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Athens Journal of Sciences

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Sinjar Anticline Northwest of Iraq: A Tectonic Geomorphological Study

By Varoujan K. Sissakian[*], *Nadhir Al-Ansari*[±], *Jan Laue*[°] *& Aayda D. Abdulahad*[•]

The Sinjar Anticline (Mountain) is an outstanding structural and geomorphic feature in the northwestern part of Iraq. The anticline is a double plunging with almost E – W trend dividing the gently rolling plain in which it is developed into two parts, Al-Jazira Plain in the south and Rabi'a Plain in the north. The Sinjar anticline is asymmetrical with steeper northern limb (45 – 80)° and gentler southern limb (15 – 25)°, its length is about 80 km, whereas the width ranges between (9.25 – 12. 5) km. The oldest exposed rocks belong to the Shiranish Formation, whereas the youngest rocks belong to the Fatha Formation. Different geomorphological and structural forms were observed through interpretation of satellite images, geological and topographical maps of different scales, beside field observations. Among those forms are: Abandoned alluvial fans, radial, inclined, and cross-shaped valleys, whale-back shape, wind gaps, and parasitic folds. All these forms are good indications about the lateral growth of the anticline. Neotectonic measurements were carried to estimate the rates of upward and downward movements. These estimations were performed by measuring the elevation of the contact between the Fatha (Middle Miocene) and Injana (Late Miocene) formations at different selected locations on both sides of the anticline.

Keywords: *Sinjar anticline, lateral growth, neotectonic movements, wind gap, abandoned alluvial fans*

Introduction

The Sinjar anticline is in the Low Folded Zone (LFZ), which is a part of the Zagros Fold – Thrust Belt (ZFTB). This in turn is a part of the Zagros Foreland Basin, which is developed due to the collision of the Arabian and Eurasian plates (Alavi 2004, Jassim and Goff 2006, Fouad 2015).

The Sinjar anticline (mountain) is an outstanding structural and geomorphological form; developed within a wide and gently rolling plain in the central northwestern part of Iraq. Towards the north is the Rabi'a Plain with elevation ranges between (460 – 515) m, and towards the south is Al-Jazira Plain with elevation ranges between (380 – 440) m. The height of the ground surface decreases westwards in the Rabi'a Plain, whereas in Al-Jazira Plain it decreases eastwards. The Sinjar anticline is about 80 km long and 9.25 km wide in the western part and 12.5 km in

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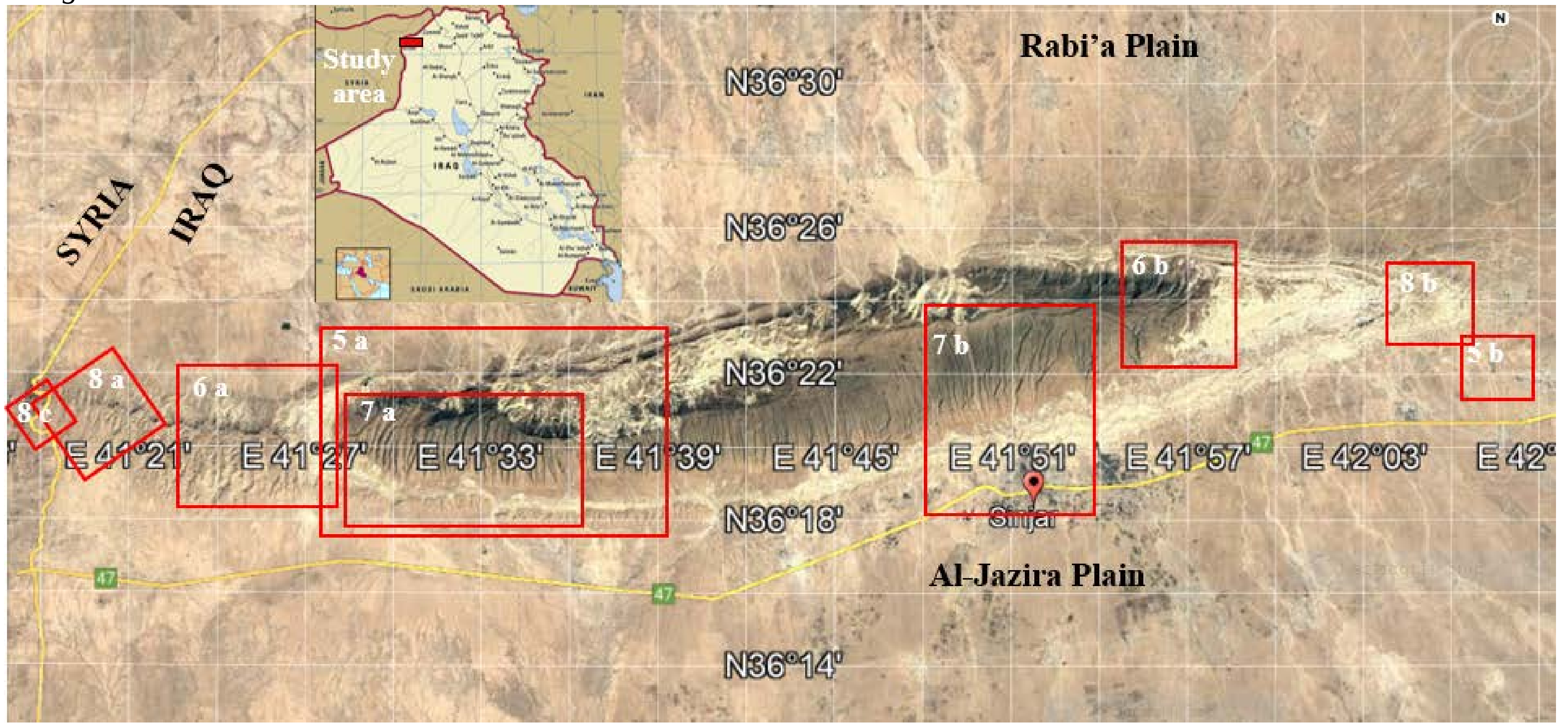
the eastern part. The highest peak is 1421 m (a.s.l.) it is located north of the Sinjar town along the southern limb that extends like a whale-back shape along the whole southern limb of the anticline (Figure 1).

