines are exhibiting lateral growth as indicated by different structural features (e.g., multiple dome folds and en-echelon plunges) and geomorphological features (e.g., water gaps, abandoned alluvial fans, and different valley shapes). The rate of uplift in the Gara anticline is higher than the rate of stream incision as indicated by the absence of water and wind gaps. In contrast, in the Mateen anticline, the rate of stream incision is higher than the rate of uplift as indicated by the presence of 3 water gaps. The absence of wind gaps in the Mateen anticline is another indication that the rate of stream incision is higher than the rate of uplift.

The presence of en-echelon plunges in both the Gara and Mateen anticlines is a good indication that each anticline was on a single alignment but because of lateral growth, each anticline was divided into 2 parts (East and West). This is also confirmed by the presence of many domes in each anticline and by the observation that the domes have already started losing their dome shape and will merge together into a single double-plunging fold. However, the development of en-echelon plunge between the already existing domes is highly possible after a certain geological time.

The maximum and minimum rates of upward movement at the Mateen anticline are 11.635 mm/100 years and 7.969 mm/100 years, respectively. In both anticlines, the maximum rate was recorded along the northeastern limb, whereas the minimum rate was near the northwestern limb. The maximum rates of incision of the Greater Zab river were recorded at the lower (younger, no. 3) terrace level, (17.949 mm/100 years), whereas the minimum rates were recorded at the upper (oldest, no. 1) terrace level (5.719 mm/100 years).

The average rate of incision of the Al-Khabour river (10.312 mm/100 years) is higher than the average rate of upward movement of the Mateen anticline (9.541 mm/100 years). In contrast, the average rate of incision of the Greater Zab river (8.265 mm/100 years) is lower than the average rate of upward movement of the Gara anticline (8.529 mm/100 years). Therefore, the river runs around the southeastern plunge and does not dissect the anticline. Although the average rate of incision of the Greater Zab river (8.265 mm/100 years) is lower than the average rate of upward movement of the Mateen anticline (9.541 mm/100 years), the river still dissects the anticline. This is attributed to the presence of deep and straight lineaments along which the river dissects the anticline.

ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. General

The mountainous portion of the Iraqi Kurdistan Region has been a conflict network zone for many decades and the political instability has affected the exploration of natural resources. However, the Kurdistan region has recently established projects to exploit hydrocarbon resources. Unfortunately, the potential of the mining industry has not been utilized because of the lack of a mineral investment law (Sissakian, 2018). Stream sediments in the catchment area provide an excellent indication of the existing mineralization in exploration studies, and they are important in geochemical prospecting to identify possible sources of anomalous element concentrations (Landry et al., 2014). Sediments in the channels of streams and rivers can contain low levels of metals derived from the weathering of mineralized rocks in the upstream catchment area (Marjoribanks, 2010).
The concentrations of heavy metals can be quite high in stream sediments located close to a deposit, and this is attributed to the weathering processes of mineral deposits. These concentrations decrease with increasing distance from the upstream deposits, except in the first-order stream segments (Fletcher, 1997). Moon and Whatley (2006) suggested that coarse-grain stream-sediment sampling is extremely valuable in areas with poor exposure or in mountainous areas where rock fragments are moved under the force of the gravity. Geochemical studies of the stream sediments have been used by numerous scholars to find minerals of economic interest in the exposed rocks within the catchment areas of streams (Meyer et al., 1979; Plumlee, 1999; Atsuyuki et al., 2005; Marker, 2015). The stream-sediment technique has played a major role in the discovery of many ore bodies around the world. A good example is the discovery of the Panguna porphyry copper/gold deposit on Bougainville Island, Papua New Guinea (Baumer’s and Fraser, 1975; Majoribank, 2010).

1.2. Aim

No stream-sediment analysis studies have been conducted in the current study area. Therefore this study is considered as the pioneering one. This study attempts to determine the concentrations of various elements in the region.

1.3. Location

The study area is shown in Fig. 1. It is an area spanning 450 km². The area is located in the extreme northeastern part of the Iraqi Kurdistan Region along the Iraqi-Iranian international border. The coordinates are [4430521, 4959908], [4430521, 4998885], [4397726, 4998885], and [4397726, 4959908] (UTM WGS 84) (Fig. 1). The only town in the area is Sidakan (25 km northeast of Soran town), with several small villages distributed in the study area. Sidakan can be reached by a paved road from the Erbil–Soran road, but the distant villages are connected with unpaved roads.

2. GEOLOGICAL SETTING

The geological setting of the study area is based on the best available data using the updated geological map and the attached geological report (Sissakian and Fouad, 2014). The geological map of the study area is presented in Fig. 1. The main outcrops in the study area include the Walash (Paleocene–Eocene) and Naopurdan (Paleocene and Oligocene) groups (Sissakian and Fouad, 2014); a detailed geological description of the Walash and Naopurdan groups is presented in the stratigraphy section (4.2). The 3 main components, including the geomorphology, tectonics, and structural geology, as well as the stratigraphy of the study area, are briefly described below.

2.1. Geomorphology

The study area has a mountainous terrain with steep slopes, scarps, and peaks (Fig. 1). The highest peak in the Iraqi Kurdistan Region is known as Halgurd with a height of 3607 m (above sea level [a.s.l.]). It is located in the eastern part of the study area (Fig. 1). However, in the Iraqi Kurdistan Region, the highest peak is located along the Iraqi-Iranian border with a height of 3611 m (a.s.l.), and it is called Cheekha Dar (Google Earth Pro, 2020). Another prominent mountain with a conical peak is located in the southern part of the area and is called the Hassan Bag (Fig. 1), with a height of 2521 m (a.s.l.). The most common geomorphological units in the area, as interpreted from satellite images, are of alluvial origin with 3 recognized features. The first of these are the valley-fill sediments, which fill the main streams and their branches with sediments that range in size from sand (Fig. 2A) to boulders of 1 m or more (Fig. 2B). However, the average size of the sediments range from 2 to 4 mm (Fig. 2A). The second feature is the flood plain sediments. The streams and valleys have narrow courses (Fig. 3A) and steep gradients (Fig. 3B). Therefore, the developed flood plains are very narrow. The top is usually covered by very fine sand and clayey soil. The third of the features are terraces. Two levels of terraces have developed along the streams and main valleys (Fig 3B). The height difference between the 2 levels range from 3 to 5 m, with the first level being 2 to 4 m above the stream base. The pebbles...
are of different sizes and lithologies, cemented by calcareous and siliceous cement (Fig. 3B).

2.2. Tectonics and structural geology

The study area is located within the Imbricate zone of the Outer Platform of the Arabian Plate (Fouad, 2012). It is also part of the Zagros fold-thrust belt, which developed within the Zagros foreland basin (Alavi, 2004; Fouad, 2012; Sissakian, 2013). The main tectonic feature in the study area is the Zagros main thrust fault, which is accompanied by other small anticlines and faults. The main features are described below (Sissakian and Fouad, 2012).

Figure 1. Location and geological map of the study area imposed over a digital terrain map (Aster Global Digital Elevation Model Validation Team, 2009) (according to Sissakian and Fouad, 2014)
2.2.1. Zagros main thrust fault

The 3 Zagros main thrust faults include 3 sheets that are referred to as the lower, middle, and upper thrust sheets, respectively (Bolton, 1954). Moreover, Bolton (1954) also referred to them as Qandil 1, Qandil 2, and Bulfat thrust massifs. However, only the middle and upper sheets are present in the study area. Bolton (1954) mentioned that the thrust fault mainly has a low angle, although locally, high angle planes were recognized. The middle thrust sheet is characterized by the thrusting of the Qandil Series over the Walash Group, whereas the upper thrust sheet is characterized by the thrusting of the Walash Group over the Naopurdan Group (Fig. 1).

2.2.2. Minor anticlines and faults

Small amplitude folds and many faults exist in the study area and are not more than 5 km in length. They are present in the northeastern part of the study area. All are in the Walash Group (Fig. 1). The different trends, especially of the anticlines, may indicate that their origin is not related to the main tectonic forces, which caused the development of NW–SE trending anticlines. They may have developed as a cause of local deformational forces within the different rock types (sedimentary and
2.3. Stratigraphy

The following geological units are exposed in the study area (Fig. 1), from the oldest (Qandil Series) to the youngest (Naopurdan Group).

2.3.1. Qandil Series (Cretaceous)

The Qandil Series is exposed on the northeastern side of the study area (Fig. 1) and forms the bulk of the Hasarust Mountain. The Qandil Series consists of sheared limestone (from the sheared zone), phyllites, and massive metamorphosed limestone with some serpentinite intrusions. The thickness of this unit is about 3000 m (Bolton, 1954). The Qandil Series is mainly thrust over the Walash Group and the Naopurdan Group. On the top of Hassan Bag Mountain, thick exposures of igneous rocks have developed with a sharp contact with the underlying sedimentary and igneous rock sequence of the Walash Group. Ali et al. (2012) mentioned that the rocks are of the Cretaceous age and are represented by ophiolite rocks. However, they did not mention to which rock unit the igneous rocks belong. Based on the study by Sissakian and Fouad (2012), we believe that they belong to the Qandil Series, which are thrust over the Walash Group east of the Hassan Bag Mountain and Hasarust Range (Fig. 4).

2.3.2. Walash Group (Paleocene–Eocene)

The Walash Group is widely exposed within the study area, especially in the eastern part. The group consists of very thick, mainly basic volcanic sequences, including agglomerate, lava flows, pillow lavas, and ashes with associated dikes. The volcanic rocks are associated with a thick sedimentary sequence, similar to that of the Naopurdan Group, that is composed of thick limestone, red mudstone, and clastics. The thickness of the group in the type locality is 1000 m, but in nearby areas, it is about 3500 m (Stevenson and Cobbett, 1954).

2.3.3. Naopurdan Group (Paleocene–Oligocene)

The Naopurdan Group is widely exposed in the study area, especially in the western part. The group consists of gray shale, coralline limestone, tuffaceous slates, felsic volcanic, basal conglomerate, graywackes, and sandy shale. The stratigraphic position and relation of the group with other formations, beds, and groups are partly obscure. Moreover, the group is considered to interfinger with the Walash Group (Al-Mehaidi, 1974). The thickness of the group in the type locality is about 2000 m, but this thickness is reduced to about 1000 to 1500 m mainly because of thrusting (Stevenson and Cobbett, 1954).

3. MATERIALS AND METHODS

The fieldwork was conducted to achieve the aim of this study and materials such as geological maps of the study area, satellite images, and relevant published papers, which deal with the subject of this study, were used (Ali et al., 2007; Lima et al., 2003). Nylon bags were used to collect the stream-sediment samples. The junctions of the main branches flowing downstream from the main elevated areas and peaks along the main streams were marked manually and considered as sampling points. Two samples were collected from each junction point (each bag contained 1 kg of stream sediment). A total of 14 stream-sediment samples were collected from the junctions of the main streams, representing 14 sub-basins (Fig. 4). However, sub-basin 5 and 10 were divided further into sub-sub-basins, but owing to security issues, we could not reach beyond locations 5 and 10. The stream samples were sieved down to 2 to 4 mm by using a wet sieving method (Moon and Whateley, 2006). The size selection was based on the idea that the potential elements from a nearby source were moved downstream by gravity (Moon and Whateley, 2006). All collected samples were subjected to x-ray fluorescence (XRF) analysis at the University of Kurdistan Hawler, Erbil (Iraqi Kurdistan Region), and 3 samples were subsequently also subjected to x-ray diffraction (XRD) analysis (samples numbers 1, 5, and 10); the XRD analysis was conducted at the Research Center of the Soran University (Iraqi Kurdistan Region). The data acquired from the XRF and XRD
analyses were used to construct the concentration maps (mg/kg) for each detected element and to construct element maps that represent the concentrations in the 2 to 4 mm sieve size samples.

3.1. Sample Collection

The stream-sediment survey was conducted in the vicinity of Sidakan in the Iraqi Kurdistan Region, which is considered an unexplored area. Garrett and Nichol (1967) and Armour-Brown and Nichol (1970) demonstrated that widely spaced stream-sediment sampling for the detection of metallogenic provinces in unexplored regions can be an effective method of delimiting wide-ranging regions of mineral potential. The points of the stream junctions were considered as the sample points for each junction point (Fig. 4); 1 stream-sediment sample was collected for each junction point. However, locally, when the stream sediments were sorted naturally owing to the stream hydraulics, 2 samples were collected from the same point. In total, 14 samples were collected in nylon sacks with each 1 being numbered, well preserved, and packed.

3.2. Concentration Maps Methodology and Characterization

The Global Mapper software was used to map the polygons and drainage net of the sub-basins. The main drainage net was generated in Global Mapper software to navigate the sampling locations (Fig. 4). Adobe Photoshop CC was used for the compilation of the concentration maps of the elements in the samples collected from the study area. To plot the concentration of the elements on the map, we normalized the concentrations of the elements by applying the following formula:

\[ EC(\%) = \left( \frac{EC_x}{Max} \right) \times 100 \]

where EC% is the normalized concentration for each element, which is determined by dividing each element concentration (ECx) by the maximum concentration.

The maps were compiled by coloring the sub-basins with different grades of the same color for each element based on the normalized values. Subsequently, by imposing a cover layer over the grayscale layers, the properties selected for the cover layer were a color code of c7fd00 and the blending mode “color”. Finally, the result was a colorful map from white to dark olive green (Figs. 5–13).

Stream-sediment sampling is one of the most commonly used geochemical exploration methods when surveying an area for its mineral distribution (Eppinger et al., 2003). In our study, samples were collected from active alluvium sediments. Samples were sieved down to a size of 2 to 4 mm by wet sieving in the laboratory. The sieved samples were dried in an oven at a temperature of 65°C for 48 hours followed by grinding of the samples into a homogeneous powder (Moon and Whateley, 2006).

The pulverized samples were pressed into pellets of 5 mm in diameter and their chemical composition were determined using XRF analysis (NEX QC+ QuantEZ Benchtop EDXRF spectrometer, Rigaku, Tokyo, Japan). The result of each element was re-calculated from the mass percentage to mg/kg. A qualitative energy-dispersive x-ray (EDX) measurement was also conducted to confirm the results obtained from the XRF method. The mineralogy of the samples was determined using a Panalytical x-ray diffractometer. The morphology of the powdered samples was determined by scanning electron microscopy. A qualitative EDX measurement was also conducted to confirm the results obtained from XRF.
4. RESULTS

Based on the data acquired during XRF and XRD analysis of the samples, the following results were obtained.

4.1. XRF Method

The chemical composition of the samples acquired from the XRF tests exhibited a large range of diverse elements, including chromium (Cr), copper (Cu), titanium (Ti), cobalt (Co), silver (Ag), uranium (U), cadmium (Cd), and nickel (Ni), which are listed in Table 1. However, only those elements with a significant concentration are presented and interpreted in this study.

The results obtained from XRF analysis showed that there is a high and anomalous concentration of Cr, Cu, and U in the study area. In addition, there are also relatively high concentrations of vanadium (V) and Ni in the samples. However, there are trace concentrations of Ag and U in the samples that exceed the normal concentrations in the crust (Taylor and McLennan, 1995) (Table 1). The qualitative EDX analysis of sample 10 confirms the existence of all the mentioned elements. Correlation factors presented in Table 2 shows the relation between the element concentrations.
A strong correlation is confirmed by calculating the p value at a significance level of 0.05; a correlation coefficient lower than 0.54 indicates that the elements are not significantly correlated. The results of correlation show strong correlations between elements that might coexist in the same medium (Table 2). There is an interesting correlation (0.76) between Cr and Ni. Because the Walash Group reaches in chromite deposits, existing Ni and Cr depositions in the Walash Group were confirmed by Al-Bassam (2008). Another interesting correlation (0.76) was found between Ag and Co. It is common for Ag to co-occur with Co (Marshal, 2000).

This study aimed to detect the minerals that are present in the study area by conducting a powder XRD analysis of some of the samples. The results indicate the presence of silicates and aluminum silicates such as albite, zeolite, chamosite, Vandendriesscheite, diopside, anorthite, lepidolite, cordierite, and carbonate minerals.

Table 1: The Concentration (mg/kg) of Major and Trace Elements in the Samples with a Size Fraction of 2 to 4 mm

<table>
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<th>Sample no.</th>
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<th>Co</th>
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<td>260</td>
<td>5</td>
<td>18</td>
<td>18</td>
<td>364</td>
<td>903</td>
<td>ND</td>
</tr>
<tr>
<td>Max</td>
<td>2040</td>
<td>221</td>
<td>428</td>
<td>9</td>
<td>23</td>
<td>27</td>
<td>281</td>
<td>401</td>
<td>ND</td>
</tr>
<tr>
<td>Min</td>
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<td>0</td>
<td>182</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>184</td>
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<td>ND</td>
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<table>
<thead>
<tr>
<th>Element</th>
<th>Cr</th>
<th>Cu</th>
<th>Co</th>
<th>Ag</th>
<th>U</th>
<th>Cd</th>
<th>V</th>
<th>Ni</th>
<th>Pb</th>
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<td>Average mg/kg</td>
<td>999</td>
<td>116</td>
<td>280</td>
<td>6</td>
<td>12</td>
<td>16</td>
<td>256</td>
<td>375</td>
<td>NA</td>
</tr>
<tr>
<td>Average in the crust mg/kg (Hu and Gao, 2008)</td>
<td>106</td>
<td>27</td>
<td>15</td>
<td>0.05</td>
<td>2.6a</td>
<td>0.06</td>
<td>106</td>
<td>34</td>
<td>20a</td>
</tr>
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</table>

Table 2: Correlation Factors between the Concentrations of the Detected Elements in the Samples

<table>
<thead>
<tr>
<th>Element</th>
<th>Cr</th>
<th>Cu</th>
<th>Co</th>
<th>Ag</th>
<th>U</th>
<th>Cd</th>
<th>V</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Cu</td>
<td>0.57</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>0.28</td>
<td>0.43</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>0.06</td>
<td>0.27</td>
<td>0.76</td>
<td>1.00</td>
<td></td>
<td></td>
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<tr>
<td>U</td>
<td>0.67</td>
<td>0.59</td>
<td>0.41</td>
<td>0.06</td>
<td>1.00</td>
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<tr>
<td>Cd</td>
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<td>0.14</td>
<td>0.10</td>
<td>0.46</td>
<td>1.00</td>
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<tr>
<td>V</td>
<td>-0.01</td>
<td>0.41</td>
<td>0.30</td>
<td>0.43</td>
<td>-0.05</td>
<td>0.25</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.76</td>
<td>0.26</td>
<td>0.33</td>
<td>0.38</td>
<td>0.48</td>
<td>0.22</td>
<td>-0.09</td>
<td>1.00</td>
</tr>
</tbody>
</table>
4.2. Spatial Distribution of the Elements

In this section, the spatial distribution of the most probable sources of the detected elements is presented by the created maps. A color code has been used to show the variation in the element concentration in the study area (Figs. 5–13).

4.2.1. Chromium

Elemental Cr spatially appeared in all the collected samples from the study area. The average concentration of Cr was approximately 999 mg/kg and ranged from 426 to 2040 mg/kg. The concentration of Cr in the study area is 9.42 times higher than the concentration of Cr in the crust (Hu and Gao, 2008).

4.2.2. Nickel

Elemental Ni appeared in all the collected samples from the study area (Table 1). Both Ni and Cr showed nearly the same concentration patterns over the study area. The average concentration of Ni was approximately 375 mg/kg and ranged from <236 to >903 mg/kg, except in the first-order stream-sediment samples. The highest concentration of Ni was measured in sample number 10 (Fig. 6).

4.2.3. Cobalt

Elemental Co was also detected in all the samples collected from the study area. The average concentration of Co was found to be 280 mg/kg and the highest concentration was 508 mg/kg in sample number 1 (Fig. 7). The sediments derived from the Hassan Bag Mountain showed the highest concentration of the Co element.
Figure 6. Concentrations of elemental Ni at the various sampling points

Figure 7. Concentrations of elemental Co at the various sampling points
4.2.4. Copper

The elemental Cu concentration ranged from not detected (ND) to 221 mg/kg (Fig. 8). The highest concentration was measured in sample numbers 5 and 13, which were 201 and 221 mg/kg, respectively. Moreover, it can be observed that Cu was not detected in sample number 11.

![Cu Concentration](image)

Figure 8. Concentrations of Cu at the various sampling points (the dashed polygon correspond to no detected Cu)

4.2.5. Uranium

Uranium was detected in all of the collected samples from the study area with an average concentration of 12 mg/kg (Table 1). The concertation of U ranged from 5 to 23 mg/kg (Fig. 9).

4.2.6 Silver

The concentration of Ag ranged from not detected to 9 mg/kg (Table 1), with an average of 6 mg/kg, which is 120 times higher than the average Ag concentration in the crust (Taylor and McLennan, 1995). As can be seen from Fig. 10, various concentrations of Ag were detected in different sub-basins; the samples collected in sub-basin numbers 3, 11, and 13 showed anomalous results.

4.2.7 Vanadium

The analysis for the V concentration showed almost the same concentrations in all of the collected samples from the study area. The concentrations of V ranged from ND to 364 mg/kg (Table 1 and Fig. 11). Low concentrations of V were measured in sample number 10, which was derived from the Qandil Series at the Hasarust Mountain.

4.2.8 Cadmium

The Cd concentration ranged from ND to 27 mg/kg with an average of 16 mg/kg, which is approximately 266 times higher than the average Cd concentration in the crust (Hu and Gao, 2008) (Table 1). The highest concentration was measured in the southern part of the Hassan Bag Mountain (Fig. 12).
Figure 9. Concentrations of U at the various sampling sites
Figure 10. Concentrations of elemental Ag at the various sampling sites (the dashed polygon correspond to areas with no detectable Ag)

Figure 11. Concentrations of elemental V at the various sampling sites (the dashed polygon correspond to areas with no detectable V)
5. DISCUSSION

To indicate the possibility of finding metallic deposits in the exposed rocks within the study area, we compared the average concentrations of the 9 indicated elements in the 14 collected samples with the average concentrations of the elements in the crust, as determined by Hu and Gao (2008) and Taylor and McLennan (1995) (Table 1). We have found that there are several anomalous concentrations when compared with the concentrations of the elements in the crust and basaltic rocks (Fig. 13). Moreover, we found that the average concentration for each of the mentioned elements was higher than those in the crust (Hu and Gao, 2008; Taylor and McLennan, 1995).

Some anomalously high concentrations can be seen for all of the indicated elements, except for Pb, in the sub-basins in the middle part of the study area. These are in sample numbers 2, 3, 4, and 6 and can be attributed to (1) the exposed rocks in the concerned sub-basins that contain higher concentrations of the elements than those exposed at the rims of the main basin, (2) the presence of fine tributaries that are not present in the topographic map and therefore the limits of the sub-basin are not accurately indicated, or (3) the presence of topographic obstacles in the streams which caused more dumping of the stream sediments than the other streams with normal gradients.
The concentration of Cr was highest in sample numbers 5 and 10 (Fig. 5), and this can be attributed to both samples (5 and 10) being driven along from the upstream serpentinite intrusions (Fig. 1). Existing in these serpentinite intrusions is the main reason that could explain the higher concentration of Cr in these 2 samples as mentioned by Pearre and Van Heyl (1960). The concentration of Ni was measured to be nearly 5 times higher than the concentration of Ni in the crust (Hu and Gao, 2008), and the Ni concentration in the study area was 4.5 times higher than the concentration of Ni in igneous rock (Wells, 1943). The highest concentration of Ni is in sample number 10 (903 mg/kg) where, upstream of this sub-basin, the rocks are derived from the Qandil Series (Fig. 1). In addition, there is a strong correlation between the Cr and Ni concentrations (correlation coefficient of 0.76) (Table 2), which is indicative that both elements coexisted in the study area and that both could be derived from serpentinite that is rich in Cr and Ni. There are, thus, 2 possible reasons for the coexistence of Cr and Ni: first, 1 of the major outcrops of the study area is the Walash Group, which is rich in Ni and Cr (Al-Bassam, 2008), and second, serpentinite is found in the study area (Morrison et al., 2015 and Pędziwiatr et al., 2018).

The concentration of Co is higher in the Hassan Bag-related sub-basins (No. 11 and 13) because the exposed rocks of the Hassan Bag contain calc-alkaline basalt rocks (Ali et al., 2012). In general, the average concentration of Co in the study area is 2.4 times higher than the average concentration of Co in the igneous and metamorphic rocks such as dunite and serpentinite (Schulz, 2018). The concentration of Cu shows nearly the same trends as observed for the concentration of Co, except in sample number 5, which showed a significantly higher concentration (221 mg/kg). The average concentration of Cu (116 mg/kg) in the study area is nearly the same concentration as Cu in the Basaltic rocks (Hu and Gao, 2008). The main reason for the higher concentration in sample number 5 is because of the presence of several serpentinite intrusions in the sub-basin where sample 5 was collected. Similar cases have been discussed by other authors (Saglam, 2017; Shallari et al., 1998).

Figure 13. The ratio of the average concentrations of the elements measure for the study area and the concentration of the elements in the crust (the vertical scale is a logarithmic scale).
Another interesting result is the concentration of U. The detected concentration was considered to be a significant value when compared with the average concentration of U in the crust, which is only 2 mg/kg (Pękala et al., 2017). The XRD results suggest the presence of Vandendriesscheite, which is a U and Pb containing mineral, which could explain the relatively high concentration of U in the collected samples. However, Pb was only detected in sample number 9 and the concentration of Pb in sample number 9 was 0.003 mg/kg. Additionally, there is a significant correlation between U and Cr (correlation coefficient 0.67) (Table 2). The possible reason for the coexistence of U and Cr is the composition of the Walash Group, which contains both U and Cr (Aswad et al., 2014).

The concentration of Ag in the study area is nearly 120 times higher than the average concentration of Ag in the crust (Taylor and McLennan, 1995) (Fig. 13). We believe that there is Ag enrichment in the rocks of Hassan Bag (alkaline basic rock). Such enrichments have been mentioned previously by Boyle (1968). Moreover, he mentioned that most of the silver is found in sulfides and ferromagnesian minerals and, therefore, the basic rocks will contain higher concentrations of silver. This is another explanation for the anomalous concentrations measured in sub-basins numbers 3, 11, and 13 in which the stream sediments are derived from the basic rocks that are exposed in the Hassan Bag Mountain.

The high concentration of Cd in some of the samples is most probably related to the mafic rocks, which are exposed in Hassan Bag Mountain. Dostal and Elsonu (1979) mentioned that mafic rocks usually contain high Cd concentrations.

Vanadium can be found in most of the rocks of the earth’s crust, but the highest concentrations are found in ultrabasic and basic rocks, which is about 200 mg/kg (Aubert and Pinta, 1980). The concentration of V in the study area was 2.8 times higher than the concentration of V in basic and ultrabasic rocks. This can be attributed to the exposed mafic alkaline igneous rocks at the Hassan Bag Mountain. The high concentration of V in these types of rocks was determined by McCormick (1978).

Based on the results obtained from XRF and XRD analysis of the collected samples, which showed high and anomalous concentrations, we highly recommend further studies to conduct systematic geochemical exploration with detailed geological mapping.

6. CONCLUSIONS

The reconnaissance survey of the stream sediments in the study area revealed significant concentrations of some elements. This was determined by studying 14 samples collected from 14 sub-basins. The collected stream samples were subjected to XRF analysis and 4 of the samples were further subject to XRD analysis as well. The results obtained from XRF analysis showed that the average concentrations of Ag and Cd are 6 mg/kg and 16 mg/kg, respectively, indicating that the concentration of Ag is 80 times higher than the Ag concentration in the crust. We believe that the reason for this high anomalous result can be attributed to the exposed basic igneous rocks at the Hassan Bag Mountain. The anomalous samples are located in the sub-basins that drain from the mentioned mountain.

Additional high anomalous results were determined for the average concentrations of Co and Cr (280 mg/kg and 999 mg/kg, respectively). The average concentration of Co and Cr is 25 and 9 times higher than those in the crust, respectively. The higher values can be attributed to the exposed serpentinized bodies in the related sub-basins, in addition to the exposed igneous rocks within the Qandil Series.

The XRF results of the collected stream samples also showed anomalous concentrations for the remaining elements (Ni, V, Zn, and U) which were most probably derived from the exposed igneous rocks in the study area. The differences in the concentrations can be attributed to the concentrations of the mentioned elements in the parent rocks, the size of the sub-basin, and the remoteness of the exposed igneous rocks of the sampled locations.
However, the indicated Cu concentrations in the collected samples were low when compared with those of other elements. Among the 14 collected samples, 3 of them showed concentrations that were lower than the average concentration in the crust, which is 55 mg/kg, whereas the average concentration in the collected samples was 116 mg/kg. The results for Pb (not detected in the samples) remain unclear. However, unintentional analytical errors cannot be ignored, not only for the Cu and Pb measurements but also for all the other elements in the samples.

It is worth mentioning that the results of the current reconnaissance stream survey do not indicate the presence of concentrations of elements with economic potential. Nevertheless, more detailed sampling of those sub-basins that showed anomalous results may give different results than those presented in this study.

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REFERENCES


Severity of Coronavirus Disease 2019 in Patients with Cancer

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1. INTRODUCTION

In December 2019, an outbreak of unexplained pneumonia cases was reported in Wuhan, China (Wuhan Municipal Health Commission. Report of Clustering Pneumonia of Unknown Etiology in Wuhan City, 2019. http://wjw.wuhan.gov.cn/front/web/showDetail/2019123108989. Accessed December 31, 2019., n.d.). A few days later, the causative microbe in this mysterious disease was recognized as a novel coronavirus (nCoV) by various independent laboratories (Lu et al., 2020; Zhou et al., 2020; Zhu et al., 2020).

The causative virus has been, since, identified as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and the disease it causes has been named coronavirus disease 2019 (COVID-19) by the World Health Organization (He et al., 2020). As of 20 August 2020, over 22.4 million confirmed cases and over 788,000 related deaths have been reported globally (https://coronavirus.jhu.edu/map.html). However, the true number is probably much higher than the official estimates based on the fact that many cases are asymptomatic carriers or go undiagnosed because of a lack of testing.

Most of the studies indicated that patients with cancer are at a higher risk of COVID-19-related complications and death when compared with the general population (Afshar et al., 2020; Mehta et al., 2020; Miyashita et al., 2020). In this context, Kuderer et al. (2020) examined the severity of COVID-19 in patients with cancer (n=1035) and obtained the following statistics: patients admitted to the
intensive care unit (ICU) = 14%; patients that required mechanical ventilation = 12%; and death ratio = 13%. By contrast, these values are much lower in patients without cancer, namely 3.2%, 2.3%, and 3.7%, respectively (Meng et al., 2020). The drivers for the increased disease severity in patients with cancer are poorly understood. One study proposed that the high rate of COVID-19-related mortality in patients with cancer are likely dependent on the comorbidities present before initiation of radiation or current anticancer therapies (Vuagnat et al., 2020). In this review, we discuss the known factors that could possibly augment the severity of COVID-19 in patients with cancer. We also review the current information about the efficiency of novel therapeutic options for COVID-19, specifically in patients with cancer.

2. FACTORS THAT CONTRIBUTE TO THE HIGH MORTALITY RISK FOR COVID-19 IN PATIENTS WITH CANCER

Recent studies have reported on retrospective case studies of COVID-19 in patients with cancer with an astonishingly high mortality rate (11.0%–28.6%) (Afshar et al., 2020; Miyashita et al., 2020; Zhang et al., 2020). Importantly, Dai et al. (2020) demonstrated that patients with hematologic cancer (leukemia, myeloma, and lymphoma), lung cancer, or metastatic cancer (stage IV) had the highest frequency of severe events, which is described as a condition that demands admission to the ICU, the use of mechanical ventilation, or can lead to death. Conversely, patients with nonmetastatic cancer experienced a similar frequency of severe conditions as patients without cancer (Dai et al., 2020). Although the investigators did not explain the rationales behind a worse COVID-19 outcome in patients with metastatic cancer, we believe that there is an increased risk in patients with metastatic cancer because these patients are mostly immune suppressed as a consequence of their treatment.

COVID-19 leads to a cytokine release syndrome and viral acute respiratory distress syndrome caused by uncontrolled severe acute inflammation (Addeo et al., 2020). Particularly with lung cancer, patients suffer from chronic pulmonary inflammation that is mainly elicited by the tumor microenvironment and the frequent underlying lung pathology (Ballaz et al., 2003; Sekine et al., 2012). Therefore, patients with lung cancer are prone to the complications of severe pathogenesis and mortality from COVID-19 (Dai et al., 2020; Rogado et al., 2020; L. Zhang et al., 2020).

Anticancer treatment is 1 of the possible driving factors that is linked to COVID-19 severity in patients with cancer, which causes a systemic immunosuppressive state (Liang et al., 2020; Patel et al., 2020; Tian et al., 2020; van de Haar et al., 2020; C. Wu et al., 2020). Yang et al. (2020) have conducted an investigation to determine if cytotoxic chemotherapy acts as a risk factor for mortality in COVID-19-infected patients with cancer. Accordingly, it was found that cytotoxic chemotherapy enhances the risk for fatal outcomes from COVID-19 (Yang et al., 2020), which is possibly caused by long-term myelosuppression and impaired immunity. Other studies obtained similar results for patients who received chemotherapy or underwent surgery in the 30 days before infection with COVID-19, according to which the patients were characterized to have a higher risk for severe events when compared with those who did not undergo chemotherapy or surgery (Al-Quteimat et al., 2020; Dai et al., 2020). In order to further confirm these data, the United Kingdom Coronavirus Cancer Monitoring Project has analyzed the mortality rate in 800 patients with cancer who were diagnosed with symptomatic COVID-19 (Lee et al., 2020). The obtained data proposed that the mortality from COVID-19 in patients with cancer was primarily driven by age, gender, and comorbidities (hypertension, cardiovascular disease, diabetes, and pulmonary disease) (Lee et al., 2020). Remarkably, they found no significant difference in the mortality from COVID-19 between patients with cancer receiving cytotoxic chemotherapy, immunotherapy, hormonal therapy, targeted therapy, or radiotherapy treatment and those not receiving active treatment (Lee et al., 2020). In agreement with these findings, Dai et al. (2020) found no difference in COVID-19 severity between patients with cancer, who underwent only radiotherapy, and patients without cancer. Thus, the effect of immunosuppression in patients with cancer on the mortality rate from COVID-19 remains controversial and requires further investigation. As yet, no evidence is available to support changing or withholding chemotherapy or immunotherapy in patients with cancer owing to a diagnosis with COVID-19. The clinical judgment is paramount in this decision, according to which the common expectation is to continue treatments, if lifesaving.
One of the major factors that most likely contribute to the high mortality risk associated with COVID-19 in patients with cancer is limited access to essential healthcare and an inability to receive the necessary medical services in a timely fashion, especially in high-risk epidemic areas, because of the high demand for medical staff and healthcare facilities (Alhalabi et al., 2020; H. Wang et al., 2020). However, the detailed contribution to COVID-19 mortality associated with this factor remains largely unknown and warrants further investigation. Taken together, various factors could increase the severity of COVID-19 in patients with cancer and the patient’s inherent immunity might be a decisive factor for their prognosis after effective supportive care.

3. THE EFFECT OF COVID-19 SUPPORTIVE TREATMENTS ON THE MORTALITY RATE IN PATIENTS WITH CANCER

Since no potential cure has been reported for COVID-19 to date, the management strategies primarily focus on supportive treatment and protective measures to prevent further transmission of the virus (World Health Organization. Clinical management of severe acute respiratory infection (SARI) when COVID-19 disease is suspected.). Different treatment modalities are emerging for patients with COVID-19, although all the existing therapies are still being investigated. However, there is a big knowledge gap on how to tackle the crucial clinical questions about the complexities that may develop from the supportive treatments for COVID-19 in patients with cancer. Thus far, the most effective treatments for COVID-19 comprises corticosteroids (e.g., dexamethasone), tocilizumab, and remdesivir (Baden et al., 2020; Jafari et al., 2020; R. Wu et al., 2020). In addition, convalescent plasma therapy (CPT) transfusion is currently considered for the rescue of severely ill patients with COVID-19 upon hospitalization (Duan et al., 2020; Islam et al., 2020).