The following works were carried out concerning the Sinjar anticline, majority of the carried-out works have emphasized on the developed alluvial fans on both sides of the anticline: Ma'ala (1977) in Sissakian and Al-Jibouri (2012) performed regional geological mapping of Sinjar anticline and surrounding plains, he described the tectonic, structure, stratigraphy, and geomorphology of the concerned area. Al-Daghastani (1989) mapped Sinjar Anticline and the alluvial fans by means of remote sensing technique. His study was emphasized on the developed alluvial fans along both sides of the anticline. Al-Daghastani et al. (2004) in an attempt of rainwater harvesting have mapped the Sinjar alluvial fans using remote sensing techniques. They have analyzed and classified the landforms to obtain the details about rainwater harvesting, they also prepared a geomorphological map with emphasizing on the alluvial fans. Al-Daghastani and Al-Dewachi (2009) performed a comprehensive geomorphological study of the Rabi'a Plain north of the Sinjar Mountain using remote sensing technique. They concluded that the development of the alluvial fans is related to different episodes of Neotectonic movements. Sissakian (2011) studied the alluvial fans of Sinjar anticline, which are developed along both sides of the anticline, he recognized five stages of alluvial fans, the fifth being in Syria. He also confirmed that the five stages are separated from each other due to Neotectonic activities. Fouad (2012) studied tectonically the Low Folded Zone where the Sinjar anticline is developed. He mentioned that most of the folds are structural highs above earlier structural lows, and consequently they are considered as inversion structures. Moreover, he added that structural analysis of tectono-stratigraphic sequences in Mosul region indicate that the folds have had formed in two distinct episodes; an early Campanian – Maastrichtian episode of extension and rift formation, followed by Pliocene – Pleistocene episode of compression and fold formation.

Figure 1. *Satellite Image of the Sinjar Anticline, Note the Whale-back Shape and the Developed Alluvial Fans, Especially Along the Northern Limb*



Note: The red rectangles are the locations of the presented figures in the text with their serial numbers.

The studied area is in the northwestern part of Iraq. It includes the whole Sinjar anticline and parts of the surrounding plains (Figure 1). The coverage area is about 200 km^2.

This study aims in describing the tectonic and geomorphological development and existing forms of the Sinjar anticline. Moreover, to estimate the rates of upward and downward Neotectonic movements in the concerned area.

Materials and Methods

Geological and topographical maps of different scales and satellite images were used to conduct the current study. From the visual interpretation of satellite images, different geomorphological forms were recognized, such as abandoned alluvial fans, radial, inclined, cross-shaped, and fork-shaped valleys, wind gaps, all these forms are indications for the lateral growth of anticlines (Burbank and Anderson 2001, Keller and Pinter 2002, Ramsey et al. 2008, Fossen 2010, Collingnon et al. 2016).