3.1. Corticosteroids drugs

Corticosteroids drugs including dexamethasone (Horby et al., 2020) are widely used as supportive treatment for COVID-19 (Russell et al., 2020; Villar et al., 2020). Various studies have suggested corticosteroids as a potential supportive treatment that could decrease the duration of mechanical ventilation and the overall mortality rate in patients with severe COVID-19; however, the evidence is inconsistent (Ye et al., 2020). The effect of corticosteroids on COVID-19 in patients with cancer is still unclear. Based on previous studies (Arabi et al., 2018), patients with cancer who were diagnosed with Middle East respiratory syndrome (MERS), caused by a coronavirus closely related to SARS-CoV-2 (Ragab et al., 2020), were more likely to require mechanical ventilation and vasopressors after administration of corticosteroid therapy including dexamethasone, hydrocortisone, and methylprednisolone (Arabi et al., 2018). Importantly, the authors concluded that the administration of corticosteroids did not affect the mortality rate (Arabi et al., 2018). It has been suggested that patients with cancer diagnosed with COVID-19 might, more likely, be harmed by corticosteroid treatment (Russell et al., 2020). The negative effect of corticosteroids could be driven by their function in immunosuppression (Thng et al., 2020). Dexamethasone has been shown to attenuate immune responses in patients with cancer through suppression of T cell proliferation and differentiation (Giles et al., 2018). Thus, further investigations are required to shed more light on the role of dexamethasone in the treatment of COVID-19 in patients with cancer.

3.2. Tocilizumab

Tocilizumab is a humanized monoclonal antibody that acts against both soluble and membrane-bound forms of the interleukin-6 (IL-6) receptor (Venkiteshwaran, 2009). Tocilizumab is recommended for treating severe rheumatoid arthritis (Smolen et al., 2008). Tocilizumab has also been approved as a therapy for chimeric antigen receptor T-cell-therapy-induced cytokine release syndrome (Kewan et al., 2020). Cytokine release syndrome is caused by an uncontrolled immune activation that is characterized by the occurrence of a “cytokine storm” (Lee et al., 2014), which is similar to the type seen in the most severe cases of COVID-19 (Levi, 2020). Alattar et al. (2020) reported that administration of tocilizumab in patients with severe COVID-19 is correlated with a dramatic decline in inflammatory markers, radiological improvement, and reduced ventilatory support requirements (Alattar et al., 2020). Other studies from China (Jafari et al., 2020; Wu et al., 2020) and the United States (Kewan et al., 2020) have also supported these results and confirmed that tocilizumab could induce recovery in patients with severe COVID-19.
cases of COVID-19 (Jafari et al., 2020; R. Wu et al., 2020). Despite being recommended as a promising treatment in COVID-19 patients with cancer (Ascierto et al., 2020; Levi, 2020), very little is known about tocilizumab’s efficacy and interaction with anticancer therapeutic agents. Therefore, more studies to assess the efficacy of tocilizumab in the population with cancer are needed. Indeed, a prospective, randomized multicenter study is currently recruiting patients with advanced or metastatic cancer who have been diagnosed with COVID-19 across Europe (NCT04333914), and tocilizumab is among the agents that are proposed in this investigation.

3.3. Remdesivir

Early in 2020, the Wuhan Virus Research Institute proposed remdesivir as the fastest-acting and most powerful antiviral agent against COVID-19 in vitro (Cao et al., 2020). Remdesivir, a nucleoside analog antiviral agent that perturbs viral replication by blocking RNA polymerase, has shown the ability to inhibit replication in various types of coronaviruses including those that cause MERS and severe acute respiratory syndrome (Eastman et al., 2020; Yeoh et al., 2020). Early clinical trials of remdesivir treatment for COVID-19 were conducted in Hubei, China, between February 6, 2020, and March 12, 2020, and enrolled 237 patients (158 to remdesivir and 79 to placebo) (Y. Wang et al., 2020). Importantly, the clinical benefits of remdesivir in patients with COVID-19 were statistically insignificant (Y. Wang et al., 2020). On April 3, 2020, the European Medical Agency approved remdesivir treatment for patients with COVID-19 requiring mechanical ventilation (Singh et al., 2020). The clinical trial results showed that there may be a benefit to using remdesivir compared with the placebo in severe COVID-19 cases (Davies et al., 2020; Grein et al., 2020). Additionally, remdesivir has also been suggested as a potential inhibitor of viral infection in a human liver cancer (Huh-7) cell line (Wang et al., 2020). However, no data are available to show the effect of remdesivir treatment in patients with cancer diagnosed with COVID-19.

3.4. Convalescent Plasma Therapy Transfusion

CPT was used for the first time by von Behring and Kitasato as a rational approach to treat diphtheria in 1890 (Behring et al., 1890). Initially, convalescent plasma was obtained from individuals who recovered from the viral infection and were able to donate their antiviral immunoglobulin-containing blood; once transfused into the patient suffering from active infections, the antibodies from the convalescent plasma are thought to neutralize the virus and limit its replication and, consequently, reduce the symptoms and mortality (Behring et al., 1890; Luke et al., 2010; Rojas et al., 2020). Historical evidence demonstrated CPT to be a highly effective treatment for influenza pneumonia and what is now known as acute respiratory distress syndrome during the Spanish influenza pandemic (Bass et al., 1919; Redden, 1919; Sanborn, 1920).

The COVID-19 pandemic has placed emphasis on CPT to treat infectious diseases. Recent investigations from China demonstrated that human convalescent plasma is a potential therapeutic option that can decrease the severity and/or shorten the length of illness caused by SARS-CoV-2 (Duan et al., 2020; Shen et al., 2020; M. Ye et al., 2020; Zeng et al., 2020; B. Zhang et al., 2020). The majority of the findings suggested that CPT therapy in patients with COVID-19 appears to be safe and clinically effective in reducing mortality (Islam et al., 2020; Rajendran et al., 2020; Rojas et al., 2020; R. Wu et al., 2020). It is worth mentioning that the majority of these studies have used small sample sizes that ranged between 4 and 10 patients (Duan et al., 2020; Shen et al., 2020; M. Ye et al., 2020; Zeng et al., 2020; B. Zhang et al., 2020). However, a recent multicenter study that was conducted in the USA by Mayo Clinic researchers examined the effect of CPT on 20,000 patients hospitalized with COVID-19 across the USA between April 3, 2020, and June 2, 2020 (Joyner et al., 2020). The data support the notion that CPT is safe in hospitalized patients with COVID-19 and earlier administration of plasma within the clinical course of COVID-19 is more likely to reduce mortality. Indeed, the Food and Drug Administration has issued an emergency-use authorization for emergency use of COVID-19 convalescent plasma for the treatment of patients hospitalized with COVID-19 on August 23, 2020. (https://www.fda.gov/vaccines-blood-biologics/investigational-new-drug-ind-or-device-exemption-ide-process-cber/recommendations-investigational-covid-19-convalescent-plasma).

CPT in patients with cancer diagnosed with COVID-19 has also shown high levels of efficacy. Based on the study by Hatzl et al. (2020), convalescent plasma has been used for 2 patients with COVID-19 with hematological cancer...
(patient #1: diffuse large B-cell lymphoma; patient #2: follicular lymphoma) who have been on mechanical ventilation for 6 and 11 days, respectively. Impressively, both patients were off the ventilator 5 and 4 days after CP therapy, respectively (Hatzl et al., 2020). Moreover, the levels of inflammatory markers including IL-6 and serum ferritin also decreased dramatically (Hatzl et al., 2020). Although, the sample size does not allow any definitive conclusions to be drawn, these data provide continued optimism regarding the safety of COVID-19 convalescent plasma. We believe that using CPT in patients with cancer may provide some challenges, such as transfusion-related acute lung injury, circulatory overload, and hemolysis. Therefore, further investigation is warranted to get a more comprehensive picture.

4. CONCLUSIONS

The current review is based on the latest information available for this field at this time. The available data are insufficient to draw statistical and generalizable conclusions about the factors that might be correlated with better or worse outcomes for patients with cancer. The mortality rate of COVID-19 in patients with cancer should be interpreted with caution because of the limited information in some primary studies, for example, it is unclear if all the deaths were caused by COVID-19, cancer, or other comorbidities. Moreover, the majority of these studies analyzed small cohorts. In addition, some studies did not consider the cancer types, stages, and treatments. Furthermore, their samples comprised only hospitalized patients with cancer, whereas patients with cancer who died from COVID-19 outside the hospital setting were missed.

Based on the findings that we reviewed in this minireview, we recommend diligent preventive-care measures, as well as full supportive care for immunosuppressed patients to decrease the risk of infection. We believe that there is an urgent need for well-designed investigations to determine the management and treatment of COVID-19 in the oncology setting, as well as identify the clinical effects of continuing or withholding cancer therapy in patients with cancer diagnosed with COVID-19. Importantly, future studies should use large-scale datasets and pay attention to the detailed characteristics of infected patients with cancer, such as the cancer types and stages, chemotherapy or radiation-related variables, inflammatory profile, and care protocols that are followed during COVID-19 stages.

ACKNOWLEDGMENT

The authors would like to thank all the doctors and nurses who bravely fight against the virus during the COVID-19 pandemic.

REFERENCES


Modeling Features of a Single Phase-to-Earth Fault in a Medium Voltage Overhead Transmission Line

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1. INTRODUCTION

Fault is simply defined as a number of undesirable but unavoidable incidents that can temporarily disturb the stable condition of the power system, which occurs when the insulation of the system fails at any point. Moreover, if a conducting object comes into contact with a bare power conductor, a short circuit, or fault, is said to have occurred. Single phase-to-earth faults are the most frequent failures in medium and high voltage systems. The values of the currents and of the temporary overvoltage with the power frequency in the case of a single pole earth fault depend on the neutral point treatment, earth capacitances of the overhead lines or cables connected to the network, voltage level, the value of the fault resistance, and the distance between the supply busbars and the fault location (Komen et al., 2007).

Mahanty and Gupta (2007) created a methodology for fault analysis utilizing current samples with the help of fuzzy logic. In this technique, only 1 end of the 3-phase current samples was considered to have achieved the fault classification (Mahanty and Dutta, 2007). Shashi et al. (2012) developed a scheme to detect the line-to-ground fault by using fuzzy logic. The developed method requires current samples after the fault at 1 side of the transmission line only (Shashi et al., 2012). Ashok et al. (2013) proposed discrete wavelet transform (DWT) for classification of faults in transmission systems. A solution for the protection of a 3-terminal transmission system using DWT for fault classification was presented by

ABSTRACT

The modeling and calculation of a single phase-to-earth fault of 6 to 35 kV have specific features when compared with circuits with higher nominal voltages. In this paper, a mathematical analysis and modeling of a 3-phase overhead transmission line with distributed parameters consisting of several nominal T-shaped, 3-phase links with concentrated parameters replaced by 1 nominal T-shaped link were carried out. Further analysis showed that not accounting for the distributed nature of the line parameters did not cause significant errors in the assessment of the maximum overvoltage in the arc suppression in single phase-to-earth faults, and that sufficient accuracy insures the representation of the line by only 1 nominal T-shaped, 3-phase link. Such a modeling technique makes it impossible to identify the location of single-phase faults, which is the property of higher harmonic amplification of individual frequencies. Chain equivalent schemas with constant parameters are valid for a single frequency, thereby providing an opportunity to study the nature of the wave process by the discrete selection of parameters. Next in the mathematical representation, we consider the overhead transmission lines as lines with distributed parameters.

Keywords: Power system, Single phase-to-earth fault, Overhead transmission lines, Matlab Simpower Simulink

1. INTRODUCTION

Fault is simply defined as a number of undesirable but unavoidable incidents that can temporarily disturb the stable condition of the power system, which occurs when the insulation of the system fails at any point. Moreover, if a conducting object comes into contact with a bare power conductor, a short circuit, or fault, is said to have occurred. Single phase-to-earth faults are the most frequent failures in medium and high voltage systems. The values of the currents and of the temporary overvoltage with the power frequency in the case of a single pole earth fault depend on the neutral point treatment, earth capacitances of the overhead lines or cables connected to the network, voltage level, the value of the fault resistance, and the distance between the supply busbars and the fault location (Komen et al., 2007).

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Dileep Kumar and Raghunath Sagar. Simulation studies are carried out in power systems computer-aided design software in combination with electromagnetic transients including direct current on 400 kV, 300 km transmission line models designed for different types of single phase-to-ground faults (Dileep and Raghunath, 2014). Prasad et al. (2015) have implemented a new approach using 2 fuzzy rule systems, whereas Prasad and Belwin Edward (2016) implemented a new method using currents at 1 end of the overhead line with the help of DWT (Prasad and Belwin, 2016). Muhammad (2016) located different faults in high voltage transmission lines in the Kurdistan power system, which was proposed and carried out in order to determine which artificial neural network (ANN) fault locator structure delivered the best performance (Aree, 2016). Abdulrahman (2019) presented fault location recognition in the Kurdistan Regional power transmission system using ANN.

This paper proposes a mathematical model for a single phase-to-ground fault using a 3-phase overhead transmission line model with distributed parameters. For the network under consideration, the following factors had to be taken into account. First, the level of the current of the sustained metallic single phase-to-ground fault in all cases had to be taken into account with the exception of circuits with low ohmic grounded neutrals with lower rated currents. Second, the network depends significantly on the total length of the electrical circuit connected to the common busbar of the supply center. Third, even with a metallic ground fault, it cannot be calculated according to the usual technical handbook data because the technical literature only provides the total capacitive currents or conductance of overhead transmission lines and cables. In high ohmic neutral grounding, the value of the resister does not depend on the mode of operation and is chosen on the basis of the condition of the extinguishing arc for the half period of the industrial frequency.

In order to describe the behavior of the network during single phase-to-earth faults, a simulation model was created using MATLAB SimPowerSystem software. SimPowerSystems provides component libraries and analysis tools for modeling and simulating electrical power systems (Ćućić et al., 2008).

2. MATHEMATICAL MODELS

Consider an electrical sub-circuit in which a single phase-to-ground fault occurred through a resistance \( R_g \) as shown in Fig. 1, where capacitor \( C \) is shown between phase conductors and the ground and \( R_N \) indicates the neutral grounding resistance.

![Figure 1. Equivalent circuit for an overhead transmission line with a single phase-ground fault](image)

The differential equation for the voltage balance via capacitance \( C \) for 1 of the phases is:

\[
e_a - \frac{1}{C} \int_0^t i_a dt = R_N i_N
\]  

(1)
In order to get rid of the integral, a derivative of the left and right side of the equation is used. Using this technique on the remaining 2 phases, as well as writing down the voltage balance equation for the resistance circuit of the single-phase ground fault $R_g$, we get:

\[
\frac{de_a}{dt} = \frac{i_a}{C} = R_N \frac{di_N}{dt},
\]

(2)

\[
\frac{de_b}{dt} = \frac{i_b}{C} = R_N \frac{di_N}{dt},
\]

(3)

\[
\frac{de_c}{dt} = \frac{i_c}{C} = R_N \frac{di_N}{dt},
\]

(4)

\[e_a - R_g i_g = R_N i_N',\]

(5)

\[i_a + i_b + i_c + i_g = i_N\]

(6)

Adding together the left-hand side and right-hand side of equations (2) to (4) and taking into account that

\[e_a + e_b + e_c = 0\]

(7)

we obtain a new system of 2 equations:

\[\left(p t \cdot 3 R_N + \frac{1}{C}\right) i_N - \left(\frac{1}{C}\right) i_g = 0\]

(8)

where $p_t = \frac{d}{dt}$

The characteristic equation of the system of equations (5) and (8) will be:

\[p 3 R_g R_N C + R_g + R_N = 0\]

From here we have:

\[p = -\frac{R_g + R_N}{3 R_g R_N C}\]

That is, the current of the single phase-to-ground fault contains a periodic component of:

\[i_\tau = I_\tau e^{-t/T_\alpha}\]

(9)

where,

\[T_\alpha = \frac{3 R_g R_N C}{R_g + R_N}\]

(10)
According to equation (10), the lower the time constant $T_a$, the lower the resistance of the ground arc fault $R_g$. It is therefore believed that $R_g \to \infty$, which increases the time constant to its maximum value and, accordingly, aggravate the condition of the extinguishing of the arc. If it is just the case that should be considered as a calculated, then,

$$T_a = \frac{3R_NC}{1 + \frac{R_N}{R_g}} = 3R_NC$$  \hspace{1cm} (11)

If in expression (9), $T_a = \frac{t}{3}$ is inserted, then for the time $t$ the current $i_\tau$ drops to less than 5% of the initial value, which guarantees the extinguishing of the arc. At the same time, there is a requirement that such an extinguishing should occur during the first half period of the main frequency, which means the first current transition through zero, therefore implying $t = 0.01s$. Thus, we have $T_a = \frac{0.01}{3} s$. Based on equation (11), we obtain a calculated expression for determining the required value of the ground resister:

$$R_N = \frac{T_a}{3C} = \frac{0.01}{3 \times 3 \times C} = \frac{1}{900C}$$  \hspace{1cm} (12)

It is important that in formula (12) $C$ is the phase capacitance of the networks line in relation to the ground rather than the total phase capacitance. Fig. 2 gives the necessary explanation of how to distinguish between the phase-to-phase conductance between conductors and the phase conductance of the conductors in relation to the ground.

Fig. 2 shows the capacitive conductance between conductors and the ground ($C$) and between the phase conductors ($C_m$). The latter is connected in delta. We transform it into star in Fig. 3.

It is obvious that in the symmetrical load mode the neutral points of capacitive star $C$ and capacitive star $C_m'$ have equal potentials, and, accordingly, the line possesses a total phase capacitance of $C_{ph} = C + C_m'$, which is cited in technical catalogues as per 1 km or per 100 km lines. In the single phase-to-ground mode, the capacitance star $C_m'$ does not affect the level of the fault current because its neutral is isolated from the ground. Therefore, phase-to-phase capacitances should not be included in the calculations. However, the reference literature does not provide the necessary data for the capacitance of conductors relative to the ground. Certain features are provided by the Simulink software product in which the geometric size of the supports and conductors can calculate the capacitance of the overhead transmission lines in relation to the ground. Approximate values can be calculated based on the recommendations made by F.A lekhachev who proposed to use the following ratios between capacitances in relation to the earth and between phases:

for cables: $\frac{C_m'}{C} = \frac{1}{3}$ and for overhead transmission lines: $\frac{C_m'}{C} = \frac{1}{5}$  \hspace{1cm} (13)

When converting the delta to the star, we obtain $C_m' = 3C_m$. Therefore, the total capacity of the line equal to:

$$C_0 = C + C_m' = C + 3C_m$$

Here, taking into account equation (13) we obtain:

for cables: $C_0 = C + 3C_m = C + \frac{3}{3}C = 2C$ and

for overhead transmission lines: $C_0 = C + 3C_m = C + \frac{3}{5}C = \frac{8}{5}C$  \hspace{1cm} (14)

When using the reference (catalog) values for the total capacitance $C_0$, we can determine the desired capacitance of phase conductors in relation to the ground.
For cables, 
\[ C = \frac{1}{2} C_0 \]  
(15)

For overhead transmission lines, 
\[ C = \frac{5}{6} C_0 \]  
(16)

The ratios (15) and (16) are extremely important because they clearly show how different the capacity of the line relative to the ground is from its total (full) capacity. These same expressions should serve as a basis for calculating the ground fault current \( I_g \) when examining a designed electrical network project according to the permissible level of ground fault current. For networks of 6 kV, this current should not exceed 30A; for 10 kV networks, it should not exceed 20A; and for 35 kV networks, it should not exceed 5A. The ground fault current should be calculated by taking into account the capacitance values of formulas (15) and (16) as follows:

\[ I_g = \sqrt{3} U_{\text{rated}} \sum_{n=1}^{N} \omega C_{0n} l_n \]  
(17)

where \( N \) is the number of lines supplied by the common bus, \( l_n \) is the length of the nth line, and \( C_{0n} \) is the total phase capacitance related to the ground for the nth line.