For estimating the rates of the upward and downward movements as Neotectonic movements, we have used the method, which depends on the elevation and/ or the depth of the contact between Middle and Late Miocene rocks from the present topography (above the sea level), which is the same concept of Obruchev (1948) and adopted by ATOMENERGOEXPORT (1985) and is confirmed by Pavlides (1989) and Koster (2005). The upwards and downwards movements were presented by means of contour lines, which mark the up warded and down warded areas as the Neotectonic Phase has started from the Upper Miocene Period (Obruchev 1948). The elevation of the contact between the Middle Miocene Fatha Formation (Marine sediments) and the Upper Miocene Injana Formation (Clastic continental sediments) represents the beginning of the Neotectonic Phase in Iraq (ATOMENERGOEXPORT 1985). This is attributed to the change of the marine environment to continental, due to the collision of the Arabian and Eurasian plates. The elevations of the concerned contact (above sea level) were indicated either from topographic maps (at a scale of 1:100000) or from the Google Earth images. The indicated elevations represent the amount of the upwards Neotectonic movements. In areas covered by the Injana Formation, the depths of the contact (below the surface) were indicated either from existing wells, cross sections and/ or by subtracting the average thickness of the Injana Formation from the height of a certain point from the surface elevation at the concerned point. The result is the depth of the contact between the Fatha and Injana formations; accordingly, will represent the downward amount of the Neotectonic movement.

For recognizing Neotectonic evidences and lateral growth of the Sinjar anticline we have used the opinions of many researchers: Rockwell et al. (1985), Pavlides (1989), Becker (1993), Cartwright et al. (1995), Dawers and Anders (1995), Kumanan (2001), Cloetingh et al. (2002), Blanc et al. (2003), Décallau et al. (2006), Koster (2005), Bretis et al. (2011), Mumipour and Najad (2011), Skilodimou et al. (2014), Burberry (2015) Gurpuz and Saein (2019).

Geological Setting

The geological setting of the studied area is briefed including tectonics and structural geology (Fouad 2015), Geomorphology (Yacoub et al. 2012), and Stratigraphy (Sissakian and Al-Jibouri 2012), and Neotectonics. The geological map of the Sinjar anticline is presented in Figure 2.

Tectonics and Structural Geology

The studied area is in the Low Folded Zone (LFZ), which belongs to Outer Platform of Iraq (Fouad 2015). The LFZ is a pert of the Zagros Fold – Thrust Belt, which is developed due the collision of the Arabian and Eurasian plates (Alavi 2004, Fouad 2015). The Sinjar anticline is 80 km long and 20 km wide, almost trending E – W, with steeper northern limb (45 – 80)° and gentler southern limb (15 – 25)°. A normal fault trending E – W runs along the northern limb; many other small faults occur too (Figure 2). Locally, along the southern limb a low amplitude anticline occurs, it is developed within the Sinjar Formation with a length of about 15 km and separated from the main axis of the Sinjar anticline with a shallow syncline (Figure 2).

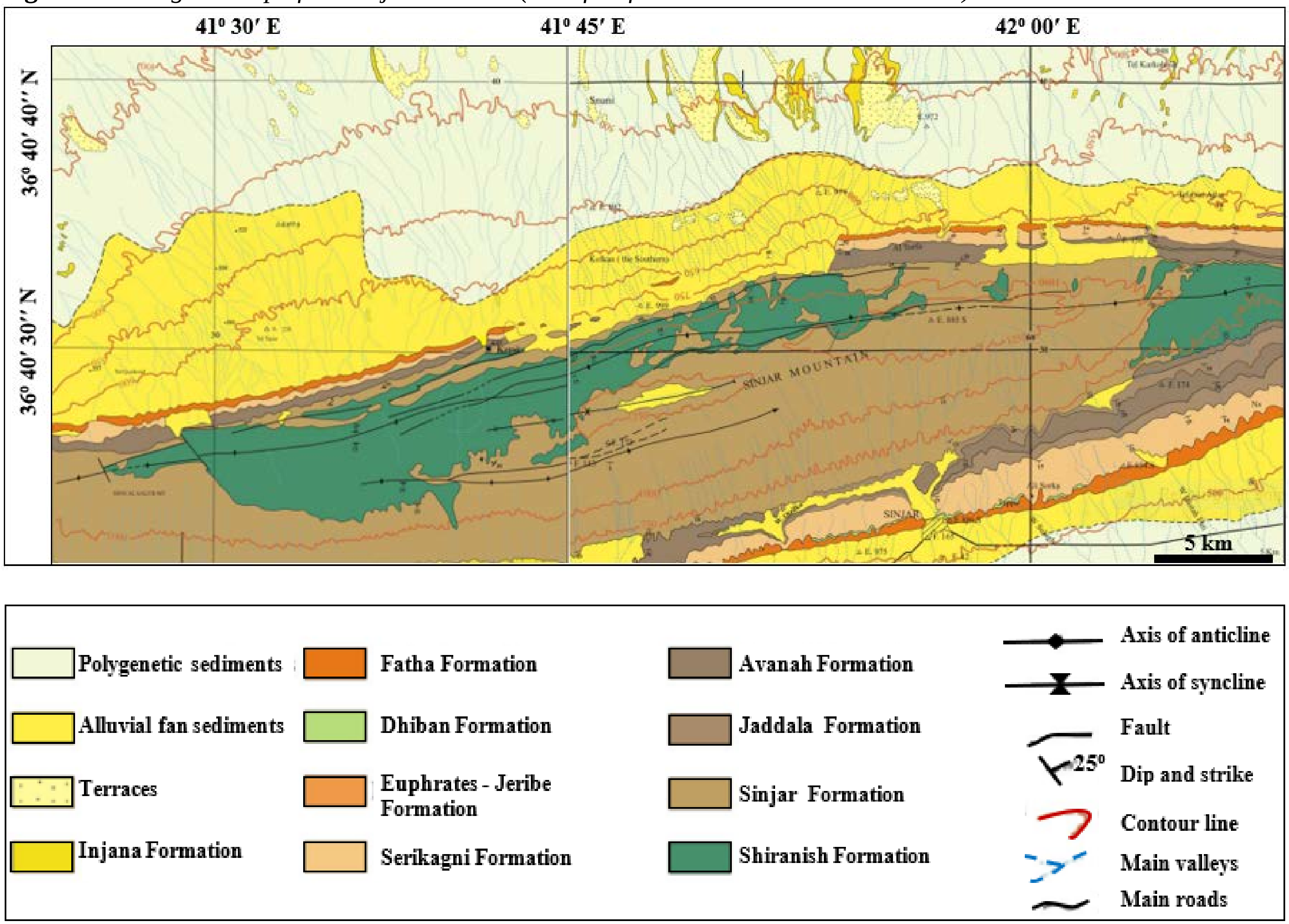
Stratigraphy

The exposed rocks in the studied area range in age from the Late Cretaceous, represented by the Sinjar Formation up to Late Miocene, represented by the Injana Formation (Sissakian and Al-Jibouri 2012). A generalized columnar section of the exposed formations is represented in Table 1.

Table 1. *Generalized Columnar Section of the Exposed Formations in the Studied Area (Red Line Represent Unconformity) (After Sissakian and Al-Jibouri 2012)*

Formation	**Age**	**Thickness (m)**	**General Description**
Injana	**Late Miocene**	**900 – 100**	Sandstone interbedded with siltstone and claystone in rhythmic cycles, all rocks are reddish-brown in color
Fatha	**Middle Miocene**	**550 – 630**	Green marl interbedded with limestone and gypsum in rhythmic cycles, in the upper cycles, reddish brown claystone occurs.
Jeribe		**100 – 125**	Well bedded greyish white limestone
Dhiban	**Early Miocene**	**5 – 100**	Mainly limestone with rare limestone
Serikagni		**65 – 300**	Well bedded white limestone with some marl intercalations
Avanah	**Middle Eocene**	**85**	Marly limestone interbedded with marl
Jaddala		**500 – 550**	Marl interbedded with marly limestone
Sinjar	**Early Eocene- Late Paleocene**	**170**	Well bedded, white and very hard limestone
Aaliji		**50**	Shale and marl
Shiranish	**Late Cretaceous**	**565**	**Bluish green, papery marl, in the upper part well bedded greyish white limestone in the lower part**

Figure 2. *Geological Map of the Sinjar Anticline (Modified from Sissakian and Fouad 2015)*



Geomorphology

The study area is within the Low Amplitude Mountainous Province (Sissakian and Fouad 2015). Apart from the Sinjar Mountain (anticline), the surrounding areas form flat terrain dissected by dense valleys, which flow dong from the mountain. The highest point is 1462 m, on the top of Sinjar Mountain, whereas the lowest point is about 300 m, in the southeastern part of the study area.

Geomorphological Units

The following geomorphologic units are developed in the studied area:

A. Units of Denudational Origin

- **Pediments:** These units are well developed on both sides of the Sinjar Mountain and along the main scarps. The thickness ranging from (1 – 5)m.
- **Dissected Slopes:** These are developed around the Sinjar Mountain; near both flanks with thickness ranging from (1 – 12) m.
- **Polygenetic Sediments:** These sediments are mainly of fine clastics and cover vast parts of the flat areas of Al-Jazira and the Rabee'a plains.

B. Units of Structural – Denudational Origin

- **Hogbacks and Cuestas:** These are developed on both sides of the Sinjar anticline, within the exposures of the Sinjar and Serikagni – Jeribe formations.
- **Anticlinal Ridges:** These are well developed around Sinjar anticline, especially within the Sinjar Formation; especially in the southern limb.

C. Units of fluvial Origin

- **Alluvial Fans:** These are well developed around Sinjar anticline; in (2 – 5) stages. The older stage rests directly on the Fatha and Injana formations (Figure 2). They cover many square kilometres (each one) and are composed of limestone gravels; up to 1 m in size, the size decreases in the younger stages. The thickness of each stage ranges from (3 – 10) m. Locally, they interfere with the dissected slopes and terraces.