When a resistive ground is installed, the fault current to the ground \( I_g \) in a steady state mode is determined by the total capacity of the network related to the ground \( C \), transformer parameters \( R_T \) and \( X_T \), and the resistor \( R_N \) and will be calculated using the following formula:

\[ I_g = 3I_0 = U_{ph} \left\{ j3\omega C + \frac{3}{3R_T + jX_T} \right\} \]  
(18)

3. SIMULATION AND RESULTS

The system modeling is shown in Fig. 4. The simulation model consists of a 3-phase, 6 kV source, network transformer, and overhead transmission.
Table 1 shows all the simulation parameters used for this work. The resistance ($R_g$) and each capacitor ($C$) are connected to the ground. The 3-phase source is connected in Y with a grounded neutral resistance ($R_n$). This block generates a 3-phase sinusoidal 6 kV line voltage. A single pole fault with earth is represented as a 1-phase circuit breaker connected to the ground.

<table>
<thead>
<tr>
<th>Simulation component</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-phase source</td>
<td>$V_{rms}=6kV/\sqrt{3}$, $f=50$Hz.</td>
</tr>
<tr>
<td>Three-phase transformer</td>
<td>$R=0.002$pu, $L=0.08$pu.</td>
</tr>
<tr>
<td>Transmission line</td>
<td>$D=100$km, $r=0.01273$pu, $L=0.9337e^{-3}$pu, $c=12.74e^{-9}$pu.</td>
</tr>
<tr>
<td>Fault breaker</td>
<td>Switching times=$[1/50$ $5/50]$ s, $R_{on}=0.001\Omega$, $R_g=1\Omega$, $R_s=inf$, $C_s=inf$.</td>
</tr>
</tbody>
</table>

Fig. 5 and Fig. 6 show the balanced 3-phase root mean square (rms) sine wave voltages and currents under normal and steady-state condition, respectively.

![Figure 5. Three-phase voltages without fault](image-url)
Fig. 7 shows all phase voltages at a single phase A-to-ground fault. It shows that phase voltage A drops down to approximately zero voltage after the fault has been cleared and all phase voltages return back to the rated value.

Fig. 8 to Fig. 11 show the response of all phase currents at a single phase A-to-ground fault in various cases, which shows the effect of disconnecting and connecting capacitance, neutral resistance, and ground fault resistance in the system. Figure shows the change in the time constant $T_a$ with increase in the ground resistance $R_g$. It is seen that the time constant of the system is 5 ms and it will be constant even if $R_g$ is increased above 500 ohms.
Figure 8. Three-phase current when a phase A-to-ground fault occurs without connecting C, Rn, and Rg.

Figure 9. Three-phase current when a phase A-to-ground fault occurs with connecting C but without connecting Rn and Rg.
The asymmetric fault currents obtained from the simulation were compared for each case of disconnecting C, R_n, and R_g and connecting C, R_n, and R_g. It simulated and analyzed the harmonic of the current in phase A by using fast Fourier transform analysis as shown in Fig. 12. It can be seen that when connecting C, R_n, and R_g, the total harmonic distortion (THD) became very allowable according to all THD power system standards, and it was reduced from 20.47% to 0.04%.
4. CONCLUSIONS

Transmission lines are used to transmit a huge amount of power over a long distance. However, because these lines are located in the open atmosphere, they are highly affected by different types of abnormal conditions or faults. This study starts with a thorough analysis of a high resistance ground fault condition. From a detailed fault analysis, it has been concluded that the lower the time constant, the lower the resistance of the ground arc fault, and, therefore, by increasing the ground arc fault resistance, the time constant to its maximum value is increased and, accordingly, the condition of the extinguishing the arc is aggravated. At the same time, there is a requirement that such an extinguishing should occur during the first half period of the main frequency; this means during the first current transition through zero. This study presents the desired capacitance of the phase conductors in relation to the ground for both cables and overhead transmission lines. It has been proven from the simulation results that the proposed methodology is not affected by the presence of high resistance in the faulted
path. The proposed scheme has been simulated in MATLAB/SIMULINK software. Furthermore, it is highly accurate because it measures the correct values of resistance and reactance of the faulted portion of the transmission line. From the simulation results, it has been proven that the proposed scheme measures the fault impedance very precisely. The proposed scheme is based on the response of the fundamental quantities of the voltage and the current signals with all system parameters, neutral resistance ground arc fault resistance, and phase capacitors. It also provides a better stability against close-in faults.

REFERENCES


Analysis of 0W-20 Totachi Brand Oil to Determine the Rate of Oil Deterioration

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1. INTRODUCTION

There are many purposes for using fresh engine oil in a lubrication system, but the main function is to keep the moving parts such as pistons, crankshaft, camshafts, valves and others separated, because separation is required to reduce the friction between the movable parts and to protect them from wear (Lajqi et al., 2016).

To protect the moving parts of a vehicle’s engine, the oil produces a film on the engine’s surface parts and cylinder walls, and the thickness of the engine oil films changes according to the engine oil type. Lubricating oil films in the engine prevent contact between the moving and nonmoving engine parts.

The lubrication system or the oil in the engines also helps the...
The engine’s cooling system to remove some of the heat produced during combustion inside the piston chamber and by friction. This means that the oil transfers heat from the high temperature areas to the sump when the oil is collected. Oil oxidation occurs when the oil temperature increases. Oxidation in a lubricant system aggravates the lubricants and creates a series of problems in the system. Corrosive acids, resins, and slugs are formed when the oil temperature increases (Owrang et al., 2004). Another function of oil in engines is to prevent corrosion (Sutar and Singare, 2018), for which purpose special anticorrosives are added to the oils. Sealing is used to prevent lubricants from leaking out of the engine, and therefore the oil that is used must also help to lubricate the seals without causing deterioration, shrinking, or hardening. There are many different quality levels and types of oils. For example, full synthetic oils are the best type and are derived from petroleum and nonpetroleum chemical compounds (Kumbir and Sabaliauskas, 2013). Many standard tests can be used to determine the condition of the oil in a lubrication system before using and after running an engine.

1.1. Kinematic Viscosity

Viscosity is a measure of the resistance to flow at a given temperature. It is very important to choose the correct oil viscosity for an engine. The owner’s manual for a specific engine is the best source to identify the correct oil to use in the engine. During different operating conditions, such as when the engine is running at a low temperature or under load, the lubricating fluids must retain their properties, and the viscosity of the best oils changes only minimally in the working temperature range. According to the Society of Automotive Engineers (SAE), the oil grade can be used to identify the oil viscosity, and it is the same across the globe (Mang and Dresel, 2007).

The SAE has established a viscosity classification for engine oils to describe the kinematic viscosity. For example, in an SAE 0W-20 extra fuel economy engine oil, the first number indicates the flow of the oil at cold engine temperatures. The lower the first number, the better the flow at a cold engine temperature. The “W” indicates that the oil is suitable for use in winter. According to the SAE chart, 0W has acceptable viscosity properties to enable proper functioning at around -40°C. The second number indicates the lowest viscosity requirement at a high engine temperature to guarantee acceptable lubrication for the engine without damaging it (Pereira et al., 2007). Certain engine manufacturers set tight limits on the allowable changes in viscosity. According to Coates and Setti (1986), the maximum permissible changes (increasing or decreasing) in viscosity is 25%. An increase in viscosity is caused by contamination, nitration, or oxidation, whereas a decrease in viscosity occurs when the amount of fuel in the oil increases (Kaleli and Yavasliol, 1997). Temperature has a direct effect on the oil viscosity. Farhanah and Bahak (2015) studied the relationship between viscosity and temperature using 3 different engine oil manufacturers with the same SAE viscosity grade. They rotated the viscometer in accordance with the American Society for Testing and Materials (ASTM) D445 stipulations, and their results showed that the temperature is inversely correlated with viscosity; therefore, any decrease in the temperature will increase the engine oil viscosity. In addition, in the study by Kaleli and Yavasliol (1997), an SAE viscosity grade of 20W-50 was used in 2 different engines. The results showed that after 15,000 km, the viscosity of the oil used in the second engine decreased at 40°C from 160.16 cSt to 103.02 cSt, and at 100°C the viscosity of the oil decreased from 18.09 cSt to 13.24 cSt. Most engine wear occurs when the engine is cold.

When starting an engine, the oils must reach all the moving parts. If an oil with the wrong viscosity is used, and in this example an oil with a viscosity that is too high, the oil pump cannot push the required rate of oil to the upper parts of the engine when the engine is started. Wear occurs when the oil reaches the moving parts too late. In some newer engines when the wrong viscosity oil is used, the engine does not start, especially in diesel engines, because in those types of engines the oil is used to operate the pump to prime the fuel injectors. In addition, wax is produced when diesel fuel dilutes the oil, especially at low temperatures (Niculescu et al., 2016).

1.2. Flash Point and Fire Point

Another parameter used to determine the oil quality is the flash point. The flash point is the lowest temperature that causes the vapors in air to burn momentarily or ignite when exposed to a naked flame or spark under specific laboratory conditions (Kaleli and Yavasliol, 1997; Ljubas et al., 2010). A reduction in the flash point is caused by the penetration of fuel. In the laboratory, there are 2 ways to determine the flash point of the oil. The first method is called the open flash point (open Cleveland method), which is used for fuels with low flammability, and is conducted at temperatures above 50°C in an open container (Shri Kannan et al., 2014).

The second method is called the Pensky-Martens closed cup method, which is used for fuels with high flammability, and is conducted at temperatures below 50°C in a closed container (Azad et al., 2012). However, if heating of the oil continues after the flash point, a temperature will be reached at which the vapors from the oil are released fast enough to support
Combustion for a minimum of 5 seconds under specific laboratory conditions. This temperature is called the fire point. The fire point temperature is usually higher than the flash point temperature. Researchers have reported that the flash point decreases from 204°C to 128°C after approximately 10,000 km for the SAE 20W-50 oil type (Kaleli and Yavasliol, 1997).

2. METHODS AND MATERIALS

Table 1: The performance grade properties of the SAE 0W-20 oil

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>API SN</td>
<td>Fully synthetic</td>
</tr>
<tr>
<td>ILSAC GF-5</td>
<td></td>
</tr>
<tr>
<td>High temperature high shear</td>
<td>(HTHS) ≥2.6 cSt</td>
</tr>
<tr>
<td>Dexos 1™ 2011</td>
<td></td>
</tr>
<tr>
<td>Resource conserving</td>
<td></td>
</tr>
<tr>
<td>API SN</td>
<td>Fully synthetic</td>
</tr>
<tr>
<td>ILSAC GF-5</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: The physical characteristics of the SAE 0W-20 oil

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity at 40°C</td>
<td>40.8 cSt</td>
</tr>
<tr>
<td>Kinematic viscosity at 100°C</td>
<td>8.0 cSt</td>
</tr>
<tr>
<td>Flash point</td>
<td>236 °C</td>
</tr>
<tr>
<td>Density at 30°C</td>
<td>0.851 Kg/L</td>
</tr>
<tr>
<td>Pour point</td>
<td>-42 °C</td>
</tr>
<tr>
<td>Kinematic viscosity at 40°C</td>
<td>40.8 cSt</td>
</tr>
<tr>
<td>Kinematic viscosity at 100°C</td>
<td>8.0 cSt</td>
</tr>
<tr>
<td>Flash point</td>
<td>236 °C</td>
</tr>
<tr>
<td>Density at 30°C</td>
<td>0.851 Kg/L</td>
</tr>
</tbody>
</table>

Table 3 shows the information about the oil samples taken from the vehicles. The Totachi oil samples were collected from a Totachi car service shop in Sulaymaniyyah, Iraq. The oil samples from the vehicles were taken directly from the sump and kept in closed clean bottles until the day of the analysis. In the scope of this study, the Cleveland open cup flash point method according to the tester manual, NCL 120, Normes: ASTM D 92, IP 36, ISO 2592 was used to determine both the flash point and the fire point of the used oil. A thermometer with a 300°C measuring range was used to measure the flash point and fire point temperatures. To determine the kinematic
viscosity of the oil, a KV1000 kinematic viscosity bath was used with a variable limit control according to the ASTM D445 stipulations. A Koehler viscometer that was manufactured in strict accordance with the ASTM D446 stipulations and calibrated against fully traceable ISO 17025 certified standards, was used. Before the kinematic viscosity test was conducted, the oil was filtered to remove any tiny particles produced as a result of the friction between the moving parts. These experiments were conducted in the petroleum laboratories of the Kurdistan Institute in the Sulaymaniyah province.

### Table 3: Vehicle make, model, odometer, and trip length of the samples that were collected

<table>
<thead>
<tr>
<th>Make</th>
<th>Model</th>
<th>Engine capacity</th>
<th>Engine Year</th>
<th>Odometer</th>
<th>Trip length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissan</td>
<td>Altima</td>
<td>2.5 L</td>
<td>1</td>
<td>2018</td>
<td>52,123–53,146</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2017</td>
<td>73,221–75,226</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2017</td>
<td>93,423–96,519</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>2016</td>
<td>88,507–92,534</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>2017</td>
<td>108,715–113,778</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>2016</td>
<td>64,802–71,028</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>2017</td>
<td>85,407–92,505</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>2017</td>
<td>73,254–81,320</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>2016</td>
<td>66,004–75,334</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>2017</td>
<td>72,060–82,154</td>
</tr>
</tbody>
</table>

### 3. RESULTS

The test results for the kinematic viscosity, flash point, and fire point of the Totachi engine oil that was extracted from the different gasoline engines (Nissan Altima) are shown in Table 1 and Table 2. The results were modeled using a linear function. The general linear function is calculated as follows:

\[ Y(x) = Kx + q \]  

The kinematic viscosity of the Totachi brand gasoline engine oil at cold start as shown in Figure 1 is calculated as follows:

\[ \nu (s) = -1.0536 \cdot s + 47.738 \ [cSt; Km] \]  

The kinematic viscosity at 40°C as shown in Figure 2 is calculated as follows:

\[ \nu (s) = -1.0945 \cdot s + 41.072 \ [cSt; Km] \]  

The kinematic viscosity at 100°C as shown in Figure 3 is calculated as follows:

\[ \nu (s) = -0.3582 \cdot s + 7.9829 \ [cSt; Km] \]

Here, \( \nu \) is the kinematic viscosity and \( s \) is the trip length. As shown in Figure 1, Figure 2, and Figure 3, the kinematic viscosity at a cold start, 40°C, and 100°C decreased as the trip length increased.

Figure 4 and Figure 5 show the flash point and fire point for the used lubricating oil, which is also shown in Table 3 and Table 4. According to the figures, the flash point and fire point decreased when compared with the unused oil. The reduction in the values of the flash point and fire point occurred because of the presence of volatile impurities in the oil with increasing trip length. To get the final results of the flash point and fire point, the test was repeated 3 times for every engine oil sample. The average value of the tests for every oil sample was used to determine the rate of deterioration at the flash point and fire point.

### 4. DISCUSSION

In the Kurdistan region, several types of lubricating engine oil are used in engine lubrication systems. In this study, 0W-20 Totachi international oil brand was used to determine oil viscosity, flash point, and fire point. At a low temperature, thin engine oils pour more easily and have a low viscosity compared to thick oil. The advance of thin oil reduces the friction between the engine’s moving parts, allowing the engine to easily starts even in cold engines temperatures during cold weather. Engine oil viscosity can be differentiated according to the SAE standard scales.
Table 4: Kinematic viscosity, flash point, and fire point of the engine oil samples

<table>
<thead>
<tr>
<th>Engine</th>
<th>Oil type</th>
<th>Viscosity at cold start (cSt)</th>
<th>Viscosity (cSt) at 40°C</th>
<th>Viscosity (cSt) at 100°C</th>
<th>Flash point (°C)</th>
<th>Fire point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unused</td>
<td>47.2</td>
<td>40.8</td>
<td>8.0</td>
<td>236</td>
<td>248</td>
</tr>
<tr>
<td>2</td>
<td>Unused</td>
<td>45.4</td>
<td>39.9</td>
<td>7.95</td>
<td>229</td>
<td>240</td>
</tr>
<tr>
<td>3</td>
<td>Unused</td>
<td>45.1</td>
<td>37.2</td>
<td>7.8</td>
<td>220</td>
<td>233</td>
</tr>
<tr>
<td>4</td>
<td>Unused</td>
<td>43</td>
<td>37</td>
<td>7.55</td>
<td>216</td>
<td>228</td>
</tr>
<tr>
<td>5</td>
<td>Unused</td>
<td>43.3</td>
<td>35.4</td>
<td>7.49</td>
<td>209</td>
<td>220</td>
</tr>
<tr>
<td>6</td>
<td>Unused</td>
<td>41.2</td>
<td>32.05</td>
<td>7.44</td>
<td>204</td>
<td>215</td>
</tr>
<tr>
<td>7</td>
<td>Used</td>
<td>41</td>
<td>33.5</td>
<td>6.57</td>
<td>205</td>
<td>214</td>
</tr>
<tr>
<td>8</td>
<td>Used</td>
<td>39.3</td>
<td>31.6</td>
<td>6.08</td>
<td>203</td>
<td>212</td>
</tr>
<tr>
<td>9</td>
<td>Used</td>
<td>38.5</td>
<td>31.1</td>
<td>5.96</td>
<td>199</td>
<td>209</td>
</tr>
<tr>
<td>10</td>
<td>Used</td>
<td>37.1</td>
<td>30.8</td>
<td>5.94</td>
<td>198</td>
<td>207</td>
</tr>
</tbody>
</table>

Figure 1. 0W-20 Totachi oil viscosity at cold start after different trip lengths

Figure 2. 0W-20 Totachi oil viscosity at 40°C after different trip lengths
**Figure 3.** 0W-20 Totachi oil viscosity at 100°C after different trip lengths

**Figure 4.** 0W-20 Totachi oil flash point after different trip lengths
The number after “W” indicates the oil’s viscosity at 100°C and represents the oil’s resistance to thinning at high temperatures. The oil viscosity decreases because of dilution with gasoline, whereas it may also increase because of contamination or oxidation (Abro et al., 2013). According to Figure 1 at a cold start after an increased trip length, the oil viscosity decreased from 47.2 cSt to 36.8 cSt, corresponding to a 22.03% decrease in the viscosity. In Figure 2, when the trip length increased, the viscosity at 40°C decreased from 40.8 cSt to 30.2 cSt, corresponding to a decrease of 25.98%. In addition, the viscosity at 100°C as shown in Figure 3 decreased from 8 cSt to 5.86 cSt, corresponding to a decrease of 26.75%.