D. Forms of Solution Origin

- The main form of solution origin is the sinkholes, which are developed in Sinjar Mountain, within limestone and gypsum. They are of different shapes, forms and dimensions, some caves also are present in the Sinjar Mountain.

Mass Movements

The main phenomenon in the study area is the toppling, where blocks of hard carbonate rocks of different formations are toppled on the back slopes. The blocks range in size from less than one cubic meter up to 3 m^3. Landslides are rare, they are developed along the southern limb of the Sinjar anticline due to steep deep, especially along the Sinjar Formations. Rock fall, flow, and other mass wasting phenomena can be seen at different parts of the anticline.

Neotectonic Movements

We have constructed a Neotectonic map (Figure 3), which shows the up-warded and down-warded areas, as Neotectonic activities are concerned. The presentation is in form of contour lines, the contours are drawn as mentioned in Section "Materials and Methods". Such presentation is confirmed by ATOMENERGOEXPORT (1985), Pavlides (1989), Koster (2005), and in Iraq by Deikran and Sissakian (2008) and Sissakian and Deikran (2009).

Results

From manual interpretation of satellite images, and geological and topographical maps, we have recognized the following forms. All interpreted forms are excellent indications of the lateral growth (Rockwell et al. 1985, Burbank and Pinter 1999, Burbank and Anderson 2001, Keller and Pinter 2002, Ramsey et al. 2008, Decallau et al. 2006, Bretis et al. 2011, Burtscher et al. 2012, Grasemann and Schmalholz 2012, Collingnon et al. 2016).

Abandoned Alluvial Fans

The Sinjar anticline is a very well known to have tens of alluvial fans developed along its both limbs. However, many of them are abandoned and the recent valleys are already dissecting them (Figure 4b). The dissected alluvial fans are good indications that they are abandoned, and no more sediments are supplied; therefore, indicate the lateral and vertical growth of anticlines (Burbank and Anderson 2001, Keller and Pinter 2002, Ramsey et al. 2008).

Wind Gaps

At many parts of the Sinjar anticline, wind gaps are developed (Figure 4a). They indicate the lateral and upward growth of the anticline (Burbank and Anderson 2001, Keller and Pinter 2002, Ramsey et al. 2008).

Figure 3. *Satellite Image of Sinjar Anticline Showing the Locations of the Points Where up-ward and Down-ward Movements were Measured, and the Constructed Contour Lines*