To determine the flash point, approximately 50 mL of the used engine oil was placed in the special cup on an electrical heater, which was fitted with a thermometer. The heating rate was adjustable by using an energy regulator on the front panel of the NCL 120. To determine at which temperature a flash appeared on the surface of the cup, a flame source was used and moved every time a 3°C increase in the temperature was measured on the thermometer. As recorded in Table 2 the flash point of the unused oil was 236°C. For the used engine oil, the flash point decreased continuously from 1000 km to 10,000 km. As shown in Figure 4 the flash point decreased from 236°C to 196°C, corresponding to a loss of 16.94%. The reduction in the flash point occurred because of the presence of contaminants.

Another property of the oil that continuously decreased as the trip length increased was the fire point. The fire point of the unused oil was 248°C (Table 4). The fire point after 10,000 km was 205°C, as shown in Figure 5. This is a decrease of 17.34%. The reduction in the fire point indicates an increase in the amount of impurities in the used oil.

5. CONCLUSION

Engine oil lubricants are used in engines to decrease the friction between the moving parts, for cooling, and to prevent corrosion. In this study, SAE 0W-20 extra fuel economy Totachi brand international engine oil was used in 10 different engines to determine the change in the oil properties by focusing on how the viscosity, flash point, and fire point of the lubricating engine oils decreased after being used for different trip lengths. These parameters are the most important physical characteristics of lubricating engine oils. In the experimental work, the viscosity at a cold start, at 40°C, and at 100°C, the flash point, and the fire point were determined.

According to the test results, all of the engine oil parameters degraded after 10,000 km. The viscosity at cold start, at 40°C, and at 100°C decreased by 22.03%, 25. 98%, and 26.75%, respectively. In addition, the flash point decreased by 16.94%, and the fire point decreased by 17.34%. Therefore, based on the results of the above experiments, it is recommended that drivers should change their engine oil before the due distance to avoid any eventualities and unexpected damage to their engines. Another conclusion that drivers can draw from this study is that instead of changing their engine oil every 3000 km as required when using a low-quality oil, they can instead opt to change their oil every 10,000 km with greater peace of mind by using better engine oil types.
REFERENCES


1. INTRODUCTION

Network programming started around the 1980s (Feamster et al., 2014). The emergence of megatrend increases in the domain of information and communication technologies (ICT) is increasing the challenges for future networks (Xia et al., 2015). The legacy networks involve various components (routers and switches) running on distributed protocols and require manual configuration, long implementation times, and difficult to manage proprietary networks, which make it difficult for the customer to choose the hardware and software. With the major evolution of Internet of Things (IoT), mobile networks will need to handle a big influx in data, massive amounts of network traffic, and new types of connected devices such as industrial machines, smart cars, wearable sensors, actuators, and smart appliances (Nikoukar et al., 2018). One of the major building blocks of IoT devices is the low power and lossy networks (LLNs), a set of interconnected embedded devices such as sensor enabled devices. LLNs have been used widely in various fields such as modern

**ABSTRACT**

Mobile traffic volumes have grown exponentially because of the increase in services and applications. Traditional networks are complex to manage because the forwarding, control, and management planes are all bundled together and, thus, administrators are supposed to deploy high-level policies, as each vendor has its own configuration methods. Software-Defined Networking (SDN) is considered the future paradigm of communication networks. It decouples control logic from its underlying hardware, thereby promoting logically centralized network control and making the network more programmable and easy to configure. Low-power wireless technologies are moving toward a multitenant and multiapplication Internet of Things (IoT), which requires an architecture with scalable, reliable, and configured solutions. However, employing an SDN-based centralized architecture in the environment of a low-power wireless IoT network introduces significant challenges, such as difficult-to-control traffic, unreliable links, network contention, and high associated overheads that can significantly affect the performance of the network. This paper is a contribution toward a performance evaluation for the use of SDN in wireless networking by evaluating the latency, packet drop ratio (PDR), data extraction rate (DER), and overheads. The results show that SDN adds a high percentage of overheads to the network, which is about 43% of the 57% user packets, and the DER drops when the number of mesh nodes are increased, in addition to the high loss that was observed for packets that traveled over more hops.

**Keywords:** SDN, CSMA, WSN, IoT

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networking, traffic monitoring, home monitoring, process monitoring, medical monitoring, and environmental monitoring. The LLNs were introduced by different standardization bodies such as the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 and the IETF 6TiSCH standards (Ghaleb et al., 2019). The IEEE 802.15.4 standards form the basis for many low-power IoT protocols such as 6LowPAN, ZigBee, and WirelessHART. The main weakness of low-power wireless mesh networks is related to the limitations of the sensor resources and the underlying communication technologies. The constrained devices are restricted by their processing power, memory capacity, speed, energy, transmission rate, high variability of lossy links, and location.

These devices, however, are expected to operate for months or years with low power consumption. SDN is a well-defined approach and a promising solution for other networking areas. However, employing an SDN-based centralized architecture in the environment of a low-power wireless IoT network introduces important challenges, such as the difficulty to control traffic, unreliability of links, network contention, and high associated overheads, which can significantly affect the performance of the network (Baddeley et al., 2018). This paper evaluates the overhead cost of SDN traffic network performance, delay, DER, and PDR. We illustrate the results by showing how SDN-based carrier-sense multiple access (CSMA) can enhance the Quality of Service (QoS) and achieve a considerable reduction in the delay. The rest of this paper is organized as follows: section 2 discusses the previous work related to the use of SDN in low-power IoT networks, whereas section 3 explains the evaluation environment. The results are presented and discussed in section 4. Finally, the conclusion is presented in section 5.

2. OVERVIEW AND RELATED WORK

2.1. SDN: the need, architecture, and deployment

SDN is embodied by a separation of the network, thus, moving the control logic from the node to the centralized controller. This brings potential benefits such as a globally improved network performance, enhanced network management and configuration, and encouraged innovation. In terms of network configuration and management, one of the key objectives is to achieve the possibility of reconfiguring network devices from a single point, automatically and dynamically, through software-controlled optimization based on the network status. SDN encourages innovation by providing a sufficient testing environment with isolation, easy software implementation for new applications, and quick deployment of new applications by using a software upgrade. Another benefit of SDN is that the dynamic global control can be improved with cross-layer consideration. Specifically, SDN allows for a centralized control with a global view of the network and feedback control with the information that is exchanged among different layers in the architecture of the network (Xia et al., 2015). Moreover, SDN can be easy to maintain because new services or network upgrades can be performed without affecting the whole network.

2.1.1. SDN architecture

The Open Networking Foundation (ONF) is a non-profit industry consortium aimed at the development, standardization, and commercialization of SDN architecture elements such as OpenFlow protocols and SDN controllers. The ONF introduced an SDN reference model that consists of a 3-layer model which ranges from the infrastructure layer to the control layer, and to an application layer, all stacking over each other. The infrastructure layer consists of the physical network components (e.g., ethernet switches, routers, etc.) and this forms the data plane. The main functions of the SDN switching device model are classified into 2 categories. First, they simply are responsible for collecting and reporting the network status by storing data temporarily in local devices before forwarding these to the controllers. Second, they are responsible for processing packets based on the applied forwarding rules (Ominike et al., 2016). The control layer is the most important component in the SDN architecture. It bridges the infrastructure layer and the application layer through its 2 interfaces. The controller infrastructure interface (southbound interface), which interacts with the infrastructure layer, allows the controller access to the functions that are provided by the switching devices. The functions include collecting the network status and updating the packet forwarding rules to the switching devices at the infrastructure layer. The controller communicates with the switching devices through an OpenFlow protocol. The application-controller interface (northbound interface), which handles the transactions with the application layer, provides a
variety of service access points such as an application programming interface (API). The policies received, described in high-level languages by SDN applications and network status synchronization are utilized to build the global network view (Xia et al., 2015). At the highest layer of the SDN architecture, the application layer includes the SDN applications. SDN applications are designed to fulfill the user requirements, such as the ability to access and manage the switch devices in the data plane, seamless mobility and migration, server load balancing, and network virtualization.

### 2.2. SDN for wireless networks

The recent evolutions in the wireless domain with the goal of integrating SDN and IoT are discussed in a number of previous studies (El-Mougy et al., 2015; Lasso et al., 2018; Jian et al., 2017; Anadiotis et al., 2019). However, there are many fundamental issues of what SDN indicates when it comes to low-power sensor networks such as IEEE 802.15.4, which is allowed to serve key enablers for the IoT in the near future. Similar to OpenFlow, Sensor OpenFlow (Luo et al., 2012) was the first attempt at integrating SDN in Wireless Sensor Networks (WSNs). The authors introduced a customized, low-power protocol built on the legacy southbound communications for SDN rather than using OpenFlow directly because of the complexity in the implementation of the Out-Of-Band (OOB) control-plane connection model within a sensor network.

They developed an algorithm called Control Message Quenching (CMQ) for OpenFlow to reduce the SDN control overhead. In a study by De Oliveira et al. (2015), the authors of TinySDN attempted to utilize an SDN to establish a flexible solution for WSN and IoT deployment, because an SDN-based centralized controller could achieve node retasking and routing and enable a better resource sharing and management platform. They examined the TinySDN and IPv6 routing protocol for LLNs (RPL) in terms of their routing features, interoperability, and ability to support traditional networks. The study only presented solutions to RPL shortages in the context of SDN. Costanzo et al. (2012) proposed SDNWN, an architectural framework that highlights the impact of SDN in low-power WSN. They presented the concept of utilizing protocol oblivious forwarding (POF) as a key enabler for a highly flexible and programmable SDN. It was demonstrated to minimize the memory footprint and allow the flowtable to match on bytes arrays and a packet index inside the packet rather than being included in multiple flows for specific packet types. Another SDWSN that sought to improve the traffic routing and WSN sensor programmability was implemented and tested for IEEE 802.15.4 in the study by Galluccio et al. (2015). The aim of an SDN solution for Wireless Sensor networks (SDN-WISE) is to reduce the number of packets exchanged between the SDN controller and the sensor nodes, as well as to enable sensor nodes to be programmed as Finite State Machine (FSM) for running different domains. The SDN-WISE attempts to produce APIs that allow the developers to use the programming languages of their preference when they build SDN controllers.

The prototype of SDN-WISE was developed using a real SDN controller and an Objective Modular Network Testbed in C++ (OMNET++) simulator. The aim of their system is to increase the elasticity of the network and provide realization of network programmability. Lasso et al. (2018) proposed a software-defined wireless sensor network architecture based on 6LoWPAN networks (SD-WSN6LO). Two main components were introduced in the framework, namely an SDN sensor node and SDN controller node. They demonstrated the result of power consumption for their implementation in Contiki OS, however, no details about the architecture and implementation were presented. The work of Galluccio et al. (2015) demonstrated how logical WSNs can coexist by exploiting the same set of sensor nodes and how easy it is to program the behavior of sensor nodes with a few lines of code. Their system was compared with the state-of-art SDN-WISE system in terms of reducing the number of messages exchanged between the sensors and controllers.

Furthermore, the study provided a new method of network virtualization called SDN-Visor, which allows the creation of several virtual WSNs under different controllers. The challenge of including SDN architecture with a high associated cost into low-power sensor networks is addressed in the study by Theodorou and Mamatas (2017). The authors proposed to minimize the amount of RPL control messages in SDN for an Internet Protocol version 6 (IPv6)-based IEEE 802.15.4 network through fine tuning the timer setting in RPL. The aim was to provide the scalability and management for an SDN protocol.
2.2.1. SDN controllers

The most important component in SDN is the controller, which is the cornerstone of the architecture of SDN. The main concept behind the controller is to manage the traffic in underlying network devices by using a set of instructions. A number of previous studies conducted a partial performance evaluation for controllers (Zhao et al., 2015; Rowshanrad et al., 2016; Asadollahi et al., 2017; Asadollahi et al., 2018). The performance of 5 open course controllers, namely Ryu (RYU), POX (POX), NOX (NOX), Floodlight (Floodlight), and Beacon (Beacon) was investigated in a study by Zhao et al. (2015) using optimized configurations for each of the controllers. Beacon was found to outperform the others in terms of latency and throughput by having a low latency (0.1 ms) and high throughput (1750 ms).

It also increased fairness. Rowshanrad et al. (2016) evaluated the performance of controllers such as Floodlight and OpenDaylight. They showed that OpenDaylight performed better than Floodlight for low and medium network loads in terms of latency, loss of packets, and throughput. However, Floodlight performed well with heavy network loads such as multimedia. Previous studies recognized issues with the simulation and emulation of SDN.

Asadollahi et al. (2017) introduced a linear topology to evaluate the scalability and performance of a network by emulating an Open Flow Network (OFNet) (OFNet) over the Floodlight controller. The aim was to define the performance metrics for the Floodlight controller. However, Asadollahi et al. (2018) proposed a mesh topology to evaluate the performance and scalability of a Ryu controller. They performed various experiments using the simulation tools Mininet, Ryu controller, and iPerf (iperf). The objective of the study was to test the scalability feature of the Ryu controller in the SDN environment.

3. EVALUATION ENVIRONMENT

This paper evaluated the performance of SDN for wireless communication using a simulation. A number of different types of software, packages, and tools were used for this purpose. The main components of our evaluation platform are described in detail below.

3.1. Operating systems

Linux is a full open-source, UNIX-based system with a large support community. It has immediate advantages for developers and programmers who develop their own tools, packages, and customized applications. Being an open-source system, Linux has attracted the academic community and researchers whose concerns in terms of the ability to access and have full control over the hardware and system libraries are best met by this system. In this paper, Ubuntu, a flavor of Linux 12.04 LTS (64-bit), was used as the operation system.

It was installed on a Lenovo-IdeaPad-Y510P Laptop with an Intel Core i7-4700MQ processor with 7.7 gigabytes of random access memory. In this environment, it was unnecessary to install the Contiki platform because it was included as part of the µSDN (Baddeley et al., 2018), a low overhead SDN stack, and embedded in the SDN controller for Contiki OS. However, it was necessary to install compilers such as the 20-bit mspgcc compiler (20-bit) and the precompiled MSP430-GCC version 4.7.3 (msp430). The reason for using the 20-bit mspgcc compiler was to support up to 1 MB of memory. Platforms such as Cooja and WiSMote are based on the MSP430X series central processing unit (CPU) and support more memory than the 64K address space.

3.2. Simulator

A simulator could be used as an alternative to simplify the research environment. Cooja is an open-source simulator that aids in the testing of protocols or applications on emulated motes based on operating systems such as TinyOS or Contiki OS (Dunkels et al., 2004). The main feature of the Cooja network simulator is the ability to simulate any number of platform sensor nodes (Hendrawan & Arsa, 2017). It supports a set of standards such as TR 1100, TI CC2420, Contiki RPL, IEEE 802.15.4, uIPv6 stack, and uIPv4 stack (Helkey et al., 2016). All simulations in this work were tested in Cooja using a Unit Disk Graph Medium (UDGM) distance loss. The reason for using a simulated UDGM distance loss radio environment is that it allows implementation and testing of the new directional property of nodes. A node can receive a packet from a sender only if it is within its radius, which is defined by the transmission range.

3.3. SDN framework
An SDN standard for low-power wireless networks called \( \mu \text{SDN} \) (Baddeley et al., 2018) was used for simulation in this study. \( \mu \text{SDN} \) is a lightweight SDN architecture for Contiki OS, which supports both IPv6 and interoperability with distributed routing protocols such as RPL, as well as optimizes the combination of a number of overhead reduction functions to enhance the scalability and mitigate the cost of the SDN within a low-power IoT environment.

3.4. Simulation setup

We evaluated the performance of an implemented SDN in a wireless network through simulation, presenting a use-case scenario in which the SDN can be used within low power, multihop wireless networks in order to programmatically improve the QoS and show how a CSMA-SDN can achieve significant reductions in delay. The simulations were performed on an emulated EXP5438 platform with a TI’s MSP430F5438 CPU and CC2420 radio, with evaluation in the Cooja simulator for the Contiki OS environment using a UDGM distance loss model with the configuration parameters listed in Table 1.

**Table 1: Cooja Simulators Parameters Setup**

<table>
<thead>
<tr>
<th>Cooja simulation parameters</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation period</td>
<td>1 h</td>
</tr>
<tr>
<td>Radio environment</td>
<td>UDGM with Distance Loss Model</td>
</tr>
<tr>
<td>Node transmission range</td>
<td>100 m</td>
</tr>
<tr>
<td>MAC layer</td>
<td>CSMA</td>
</tr>
<tr>
<td>Transmitting nodes</td>
<td>All</td>
</tr>
<tr>
<td>Receiving node</td>
<td>controller</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>20, 30, 40</td>
</tr>
<tr>
<td>Link quality</td>
<td>50%, 70%, 90%</td>
</tr>
<tr>
<td>Transmission data period</td>
<td>60–75 s</td>
</tr>
<tr>
<td>RPL mode</td>
<td>Non-storing</td>
</tr>
<tr>
<td>RPL route lifetime</td>
<td>10 min</td>
</tr>
<tr>
<td>RPL default route lifetime</td>
<td>( \infty )</td>
</tr>
<tr>
<td>( \mu \text{SDN} ) flowtable lifetime</td>
<td>300 s</td>
</tr>
<tr>
<td>( \mu \text{SDN} ) update period</td>
<td>180 s</td>
</tr>
</tbody>
</table>
A total of 30 random realizations of the SDN deployment was run. Data from the Contiki logs were collected and the characteristics of the network entries were analyzed using Matlab.