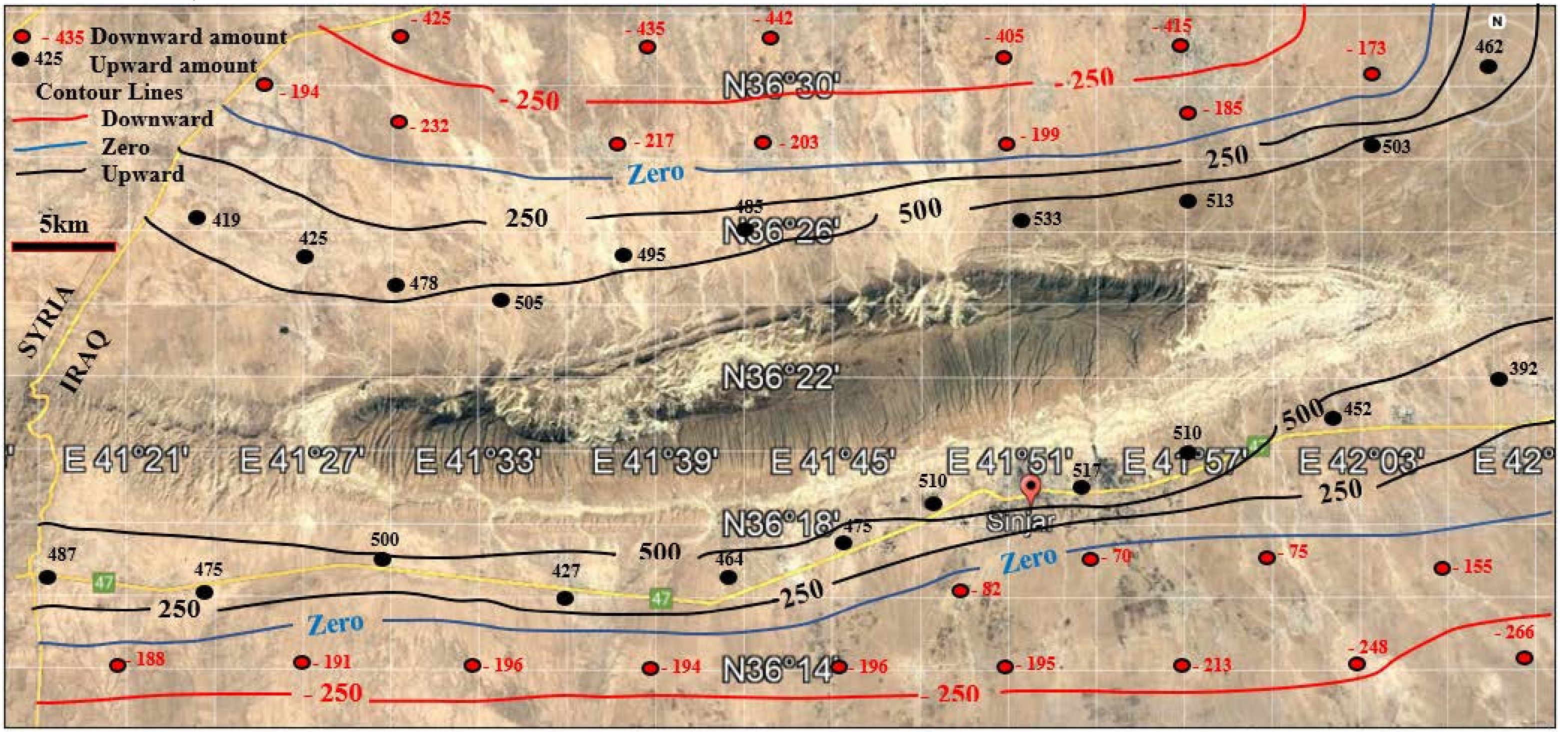
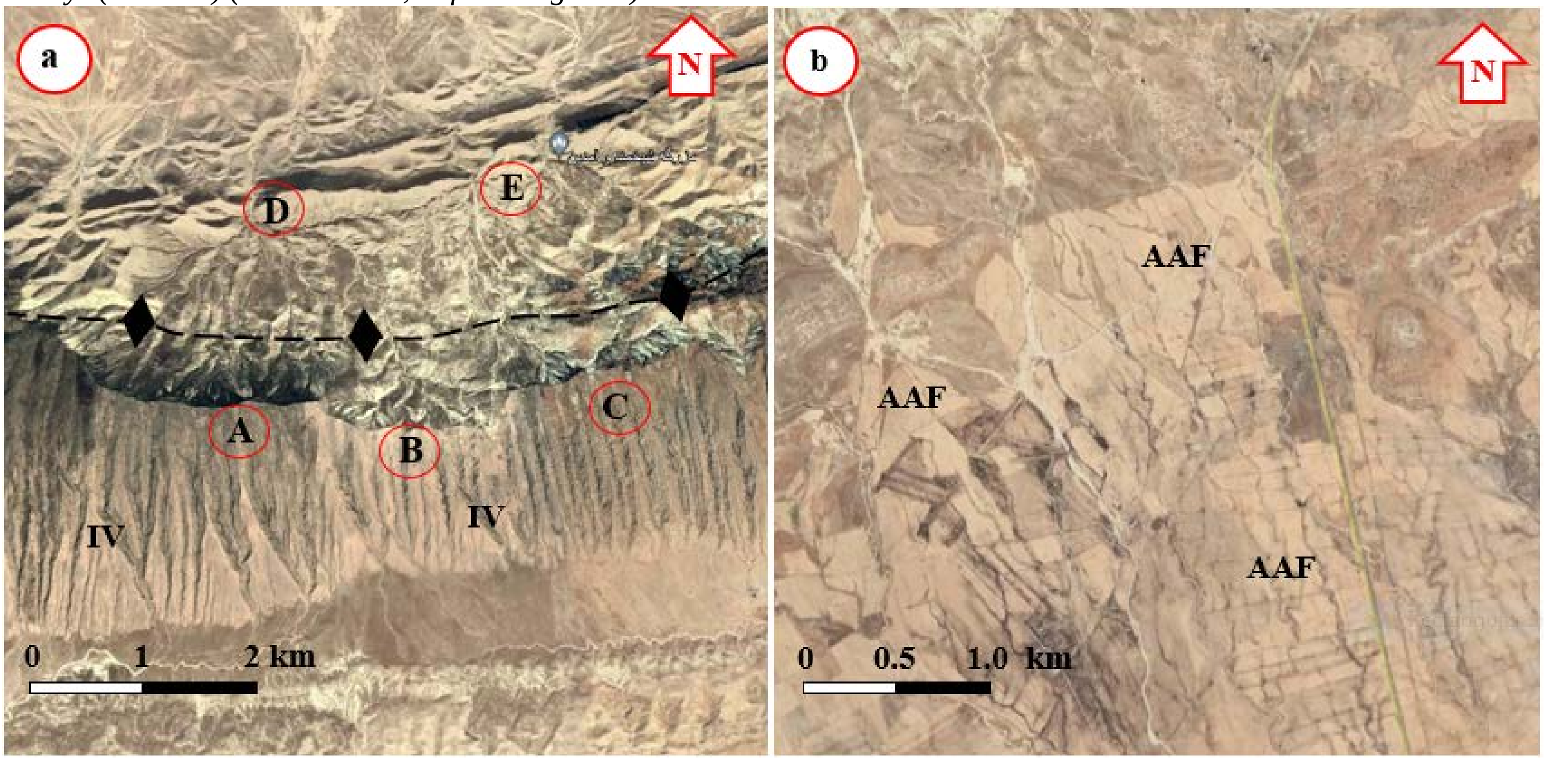