The performance metrics included the end-to-end application flow delay, PDR, DER, and ratio of network traffic. All the performance metrics are described in Table 2.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-to-end application delay</td>
<td>It determines how the SDN overhead affects the application traffic latency.</td>
</tr>
<tr>
<td>Packet Drop Ratio (PDR)</td>
<td>The ratio of the number of lost application packets to the total number of sent application packets.</td>
</tr>
<tr>
<td>Data Extraction Rate (DER)</td>
<td>The ratio of received application messages to transmitted application messages over a period of time.</td>
</tr>
<tr>
<td>Ratio of network traffic</td>
<td>Ratio of application traffic, and SDN traffic in µSDN.</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

The performance metrics of the SDN were investigated for wireless networks in the following scenarios:

(1) End-to-End Delay: In this scenario, we measured the overheads incurred by application messages and the end-to-end latency. In this experiment, the network consisted of 30 nodes with the maximum of 6 hops to the controller, a transmission ratio (Tx) of 100%, and a reception (Rx) ratio of 90% for each mesh node. In addition, the SDN controller collected information from all the nodes every 60 seconds, which included node energy, node state, and buffer congestion. Each simulation that was ran collected data from the mesh node flowtable entities, which have a 300 second lifetime. The transmitting nodes sent data to the sink every 60 to 75 seconds. It is clearly seen that there is an increase in the delay with an increase in the number of the hops. This is obviously because of the fact that packets travel longer when increasing the number of hops and every single node along the path needs to perform a flowtable check for incoming packets, which substantially contributes to the delay. This trend can be observed in Figure 1, which shows the average of the end-to-end application flow latency vs. the number of hops.

The results of the delay in this paper is corroborated by the results of the delay in other papers (Baddeley et al., 2018).
(2) PDR: It refers to the ratio of the number of lost application packets to the total number of sent application packets. The PDR is computed with the help of the formula presented below:

$$PDR = \frac{\text{Total sent packets} - \text{Total received packets}}{\text{Total sent packets}}$$ \hspace{1cm} (1)

A total of 30 mesh nodes with a maximum of 6 hops in which all the nodes need to participate in the SDN controller, were used to evaluate the SDN reliability. Figure 2 shows the PDR percentage for various hop numbers in a 30-node network. The overall trend indicated a higher percentage loss for packets that traveled over more hops. Because packets are forwarded by hops, there is high probability that packet loss will occur because of congestion and MAC layer fails shortly after initialization. In addition, because each node forwards packets through an SRHI, they require a source routing header, which needs to be received from the controller. The reason for the high network activity is because the FTQ/FTS messages are occasionally dropped and, therefore, the application messages are lost. However, this is not always the case as can be noticed in the Figure 2 in which the PDR for 3 and 4 hops are less than the PDRs for 2 hops.
(3) DER: It is 1 of the performance metrics determined in this study. It is defined as the ratio of the received packets to the total number of packets transmitted by a mesh node over a period of time. The formula for measuring the DER is as follows:

\[
DER = \frac{\text{Total received packets}}{\text{Total transmit packets}}
\] 

(2)

We evaluated this by running a simulation of the network topology with a 20-, 30-, and 40-node mesh network over 1 to 15 hops with a 50%, 70%, and 90% link quality and a transmission range of 100 m. The simulation was ran for approximately 1 hour. DER is a value between 0 to 1: the closer the value is to 1, the more effective the deployment is. With an increase in the number of mesh nodes, the DER drops, as can be seen in Figure 3. For example, for a link quality of 50%, the DER is 0.45, 0.39, and 0.32 for a network with 20, 30, and 40 nodes, respectively. The DER, however, increases with a better-quality link. The DER was calculated to be 0.45, 0.5, and 0.611 for a link quality of 50%, 70%, and 90%, respectively.

(4) Analysis of the network traffic (user data and overhead): one objective of this paper was to evaluate the overheads introduced by using an SDN with overhead reduction techniques to show the effect of mitigating the cost of an SDN within a low power, multihop mesh framework on the network performance. The network traffic ratio can be determined by using the following formula:

\[
\text{SDN Overhead Ratio} = \frac{\text{Total Overhead App Traffic}}{\text{Total Network Traffic}}
\] 

(3)

\[
\text{User Traffic} = \frac{\text{Total Network Traffic} - \text{Total Overhead App Traffic}}{\text{Total Network Traffic}}
\] 

(4)

The application ratio and the SDN traffic are shown in Figure 4. The figure shows the network traffic for the user packets and network overheads at different numbers of nodes. The user packets refer to the application traffic, whereas the network overheads refer to the type of SDN packets such as CONF, FTQ, FTS, and NSU, which are described in the SDN framework. The figure clearly demonstrates higher traffic percentages for the user packets when compared with that of the network overheads for all considered network topology scenarios (20, 30, and 40 nodes). It also shows high traffic percentages for network overheads that are generated by the SDN packets. This high traffic percentage for network overheads places SDN in a challenging position, which requires further study. For instance, the user packets and network overhead percentages were found to be 57.31% and 42.68%, respectively, for a 30-node scenario. However, similar studies (Baddeley et al., 2018) reported approximately 25% for user packets and 75% for network overheads for the same network size.
5. CONCLUSION

In this paper, we applied the SDN concept to a wireless network and evaluated its performance in terms of end-to-end delay, PDR, DER, and the SDN overhead. We used a lightweight SDN architecture designed for low-power wireless communication, called μSDN, to implement the SDN in the wireless environment in order to programatically improve the QoS. In this study, the performance was evaluated using a Cooja simulator for Contiki OS. In particular, we considered the end-to-end delay, PDR, DER, and percentage of network traffic as evaluation metrics of the performance of the SDN-based wireless network. Our results indicated that increasing the number of nodes causes a drop in the DER of about 0.45, 0.5, and 0.6 for a link quality of 50%, 70%, and 90%, respectively. Finally, SDN simplifies the network management and configuration, however, it adds a high percentage of overhead to the network of about 43% in comparison with 57% for the user packets. Further investigation on the power consumption of the network is required.

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10 kW Grid-Connected PV System Cost and Environmental Analysis for Government Offices: Darbandikhan Technical Institute as a Case Study

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A B S T R A C T

The Iraqi Kurdistan region has significant potential for implementing solar energy with an average annual rate of 5.245 kWh/m². However, most of its energy supply currently comes from nonrenewable energy sources. With the continually increasing demand for energy, an alternative energy-generation technique is required. Among the various renewable energy resources, generating electricity directly from sunlight is the best option because it can be applied by the average household and is environmentally friendly. In this study, a cost and environmental analysis for a 10 kW grid-connected photovoltaic system is presented for a government building with the aim of reducing the load demand on the grid during weekdays and also to inject the generated power into the power grid during weekends. A simulation of the proposed PV system was generated by using Photovoltaic Geographic Information System software to estimate the system’s production performance. The software showed that the highest energy production was 1,660 kWh, which occurred in August; the total electricity production was 16,184 kWh over a 1-year period. The study also showed that the geographical location of Darbandikhan City is quite sufficient for generating electric power from solar energy. It further showed that it can reduce CO₂ emissions by 356.60 tons during its lifetime when compared with a gasoline generator and by 131.38 tons when compared with that of a natural gas generator. The proposed system could serve as a good revenue source for the government by exporting the generated electricity to the grid while at the same time serving as motivation for households in the region; furthermore, this system can also be applied to other governmental offices in Kurdistan to generate some or all of its energy needs.

Keywords: Electricity generation, Grid connected PV system, Darbandikhan, Environment, Economic, Solar energy, PVGIS

1. INTRODUCTION

In recent years, the demand for national electricity in the Kurdistan region has has significantly risen because of the increase in population and industrialization (Abbas, 2013).

Based on official data, the total power demand for the region in 2009 was 2,096 MW, whereas power production was 809 MW (Diler, 2018).

According to the Kurdistan region’s electricity region’s electricity minister, the demand for electricity increased to 6,500 MW in late 2019, whereas the power production in the region was 3,800 MW (NRT, 2019). This illustrates that the request for power in the region has increased almost 3-fold during a decade. Government data show that a mere 60% of the total power demand was provided by the Kurdistan Regional Government (KRG) in 2019, which led to most households in the region experiencing...
electricity cutoffs that lasted for 8 hours or more during a day. However, the unexpected cutoffs varied according to the seasons, demands, and the remaining hours provided by private generators. Currently, the region has 9 power stations. Seven of these run on natural gas and gasoline, and the other 2 operate on hydropower. More than 80% of the electricity in the region is generated from fossil fuels, and only 15% to 20% of the energy is generated by hydropower plants (Abdullah & Abdulrahman, 2015; Diler, 2018).

Apart from a fossil fuel-driven generator’s drawback of creating environmental pollution, greenhouse gas emissions over the long term are costlier compared with those of the photovoltaic (PV) system (Johnson and Ogunseye, 2017). Based on the International Renewable Energy Agency (IRENA) database released in May 2019, the global weighted average cost of electricity generated by solar PV has fallen into the fossil fuel cost range since 2014 (IRENA, 2019). According to the newest data, renewable energies represent 25% of the global electricity generation. It is expected that 65% of energy use could be supplied by renewable sources by 2050 (IRENA, 2017).

Over the last few decades, in many developed and developing countries, renewable energy has become the main source for the production of electrical energy. Many countries, e.g., New Zealand, Norway, Sweden, Brazil, Canada, and Iceland generate more than half of their power from renewable energy sources (Muhy Al-Din et al., 2017).

The PV system, as a type of renewable energy, has recently gained increasing attention. Several studies have evaluated the potential of PV systems to generate electricity in terms of cost analysis, annual income, and carbon footprints for particular regions (Thotakura et al., 2019). When comparing the operational performance of a 1 MW grid-connected PV system with the operational performance generated by the simulation software tools, the results show that the differences between the operational data, recorded for 12 months, and the estimated energy determined by the Photovoltaic Geographic Information System (PVGIS) software, the actual PV watts, and the PV system software were 5.33%, 12.33%, and 30.64%, respectively. Hussein et al., (2013) introduced photovoltaic system design software (PVSD) that is compatible with the Iraqi climate conditions by using Visual Basic. A project, designed using this program, has been implemented by the Ministry of Science and Technology. This program determines the results for a system based on the data from existing systems that were measured over a year. Aziz et al. (2019) presented a performance analysis for a 5-kW rooftop solar PV microgrid system in Iraq. A household in Baghdad was selected for the case study. Furthermore, Dihrab and Sopian (2010) proposed hybrid PV–wind systems for power generation in 3 cities in Iraq. The results showed that it is possible to use solar and wind energy to generate enough power for some villages in the rural area.

Diler (2018) analyzed the potential and social awareness of the use and implementation of renewable energy sources in Kurdistan; furthermore, the study used a qualitative and quantitative methodology. Based on the qualitative review it was found that the region has the ability to utilize renewable energy resources, whereas the quantitative results indicated that the majority of participants think the public sector should take the first step toward renewable energy production; furthermore, about 63% of the participants were willing to pay extra to obtain this technology. In the study by Bamisile et al. (2019), RETScreen software was used to simulate and analyze the data for a 10 MW PV plant based on economic factors for 3 different locations in Kurdistan. Abdullah and Abdulrahman (2015) proposed a 200 kW PV system for Koya City. The study showed that building PV systems in the area can significantly reduce the CO2 emission in the air. Mohammed and Mahdi (2018) used a fuzzy system to predict the solar radiation for solar energy production in Duhok City. Majeed et al. (2019) conducted a technoeconomic analysis of a 2 MW on-grid solar power plant system in Chavy Land located in Sulaymaniyyah City. The simulation results, as determined by system advisor model software, showed that the system contributed significantly to power the area and reduce demand on the national grid.

The objective of this study was to propose a grid-connected PV system to the local government offices in the Kurdistan region. To conduct this study, the solar horizontal radiation values for Darbandikhan City were obtained from meteorological data from 2010 to 2019. Based on that, this study analyzed the performance of the grid-connected PV system and also analyzed the costs and environmental impact of the system. Furthermore, the results of this study indicated that the solar irradiation rate...
of the city would be sufficient for the installation of a PV system in the area.

2. METHODOLOGY

The grid-connected PV system is strongly affected by geographic and topographic factors such as climate, altitude, longitude, and terrain conditions. Geographically, the elevation of Darbandikhan Technical Institute is 522 m above sea level and located in Darbandikhan City, Al Sulaymaniyah, Iraq. The city is located at a latitude of 35° 11' 53.052" north and longitude of 45° 68' 29.264" east, with the sun shining about 7 hours in winter and up to 14 hours in summer on average (Weather Atlas, 2020). The solar irradiation rate and temperature in the city for a period of over 9 years (January 2010 to September 2019) were measured using a weather station (provided by Darbandikhan Dam Directorate). Based on that, this study analyzed the suitable grid-connected PV system for the Darbandikhan Technical Institute building. The total roof area of the building is 1,175 m² and the chosen area for the estimated plant capacity is estimated to be 135 m² on the building’s concrete rooftop. The roof is horizontally flat, which offers the advantage of choosing the desired tilt angle for generating maximum solar energy.

The simulation was conducted by using PVGIS software to analyze and evaluate the irradiation rate and the average obtained electrical energy during the year. The PVGIS software has been proven to be a useful tool for estimating the regional potential energy generating capacity and to support the decision making in energy planning (Qianna et al., 2014).

3. SOLAR PHOTOVOLTAIC MODULES

PV modules are made up of silicon semiconductor cells. Solar cells can produce electricity when exposed to sunlight. The output power generated by each single PV cell is very low. A large number of PV cells are connected in series and parallel, ensuring that the PV module produces the desired power. Several modules are then connected in series-parallel to make a PV array as shown in Figure 1 (Rashid, 2001).

A PV system is a good choice for generating electrical power. It can be situated in a residential area, typically on the rooftops of domestic, commercial, and government buildings. It can also be mounted on the ground. The rooftop PV technology can reduce the peak summer load, and the power generated by this technology can supply the residential demand for things such as lighting, cooling, televisions, fans, and other domestic needs. Whenever the load demand is greater than the power generated from the PV solar panels, the required power is drawn from the grid. The main advantages of PV technology are that it can be applied by households, it is environmentally friendly, has a long lifespan (>20 years) with a low maintenance cost (Rashad, 2014), and does not require a highly skilled person for its maintenance. In contrast, the cost of PV technology is continuously decreasing as demand and production increase. According to the IRENA, solar PV module prices have fallen by around 90% since the end of 2009 (Rashid, 2001; IRENA, 2019). The major drawbacks of this technology are the high manufacturing cost and low efficiency (15%–20%).
4. MATHEMATICAL MODELLING

4.1. GRID-connected PV system

The main components of a grid-connected PV system are shown in Figure 2 (Apricus). The system consists of the following 3 essential components: PV arrays, which are responsible for the direct conversion of sunlight to electrical energy; an inverter, which is necessary to convert direct current (DC) power to alternating current (AC) power and also to generate the sinusoidal power that is utilized by the local loads and/or for injecting the generated power into the grid; and a bi-directional meter, which is used to record the electricity flow from or to the power grid.

In the Kurdistan region, the standard single-phase AC voltage is 240 V. This voltage will determine the DC voltage needed from the PV module strings. As mentioned in Johnson and Ogunseye (2017), the DC voltage can be calculated as follows:

\[ V_{DC} = \sqrt{2} \times V_{ac} \Rightarrow V_{DC} = \sqrt{2} \times 240 = 339.412 \text{ V} \] (1)

where 10% is added to account for the measurement uncertainty in the design as follows:

\[ V_{DC} = \sqrt{2} \times V_{ac} + 10\% = 373.35 \text{ V} \] (2)

The open-circuit voltage of the module is 39.8 V. Thus, the total number of modules required in a string is calculated as follows:

\[ V_{DC} \div V_{OC} = \frac{373.35}{45.2} = 8.26 \text{ modules} = 8.5 \text{ modules} \] (3)

The maximum power point voltage \( V_{MP} \) of the string of 8.5 modules at the standard test condition (STC) is calculated as follows:

\[ 8.5 \times V_{MP} = 8.5 \times 36 = 306 \text{ V} \] (4)

The aim of connecting PV panels in series is to obtain a higher voltage. Thus, the open-circuit voltage of the string of the 8.5 modules at an STC is equal to

\[ 8.5 \times V_{oc} = 8.5 \times 45.2 = 384.2 \text{ V} \] (5)

The actual DC voltage required is 373.35 V. The surfeit voltage will take care of the voltage variation from the PV system caused by temperature increases above 25ºC, cable losses, and other environmental condition variations (irradiation). Temperature has a significant effect on the PV cell performance. With increasing temperature, the voltage and output power of PV modules will decrease (Fesharaki et al., 2011).

The short circuit current remains the same because the modules are connected in series. To obtain a higher current, a parallel connection of the string is required. Four strings connected in parallel produce 384.2 V and 35.44 A at an STC or 306 V and 33.48 A at the maximum power point as calculated below:

\[ 4 \times I_{sc} = 4 \times 8.86 = 35.44 \text{ A} \] (6)
4 × Imp = 4 × 8.37 = 33.48 A  

The PV panels are connected to a grid through an inverter without battery storage. Based on the power generating capacity of the PV system, a 10 kW inverter is required. The grid’s interactive inverter must produce a pure sine wave output, must be synchronized with the grid in terms of voltage and frequency, and must extract the maximum power from the solar cells with the help of a maximum-power point tracker. The inverter input stage modifies the input voltage until the maximum power point on the I-V curve is found. The characteristics of the PV panels, inverter, and the system parameters used in this paper are shown in Table 1, Table 2, and Table 3, respectively.

<table>
<thead>
<tr>
<th>Table 1: Specifications of the PV Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell type</strong></td>
</tr>
<tr>
<td>Number of cells</td>
</tr>
<tr>
<td>Rated power</td>
</tr>
<tr>
<td>Voltage at maximum power</td>
</tr>
<tr>
<td>Current at maximum power</td>
</tr>
<tr>
<td>Open circuit voltage</td>
</tr>
<tr>
<td>Short circuit current</td>
</tr>
<tr>
<td>Module efficiencies at STC</td>
</tr>
<tr>
<td>Dimensions (L×W×H)</td>
</tr>
<tr>
<td>Weight</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Inverter Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
</tr>
<tr>
<td>Rated AC power</td>
</tr>
<tr>
<td>Frequency range</td>
</tr>
<tr>
<td>Wave form</td>
</tr>
<tr>
<td>Efficiency (DC to AC)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3: System Parameter Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of PV panels required</td>
</tr>
<tr>
<td>Required area</td>
</tr>
<tr>
<td>Output voltage</td>
</tr>
<tr>
<td>Output current</td>
</tr>
<tr>
<td>Inclination of PV panels</td>
</tr>
</tbody>
</table>

4.2. Cost estimation

The PV panel cost is normally between one-half and one-third of the capital cost of the PV system depending on the size of the project and the PV module type (IRENA, 2012). A monocrystalline PV module is used in this study because it offers the highest efficiency among all the PV module types. The cost of this solar module per watt in local market price in the Kurdistan region is US$0.3 and the maximum power of the modules is 300 W. Thus, the total cost of this module could be estimated as follows:

\[
P_{\text{PV panels estimated cost}} = \text{maximum power in watt} \times \text{cost of solar model per watt} \times \text{total number of modules} = 300 \times 0.3 \times 34 = \text{US$3060} \quad (8)
\]

The PV system output power is 10 kW. Inverters with ratings of 0.5 kW, 1 kW, 5 kW, and 10 kW are available in the markets. Installation charges for a chosen inverter amounts to US$1,000.

The management and maintenance costs are about 15% of total estimated cost of the PV system (Azabany et al., 2014). Therefore, the estimated management and maintenance costs are calculated as follows:

\[
\text{Extra cost} = 4060 \times 0.15 = \text{US$609} \quad (9)
\]
The capital cost of the system could be estimated as follows:

\[
\text{Capital cost} = PV\ panels\ cost + Inverter\ cost + extra\ cost = US\$\ 4669 \quad (10)
\]

Apart from the calculated costs stipulated above, a grid-connected PV system requires no additional costs for resources. However, for a fossil fuel-driven generator (gasoline and natural gas), daily consumable resources are required. Abdullah and Abdulrahman (2015) noted that 1 L of gasoline can generate 3.66 kWh energy. Therefore, to produce 16,184 kWh/year, 4,421.85 L of gasoline is required. Based on a cost of US$0.5 for 1 L of gasoline, the total estimated cost to operate a 16,184 kWh gasoline generator for 1 year is around US$2,210.92. At the same time, to generate 1 kWh energy, 0.2838 m³ of natural gas is required (Abdullah and Abdulrahman, 2015). Therefore, to generate 16,184 kWh/year, 4,593 m³ of natural gas is required. The cost of 1 m³ of natural gas is US$2.5. Therefore, the total cost of natural gas to generate 16,184 kWh energy over a 1-year period will be US$11,482.54. Table 4 presents the resource cost for fossil fuel-driven generators, whereas PV modules are operated without additional resources.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Resource required to generate 1 kWh</th>
<th>Resource cost for generating 1 kWh</th>
<th>Total cost of generating 16,184 kWh/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.2732 L</td>
<td>$0.136</td>
<td>$2,210.95</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.2838 m³</td>
<td>$0.7095</td>
<td>$11,482.54</td>
</tr>
</tbody>
</table>

4.3. CO2 emission

The generation of electricity and industry are responsible for 65% of the global greenhouse gas emissions today (IRENA, 2017). For every kilowatt hour of electricity generated, a coal power plant will emit 950 g of CO₂, whereas natural gas power plants will emit 350 g. For renewable power plants, the only CO₂ emissions produced are related to their construction. Accordingly, for every kilowatt hour of electricity generated, a solar PV system emits between 60 and 150 g of CO₂ (Planète, 2016). It is clear that most of the energy supplies in the Kurdistan region come from nonrenewable energy sources (gasoline and natural gas), which has a greater impact on the environment. The most important benefit of this technology is that it is environmentally friendly and does not require extra costs because renewable energy sources, e.g., sunlight, are freely available in nature. Therefore, the proposed 10 kW rooftop grid-connected PV system can reduce the CO₂ emissions by 14,264.25 kg/year when compared with gasoline and by 5,255.25 kg/year when compared with natural gas in the atmosphere.

5. RESULTS AND DISCUSSION

Based on the data recorded by Darbandikhan Dam Directorate (Darbandikhan Dam, 2019), the average monthly solar irradiation for the city varies from 2,549 to 8,872 kWh/m² throughout the year. Under these conditions, solar PV power plants can play a crucial role in supplying a significant portion of the city’s electricity demand. According to the same source, the highest average monthly temperature recorded in the city was 44°C in August 2018. Table 5 shows the city’s solar radiation rate in Wh/m² for 9 years (Darbandikhan weather station).
The solar potential energy was estimated based on the climate data (irradiation and temperature) of the defined location, the well-known PVGIS software simulation that was used to provide the expected amount of average daily electricity production (Ed), average monthly electricity production (Em), average daily sum of global irradiation (Hd), and average monthly sum of global irradiation (Hm) received by the proposed modules as shown in Table 6. The table also shows that the average daily electricity production from the proposed 10 kW PV system is 44.2 kWh, and that the average monthly production from the same system is 1,348.67 kWh. Moreover, the annual electricity production is 16,184 kWh.

The monthly energy production of the proposed PV system is shown in Figure 3. It is clear that the maximum PV output power is generated during the months with the highest solar radiation and lowest production will be in the months with the lowest solar radiation over a period of 1 year. This is because of the fact that Darbandikhan is located in the northern part of Iraq, and hence is exposed
to and enriched with solar radiation that is direct between April and September.

![Figure 3: Monthly average power generated by the PV system in kWh](image)

Based on the financial metrics of the system that was presented in section 4, the capital cost of the system has been calculated using United States Dollar as the currency. The annual average energy production from the proposed PV system is 16,184 kWh, and the charge for 1 kWh in the region is around US $0.015. Therefore, the system can generate an annual income of around US$242.76. It thus implies that it will take 19 years to pay back the system’s initial cost. Assuming that the average lifetime of a PV system is around 25 years, the 10 kW grid connected system gives a net profit of around US $1,456.56 during that time.

6. CONCLUSION

This study investigated the national electrical power status of the KRG. Demand for electricity in this region is increasing continuously, and power generation is created by fossil fuel products. In this study, a 10 kW on-grid PV rooftop system was designed based on climate data for a government building in Darbandikhan City. It has been shown that the city has a sufficient amount of solar irradiation throughout the year for installing a PV system. The solar potential energy in the location was estimated with the help of PVGIS software. The results show that the city has the highest energy production potential during summer, which is 1,660 kWh in August, and has the least production potential during winter. Although the proposed grid-connected PV system is costly, no additional resources are required after installation, and it can pay back the system’s initial cost in 19 years. However, for a fossil fuel-driven generator, daily consumable resources are required. In addition, a PV system has lower CO₂ emissions compared with those of fossil fuel. The proposed system can reduce the CO₂ emissions in the city by 356.60 tons during its lifetime when compared with gasoline and by 131.38 tons when compared with natural gas. It is thus plausible to conclude that by installing multiple solar panels throughout all government offices, significant impacts on CO₂ emissions and load demand in the city can be achieved, which consequently leads to a decrease in the power cutoffs, especially during the months with the highest solar radiation.

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RESEARCH ARTICLE

Volumetric Calculation of Hydrocarbon Generated from the Sargelu Formation in the Kurdistan Region, Iraq

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A B S T R A C T

In an attempt to determine the amount of hydrocarbon generated from the Sargelu Formation, outcrop and borehole samples were collected. The areal distribution, density, and weight of the Sargelu Formation were determined by using traditional methods and a geographic information system. The amount of hydrocarbon generated was determined to be $3.4199 \times 10^{12}$ kg.

Keywords: Sargelu Formation, Source rock, Hydrocarbon, Volumetric calculation, Iraq

1. INTRODUCTION

The Sargelu Formation was first recognized and described by Wetzel in 1948 (in Bellen et al., 1959) in the Surdash anticline in the Sulaimani Province of the Zagros High Folded Zone in the northeastern part of Iraq. The lower part of the Surmeh Formation in Iran and the Dhurma Formation in Saudi Arabia are the age equivalents of the Sargelu Formation (Jassim and Buday, 2006a). The common source rock for hydrocarbon generation in the Folded Belt and Zagros Thrust zone is the carbonate and shale rock units of the Jurassic mainly found as part of the Sargelu Formation (Pitman et al., 2004). The organic matter (OM) of the Sargelu Formation is classified as type II and III kerogens (Odisho and Othman, 1992; Abdula, 2010, 2015). The OM is thermally in the post mature stage and within the gas-generation zone in the Miran Oil Field (Fatah and Mohialdeen, 2016). This formation entered into the oil-generation stage in the Late Eocene and entered into the condensate and gas-generation stage during the present age (Beydoun, 1993). The stratigraphic succession at the Emam Hasan and Masjid-e Suleiman oil fields of the western part of Iran was correlated by James and Wynd (1965) together with the Adaiyah, Mus, Sargelu, Najmah, and Gotnia formations of Iraq, which were described and defined in the Lexique Stratigraphique International for Iraq by Bellen et al. (1959). Qaddouri (1972) studied the Sargelu Formation in the Benavi area of the Duhok Governorate in the Iraqi Kurdistan Region. Al-Omari and Sadiq (1977) placed the Sargelu Formation within the Middle Jurassic succession. In a general review of the formation, Buday (1980) adopted the original description given by Wetzel (1948, in Bellen et al., 1959) and classified the depositional environment as a euxinic marine environment. Al-Barzanji (1989) studied the Muhawir Formation in the Iraqi Western Desert, pointing out that this formation was deposited within the same sedimentary cycle as the Sargelu Formation.
The aim of this study was to calculate the amount of hydrocarbon generated from the Sargelu Formation in the Iraqi Kurdistan Region.

2. METHODS

The sample base for this study consisted of surface outcrops of the Sargelu Formation. The thicknesses of the Sargelu Formation in different locations in the Iraqi Kurdistan Region were provided by the Ministry of Natural Resources, Erbil. Geographic Information System (GIS) software was used to prepare an isopach map. The thickness of the Sargelu Formation was calculated by using 2 different methods. The first method was by using Excel to determine the average thickness. In the second method, the GIS software was utilized to find the average thickness. In addition, mathematical equations were applied to determine the volume, density, and weight of the Sargelu Formation throughout the area.

3. GEOLOGIC SETTING

The Late Triassic-Early Jurassic was the time during which the Neo-Tethys ocean opened (Dercourt et al., 1986) (Figure 1). The Iraqi Unstable Shelf was changed to a deep-sea environment because of the opening of the Neo-Tethys and the subsidence of the Unstable Arabian Shield (Numan, 1997). Marouf (1999) believes that because of the cooling of the adjacent oceanic crust that affected crustal under loading, there was an increase in the deepening and subsidence of the basin toward the east. The major change in the depositional setting and climate pattern occurred during the Middle Jurassic. Deposition of evaporates was rare because of the more humid climate (Murris, 1980). Liassic sedimentary basins changed to euxinic basins and the sedimentation setting became more uniform (Buday, 1980). In Iraq, the Sargelu and Muhaivir Formations represent the Middle Jurassic (Figure 2). The Sargelu Formation has a broad geological distribution in Iraq and the depositional basin has a NW–SE trend (Abdula et al., 2015). The shoreline on the western edge of the basin was represented by the Rutba-Jazeera zone and the eastern shoreline with the zone of west Iran, the Sanandaj-Sirjan block (Jassim and Karim, 1984). The Sargelu Formation’s geographic distribution (Fig. 3) extends toward the southeastern part of Iraq, Kuwait, and the southwestern part of Iran in the Lurestan zone and partly in the Khuzestan region (Darvishzadeh, 1991).

Figure 1. Opening of Neo-Tethys ocean during the Permian Period (according to Muttoni et al., 2009).
Figure 2. The stratigraphic correlation of the Jurassic formations in Iraq (redrawn from Bellen et al., 1959, and Al-Omari and Sadiq, 1977).
Figure 3. (a) A tectonic map of the Iraqi Kurdistan. The study area is indicated by the black rectangular box (according to Jassim and Buday, 2006a); (b) A simplified geological map of Kurdistan showing the anticlinal axes and the related thrust faults. The studied anticlines are labeled (according to Sissakian et al., 1995; Sissakian, 1997; and Csontos et al., 2012).
The Jurassic Period is currently determined to have lasted around 55.6 Ma (201.3–145.7 Ma) (Ogg et al., 2016). In the Early Jurassic, the sea level was low with the exception of the Early Toarcian, which is thought to have had a relative high sea level, a variant overall low level during the Middle Jurassic, and a scalar rise thereafter that lasted through much of the Late Jurassic. The climates serve as collateral evidence for these trends.

Faunal and isotopic data show relatively warm climates for most of the Jurassic Period, with some exceptions, and unconfirmed evidence of widespread glaciations during much of this period. However, the relative warmth of the Hettangian Epoch through to the Toarcian Epoch seems to have been interrupted by a cooler Late Pliensbachian Epoch through to the Early Toarcian Epoch (Hinnov and Park, 1999; Dera et al., 2009; Korte and Hesselbo, 2011; Suan et al., 2015; Korte et al., 2015). Korte and Hesselbo (2011) believe that the Early Jurassic may have vacillated between greenhouse and icehouse conditions.

In Iraq’s Kurdistan Region, the Sargelu Formation crops out along the length of the High Folded, Imbricated, and Zagros Suture zones. Lithologically, the formation consists of dark gray limestones and dark papery shales. The lower part of the Sargelu Formation is usually represented by bituminous marly limestone (often dolomitized) and thin papery shale, whereas the middle part is composed of limestone, and the upper part is an intercalation of shale and bituminous limestone (Ahmed, 1997). In the uppermost part of the formation, the lithology becomes black laminated shale, and black chert bands can be seen with a continuous transition to the Naokelekan Formation, conformably (Fig. 2).

Within the Sargelu Formation, the following 3 main types of microfacies have been recognized: wackestone, packstone, and lime mudstone (Abdula et al., 2015). On the basis of these 3 microfacies and the lithofacies, the Sargelu Formation is interpreted to represent a ramp model deposition (Fig. 4). The organic-rich sediments of the Sargelu Formation revealed an euxinic (anoxic) depositional environment (Abdula et al., 2015).

The thickness of the Sargelu Formation is diverse. The thickness of the formation (Fig. 5) in the Northern Thrust, Imbricated, and High Folded zones has a range from 20 m in the northwestern part of Iraq in the Ora

---

**Figure 4.** Depositional environment of the Sargelu Formation corresponds to ramp depositional model (according to Abdula et al., 2015)
and Chalki regions to 125 m in the northeastern part of Iraq in the Sirwan Valley near Halabja. It is 115 m thick at the type locality (Bellen et al., 1959; Buday, 1980; Jassim and Buday, 2006b; Abdula et al., 2015).

4. CALCULATIONS AND RESULTS

Inefficiencies associated with the expulsion, migration, and trapping of hydrocarbons are often large. Thus, the amount of hydrocarbon generated can be an enormous number when compared with the amount in place.

4.1. Area of the Sargelu Formation Expansion

For area determination, the GIS software was utilized according to the following steps:

GIS→ Study area→ Open attribute table→ Add field→ Area→ Calculate geometry→ Square kilometer (km²)→ and Ok.

The area of the studied region in which the Sargelu Formation exists was determined to be 46,353.679 km².

4.2. Average Thickness of the Sargelu Formation

The generated thickness was calculated using 2 different methods. The first method was by using Excel to determine the average thickness. In the second method, GIS software was used to get more accurate results for the average thickness.

The following steps were used in the GIS software package:

Study area of the Iraqi Kurdistan Region (Fig. 5)→ Georeferencing→ Digitizing & creating shapefile for the study area→ Geostatistical wizard: Inverse Distance Weighting (IDW) (Data Field: Thickness) → Convert IDW to Raster→ Using Extract by Mask for Shapefile→ Right Click above the Raster Isopach (Properties: Histogram).
The average thickness of the Sargelu Formation was calculated to be 107.283 m.

4.3. Average Weight of the Sargelu Formation Samples

During the fieldwork, 7 rock samples from outcrops were collected. The dry weight for each sample was determined by using a sensitive balance. The average weight of the samples from the Sargelu Formation was determined to be 196.998 g.

4.4. Volume of the Sargelu Formation Samples

In the laboratory, the volume of the collected samples was determined by applying the following steps:

Choosing standard (stable) water volume for all samples (700 ml) → placing each dry sample into a beaker and measuring the increase in the water volume → increase in water volume = volume of sample. The average volume of the samples of the Sargelu Formation is 75 ml.

4.5. Density of the Sargelu Formation

After determining the volume and weight of the samples, the density of the samples was calculated by using the following formula:

\[
\text{Density} = \frac{\text{weight}}{\text{volume}}
\]

\[
= \frac{196.998 \text{ g}}{75 \text{ ml}}
\]

\[
= 2.627 \text{ kg/m}^3
\]

4.6. Weight of the Sargelu Formation

To determine the weight of the Sargelu Formation, the following 2 equations were used:

\[
\text{Volume} = \text{average thickness} \times \text{area}
\]

\[
= 107.288 \text{ m} \div 1000 \text{ km/m} \times 46,353.679 \text{ km}^2
\]

\[
= 4973.193 \text{ km}^3
\]

By using the volume and density, the weight of the Sargelu Formation was determined by applying the following formula:

\[
\text{Weight} = \text{density} \times \text{volume}
\]

\[
= 2.627 \text{ kg/m}^3 \times 4973.193 \text{ km}^3
\]

\[
= 1.307 \times 10^{13} \text{ kg}
\]

\[
= 1.307 \times 10^{10} \text{ ton}
\]

4.7. Average Total Organic Carbon of the Sargelu Formation Samples

The quantity of organic carbon in a source rock that contains kerogen and bitumen is called the total organic carbon (TOC), which is reported as the weight percentage (wt%) (Peters and Cassa, 1994). To determine the TOC (wt%), the data presented in Table 1 were utilized. The average TOC for each location was calculated individually, followed by calculating the total average TOC for all the locations in the Sargelu Formation. The average TOC (wt%) was determined to be 3.58 wt%.
TOC of the Sargelu Formation

The total organic carbon (TOC) of the Sargelu Formation was determined using the following equation:

\[
\text{TOC} = (\text{Weight of the Sargelu Formation}) \times (\text{Average TOC of the Sargelu Formation})
\]

The potential of a rock to generate oil can be determined by its HI. It was observed that the OM in the Sargelu Formation at Gara Mountain has the highest HI, whereas the lowest HI is at Hanjeera Village, which is located 2 km west of Raniya Town (Table 1). For this study, the HI

\[
\text{HI} = 4.679 \times 10^3 \text{ ton}
\]

4.8. Weight of TOC of the Sargelu Formation

TOC (wt%) of the Sargelu Formation was determined using the following equation:

\[
\text{TOC} = (\text{Weight of the Sargelu Formation}) \times (\text{Average TOC of the Sargelu Formation})
\]

\[
= 1.307 \times 10^{10} \text{ ton} \times 3.58 \div 10^2
\]

4.9. Average HI of the Sargelu Formation

The potential of a rock to generate oil can be determined by its HI. It was observed that the OM in the Sargelu Formation at Gara Mountain has the highest HI, whereas the lowest HI is at Hanjeera Village, which is located 2 km west of Raniya Town (Table 1). For this study, the HI...
for each location was obtained separately (Table 1). The average HI of the Sargelu Formation was determined to be 288.338 mg HC/g rock.