Figure 4. *Satellite Images of Interpreted Forms, a) Wind Gaps, Note the Valleys which Run from A, B,C to D and E, Inclined Valleys (IV), b) Abandoned Alluvial Fans (AAF), Note the Abandoned Feeder Channels (in Black) and the Recently Dissecting Valleys (in White) (For Location, Refer to Figure 1)*



Different Shaped Valleys

Different shaped valleys are developed within the Sinjar anticline, like radial, axial, cross, inclined (Figures 5 and 6). They all are good indications for the lateral growth of the Sinjar anticline (Burbank and Anderson 2001, Keller and Pinter 2002, Ramsey et al. 2008).

Whale-back Shape

The Sinjar anticline exhibits typical whale-shape (Figures 1, 3 and 6). Although parts of the anticline are eroded, especially along the northern limb; however large parts of the anticline still exhibit whale-back shape with clear erosional ridges (Figure 6). According to Burbank and Anderson (2001), Blanc et al. (2003), Fossen (2010) some anticlines can exhibit anomalous structural shapes, among those shapes is the whale-back, which is also a good indication for the lateral growth of the Sinjar anticline. The presence of whaleback anticlines is a good indication that the decollement is shallow (Sepehr and Cosgrove 2005, Burberry et al. 2010).

En-echelon Plunge

The en-echelon plunges are good indication for the lateral growth of anticlines (Keller and Pinter 2002, Ramsey et al. 2008, Fossen 2010). In the bulk of the Sinjar anticline (Figure 2), many en-echelon plunges can be observed indicating the lateral growth of the anticline.

Domes

In the bulk of the Sinjar anticline many small domes along the axial part can be observed (Figure 2). The presence of domes along any anticline may indicate that previously each dome was a distinct anticline and due to the lateral growth, they are joined together (Campbell 1958, Fossen 2010, Grasemann and Schmalholz 2012).

Neotectonic Movements

The constructed Neotectonic map of the studied area (Figure 3) shows that all the contour lines run almost parallel to the Sinjar anticline. However, there are slight deviations, these are attributed to the accuracy of the measured height of the point where the upward and/or downward calculations were done. Moreover, the used thickness of the Injana Formation and the overlying Quaternary sediments also contributes to such abnormalities.

Figure 5. *Satellite Images of the Sinjar Anticline, a) The Western Plunge, b) The Eastern Plunge. Valleys: AV= Axial, RV= Radial, CV= Curved, IV= Inclined, F – F is a Normal Fault, the Plunge Direction is the Down Thrown Side (For Location, Refer to Figure 1)*