4.10. Type of Kerogen of the Sargelu Formation

Kerogen is OM that is disseminated in sediments and made of high-molecular-weight compounds (Whelan and Thompson-Rizer, 1993).

When the HI values of samples are greater than 600 mg HC/g C<sub>org</sub> it implies that the samples are type I kerogen; if greater than 300 mg HC/g C<sub>org</sub> it implies that the samples are type II kerogen; if greater than 200 mg HC/g C<sub>org</sub> it implies that they are a mixture of types II and III kerogens; if greater than 50 mg HC/g C<sub>org</sub> they represent type III kerogen; and if less than 50 mg HC/g C<sub>org</sub> they indicate type IV kerogen (Tissot and Welte 1984; Peters and Cassa, 1994). Therefore, the studied samples are type II and III kerogens.

The T<sub>max</sub> vs. HI plot (Fig. 6) showed that the collected samples from the Sargelu Formation represent type II and III kerogens.

4.11. Hydrocarbon Generated Amount

To determine the amount of generated hydrocarbon, the Shmoker (1994) flow diagram of the method for approximate calculation of the mass of hydrocarbons generated was applied.

First step: calculate the mass of organic carbon in the source rocks.

TOC/100 (wt. %) × formation density (ρ, g/cm) × Volume of unit (V, cm<sup>3</sup>) = Mass of organic carbon (M, g TOC)  

Equation 1

The weight of the Sargelu Formation was determined to be 1.307 × 10<sup>13</sup> kg

Mass of Sargelu’s TOC = 1.307 × 10<sup>13</sup> kg × 10<sup>3</sup> kg/g

= 1.307 × 10<sup>16</sup> g

Second step: estimate the mass of hydrocarbons generated per gram of organic carbon.

Hydrocarbons generated per gram organic carbon (R, mg HC/g TOC) = Hydrogen index prior to hydrocarbon generation (HI<sub>0</sub>, mg HC/g TOC)  

Equation 2

= 550 mg HC/g TOC – 288.338 mg HC/g TOC

= 261.662 (R, mg HC/g TOC)

Third step: multiply these data to determine the total mass of hydrocarbon that was generated as follows:

Hydrocarbons generated by unit (HCG, kg HC) = R (mg HC/g TOC) × M (g TOC) 10<sup>-6</sup> kg/mg  

Equation 3

= 261.662 (mg HC/g TOC) × 1.307 × 10<sup>16</sup> (g TOC) × 10<sup>-6</sup> (g/mg)

= 3.4199 × 10<sup>12</sup> (HCG, Kg HC)
5. CONCLUSIONS

The main conclusions from this study are that the average thickness of the Sargelu Formation is 107.283 m, the density is 2677 kg/m$^3$, the weight in the studied area is $1.307 \times 10^{10}$ ton, the weight of TOC is $4.679 \times 10^8$ ton, and that the generated hydrocarbon amount is $3.4199 \times 10^{12}$ kg.
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REFERENCES


Breast Mass Classification Based on Hybrid Discrete Cosine Transformation–Haar Wavelet Transformation

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ABSTRACT

Mammography is the most effective procedure for the early detection of breast cancer. In this paper, an efficient computer-aided diagnosis system was proposed to discriminate between a benign and malignant breast mass. The system comprises mainly 3 steps, namely preprocessing of the images, feature extraction, and finally, classification and performance of the analysis. This study sampled mammographic images that originated from the mini Mammographic Image Analysis Society database. In the preprocessing phase, the region of interest was cropped and resized to 128×128. The feature extraction process started with the application of a Haar wavelet transformation to 5 levels, followed by the application of discrete cosine transformations with various coefficients selected to each level. The extracted features were then fed into the feature similarity measure, city block, for the diagnosis of breast cancer. Finally, K-nearest number was used as the classifier to classify the images as benign or malignant.

Keywords: Discrete cosine transform, Breast mass, Haar wavelet transform, Feature extraction, Mammogram

1. INTRODUCTION

Breast cancer is a type of cancer with the highest incidence rates among women. It is the most common cause of cancer-related deaths among women in many countries. Recent statistics show that breast cancer affects 1 in every 10 women in Europe and 1 in every 8 in the United States. According to the statistics of the Breast Disease Treatment Center (BDTC) in Sulaimani, breast cancer affects 1 in every 10 women.
specialized breast radiologists and general radiologists. The aim of this paper was to present a mass classification system for mammogram images based on texture extraction techniques, because texture is used to describe the variation in intensity between the pixels to supply information, making it one of the central characteristics used to analyze medical images. Therefore, it can help to distinguish and identify the objects.

2. RELATED WORK

Currently, medical image processing and CAD systems are hot topics in the medical research field. Many studies have been conducted to assist medical staff, including doctors, with diagnoses and decisions about treatment. Therefore, CAD systems perform the role of a second evaluator in clinical practice. In the following sections, we provide an overview of the previous studies related to this research area. CAD was invented for clinical practice in 1985 when it was introduced by the University of Chicago (Mathews, 2019). Later on, in 1998, after completing all the required trials and tests, the United States Food and Drug Administration approved the use of the CAD system in screening mammographic images. Thereafter, many CAD systems have been proposed for clinical applications (Bagchi and Huong, 2017). Murakami et al. (2013) showed that CAD can improve the rates of early detection of tumors in the size range of 1 to 10 mm by correctly identifying 83% of cases (10 out of 12) using full field digital mammography. For tumors larger than 10 mm in size, the sensitivity was increased to 92% (i.e., 129 out of 140). Various methods have been used for this purpose, including segmentation, feature extraction, classification, and similarity measurement.

The most crucial step is feature extraction because the mammograms contain content rich in textures and shapes (Kaur and Doegar, 2019). Therefore, using an appropriate feature extractor is very important, because the classification of the results are dependent on it. In the study by Abubacker et al. (2017), they used discrete wavelet transformation (DWT) and the gray-level co-occurrence matrix (GLCM) as feature extractors. The CAD proposed by Berbar (2017) focused on the feature extraction stage by designing a new hybrid feature extractor in which wavelet and contourlet features for breast mass classification were merged. In the study by Sharma and Khanna (2015), the Zernike of different order was used as a feature extractor and a support vector machine (SVM) was used for the classification of images from the Digital Database for Screening Mammography (DDSM). The study by Mohamed et al. (2014) proposed a CAD system for microcalcification detection in which they used GLCM for the extraction of features in the ROI in combination with different classifiers for the classification, with the SVM classifier providing the best result. In the CAD designed by Mohanty et al. (2019), they used a combination of 2-dimensional block DWT (2D-BDWT) and GLCM. Chougrad et al. (2018) designed a system for breast mass detection in mammograms based on deep convolutional neural networks. The CAD system proposed by Junior et al. (2013) is based on diversity indices (i.e., Shannon-Wiener, Simpson, J, Ed, Buzas-Gibson, Camargo, Hill, McIntosh, Total Diversity, Brillouin, and Berger-Parker), geostatistical indices (i.e., Global Getis, Local Ripley K, Joint-Counte, and Nearest Neighbor), and geometric indices extracted from concave geometries (i.e., eccentricity, circularity, solidity, orientation, circular disproportion, circular density, square density, ring density, and quadratic density) to detect masses using SVM. The images were selected from the mini MIAS database and the DDSM database. Azar and El-Said (2013) used a probabilistic neural network for breast cancer classification. Gray-level first order statistics, GLCM features, and Laws texture energy measures were extracted from the original image.

A segmentation method was proposed by Gao et al. (2010) to identify suspected mass regions in mammograms. Yu and Huang (2010) proposed a wavelet filter to detect the suspicious areas using the mean pixel value. Eltoukhy et al. (2010) used multiscale curvelet transformation coefficients to propose, conduct, and evaluate a supervised classifier for mammograms. Verma et al. (2010) investigated a novel soft clustered-based direct learning classifier which creates soft clusters within a class and learns using direct calculations of weights. Moon et al. (2011) extracted 3-D features for 147 breast cancer cases (76 benign and 71 malignant breast masses), including the texture, shape, and ellipsoid fitting and, based on the segmented 3-D tumor contour, classified the tumors as benign or malignant on the basis of a logistic regression model. They used the Student t test, Mann-Whitney U test, and receiver operating characteristic (ROC) curve analysis for statistical analysis. From the AZ values of the ROC curves, the shape features (0.9138)
were better than the texture features (0.8603) and the ellipsoid fitting features (0.8496) for classification. Elfara and Abuhaiba (2013) proposed the square centroid lines gray level distribution method for feature extraction. Yufeng (2010) used the k-nearest number (KNN) method along with fuzzy c-mean clustering as a classifier.

3. FEATURE EXTRACTION METHODS

In this section, 2 feature extraction methods that are widely used in machine vision, namely pattern recognition and signal processing have been described.

3.1. Haar Wavelet Transformation

Haar wavelet transformation (HWT) is the simplest form of DWT that operates by calculating the sums of and differences between the intensity values (Lim et al., 2001). The cropped image is taken as the input for the process and at each level the algorithm finds 4 coefficients, namely approximation, vertical, horizontal, and diagonal. The process is repeated again for the generation of approximation coefficients. In this study, it was repeated for 5 levels and for the last level coefficients (horizontal, vertical, and diagonal) to form the feature set. Figure 1 shows the first level decomposition of HWT.

![Image](image_url)

**Figure 1.** A 1 level 2-D DWT using HWT

3.2. Discrete Cosine Transformation

Discrete cosine transformation (DCT) is one of the most important methods used in the modern computer applications field, implying that the DCT calculation is a part of many systems. It views an image as the sum of sinusoids of varying magnitudes and frequencies. DCT tries to reduce the number of bits required to represent a signal. The algorithm works by removing redundancy in the signal using equation (Eq.) 1.

\[
FF(u,v) = \frac{1}{\sqrt{MN}} \alpha(u)\alpha(v) \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \cos \left( \frac{2x+1)\pi u}{2M} \right) \cos \left( \frac{(2y+1)\pi v}{2N} \right) 
\]

(Eq. 1)

Where: \(v = (0,1,\ldots,N), u = (0,1,\ldots,M)\)

\(f(x,y)\) is the intensity of the pixel in row \(x\) and column \(y\)

and \((\omega) = \begin{cases} 
\frac{1}{\sqrt{2}} & \omega = 0 \\
1 & \text{otherwise}
\end{cases}\)

4. THE FRAMEWORK

In this section, the proposed CAD system is discussed (Figure 2). First, the images are all processed and then stored along with the extracted textures in the database available for use at later retrieval. The following sections describe the proposed system step by step.
4.1. Image Pre-processing

The images undergo the following 2 stages of image preprocessing (See Figure 3):

1) First, the ROI (the region with the mass in it) is cropped from the image;
2) Second, the images are resized to 128×128 pixels.

4.2. Feature Extraction

In this study, a hybridization of 2 widely used texture transformation techniques, namely HWT and DCT, was proposed. The textures were extracted according to the following steps:

1) First level decomposition was applied, which decomposed the image into 4 subparts, namely HH, HL, LL, and LH;
2) The DCT was applied to the LL subpart of the image with various coefficients;
3) The second level decomposition was applied and again the LL subpart was decomposed into 4 subparts, namely HH1, HL1, LH1, and LL1. The third level decomposition was applied and again LL1 was decomposed into its 4 subparts, namely HL2, LL2, LH1 and HH;
4) The DCT was applied to the LL subpart of the image with various coefficients.

This process was continued until the fifth level of decomposition was reached. In particular, for each image, the 2-D HWT at 5 levels of decomposition was performed, thereby generating 20 subimages (i.e., LL1, HL1, LH1, HH1, LL2, HL2, LH2, HH2, LL3, HL3, LH3, HH3, LL4, HL4, LH4, HH4, LL5, HL5, LH5, HH5). Figure 3 shows the image decomposition for only 3 levels. In terms of how the textural features are derived from such a decomposition, for each of the LL-band subimages, DCT is applied with different coefficients.
4.3. Classification

The images used in this study were of 2 different classes of images, namely malignant and benign mass images. At the classification stage, the images were classified as either a benign mass image or a malignant mass image. For this purpose, 2 different similarity measurements were used in 2 phases for the classification steps, which were city block at the first phase and KNN for the second phase.

4.3.1. City block

The city block is a similarity measurement or distance metric that measures the path between the pixels based on 4 connected neighborhood pixels whose edges touch are 1 unit apart and those that are touching diagonally 2 units apart. The city block distance between 2 points, a and b, with k dimensions is calculated as follows:

$$\sum_{i=1}^{k} |a_i - b_i|$$  (Eq. 2)

For the first phase of the classification, the city block distance is used as a texture similarity measure between the textures of the query images, with the textures of the training images saved in the database using Eq. 2.

4.3.2. K-nearest number

The KNN algorithm is perhaps the simplest algorithm in machine learning. The model only consists of the training data that learns the entire training set and for prediction gives the output as the class with the majority in the ‘k’ nearest neighbors calculated according to some distance metric. For this study, the KNN was used to retrieve the top 5 nearest images, which were calculated according to the city block distance metric, and to choose the class with the highest probability as the result of the query image.

5. EXPERIMENT AND RESULTS

5.1. Data Set

The images used in this study were taken from the mini MIAS database (Suckling et al., 1994). The mini MIAS is a database that provides facilities for researchers that are interested in breast cancer research and is widely used. It contains 322 mammogram images of the breast. There are of 3 classes of images, namely normal, benign, and malignant and on each benign or malignant image, a description is given about the shape, margin, density, and location of the abnormality. A total of 36 images were taken for this study of which 22 contained an image of a benign mass and the other 14 contained images of a
malignant mass. The images are about 1024×1024 pixels in portable gray map format.

### 5.2. Results and Discussion

In this section, the performance of the proposed system is examined. The experiments were conducted extensively and can be classified into the following cases based on the feature extraction process:

1. Extracting features from the LL subband of the first and second level of the HWT after 24 different coefficients of DCT were applied to the LL subband. In addition, the first level of the Haar wavelet is implemented on the whole mass image, and then DCT is applied on the LL subband with different coefficients. This process is repeated for the second level as well. Table 1 presents the average accuracy for the DCT coefficient separately.

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<th>LL1 Malignant</th>
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<tr>
<td>10x10</td>
<td>90</td>
<td>78.571</td>
<td>90</td>
<td>78.571</td>
</tr>
</tbody>
</table>

The results in Table 1 show that the accuracy averages from 5x5 to 7x7 and 8x8 are almost the same and that they are better than the other remaining coefficients.

2. To obtain a better understanding of the impact of the hybrid HWT features with DCT, the third level of the HWT is evaluated by extracting
features from the LL subband of the third level of the Haar wavelet separately before DCT is applied. Table 2 presents the average accuracy for each DCT coefficient on the third LL subband of the Haar wavelet.

<table>
<thead>
<tr>
<th>DCT block size</th>
<th>Benign</th>
<th>Malignant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1×1</td>
<td>75</td>
<td>42.857</td>
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<tr>
<td>2×2</td>
<td>85</td>
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<tr>
<td>4×3</td>
<td>85</td>
<td>64.285</td>
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<td>4×4</td>
<td>80</td>
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<tr>
<td>4×5</td>
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<td>71.428</td>
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<td>71.428</td>
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</tbody>
</table>

As it can be seen from the results of Table 2, the accuracy of the DCT coefficients for 5×5, 6×6, 6×7, 7×6, and 7×7 on the third level of the Haar wavelet showed better results than the rest.

(3) To have a deeper look at the effect of the hybrid Haar wavelet features with DCT, the fourth level of the HWT is evaluated by extracting features from the LL subband of the fourth level, as previously, for the Haar wavelet and before DCT is applied. Table 3 shows the average accuracy for each DCT coefficient on the fourth LL subband of the Haar wavelet.
The results of Table 3 demonstrate that the accuracy of the DCT in the fourth level of the Haar wavelet showed better results than the previous 3 levels of the Haar wavelet.

(4) Finally, the fifth level of the Haar wavelet is evaluated and the DCT coefficient is applied as mentioned in the previous sections with different numbers of coefficients. Table 4 illustrates the accuracy average for each DCT coefficient applied on the fifth level of the Haar wavelet.

<p>| Table 3: Accuracy averages for each DCT coefficient applied on the fourth level of the Haar wavelet |</p>
<table>
<thead>
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<td>71.428</td>
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</tbody>
</table>

<p>| Table 4: Accuracy average for each DCT coefficient applied on the fifth level of the Haar wavelet |</p>
<table>
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</table>
The results shown in Table 4 indicate that the features are not accurate. Because the number of features decreased to such an extent that it was insufficient for comparison with other image features, the accuracy of the results were reduced. From the results of this study, it can be seen that the system achieved the optimum average accuracy in the application of DCT on the fourth level of the LL subband of the Haar wavelet.

5.3. Comparison to Existing Results

Thus far, there is no standardized data set available for mammography that take standardized environmental condition into consideration. This drawback is reflected in the difficulty to compare the proposed approach with other previous studies. However, a comparison with some of the previous studies is presented. In Table 5, the test results of the proposed scheme are compared with the results of Li et al. (2015), Dheeba and Singh (2015), and Ericeira et al. (2013). The results demonstrate that the accuracy in identification achieved with the proposed scheme outcompetes that of the previous studies.

<table>
<thead>
<tr>
<th>Table 5: Comparison between the results of the proposed scheme and those of previous studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
</tr>
<tr>
<td>Li et al., 2015</td>
</tr>
<tr>
<td>Dheeba and Singh, 2015</td>
</tr>
<tr>
<td>Ericeira et al., 2013</td>
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<td>Proposed Scheme</td>
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</table>

6. CONCLUSION

In this paper, a new approach for breast mass identification was presented based on DCT feature extractors in a DWT domain to classify breast mass images into one of 2 groups, namely benign and malignant. A KNN classifier was used to classify the selected feature vector. The proposed approach outperformed the approaches of competitors in previous studies (Li et al., 2015; Dheeba and Singh, 2015; Ericeira et al., 2013). The test results illustrate that the performance of the proposed approach and the average reached 95% accuracy.
REFERENCES