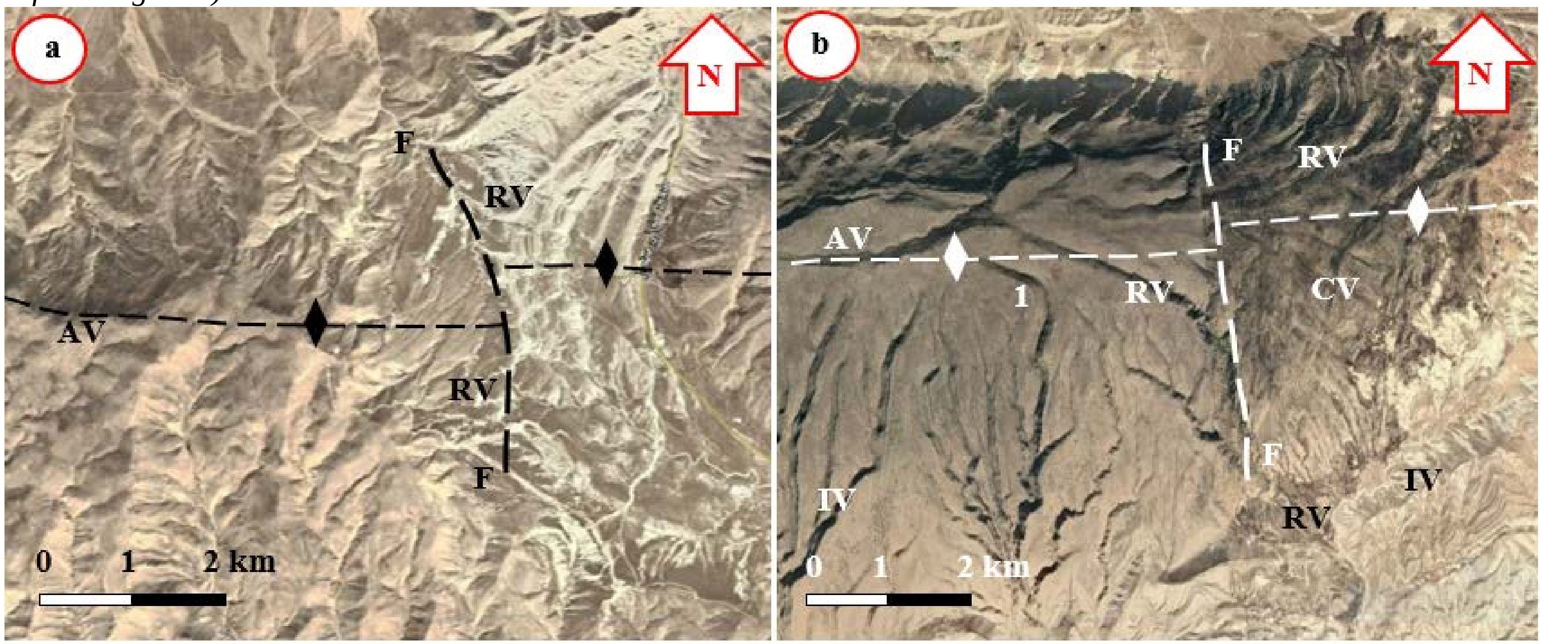
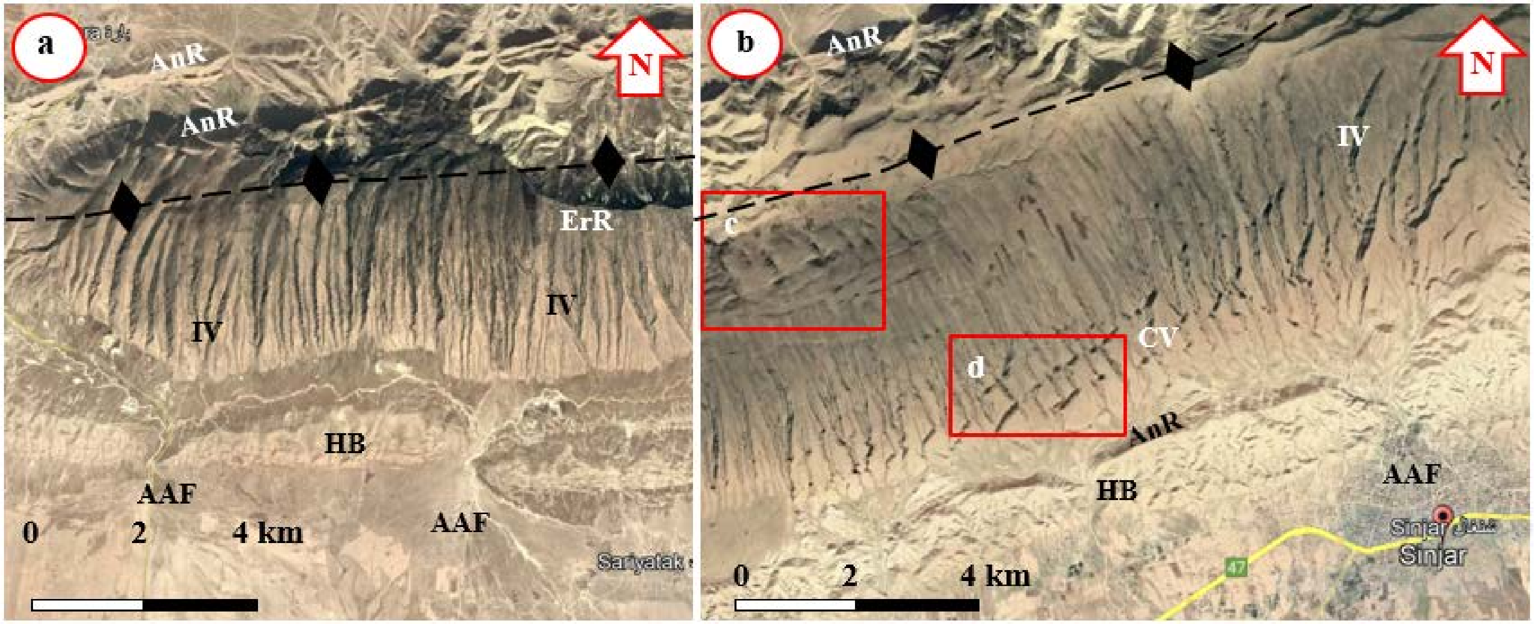
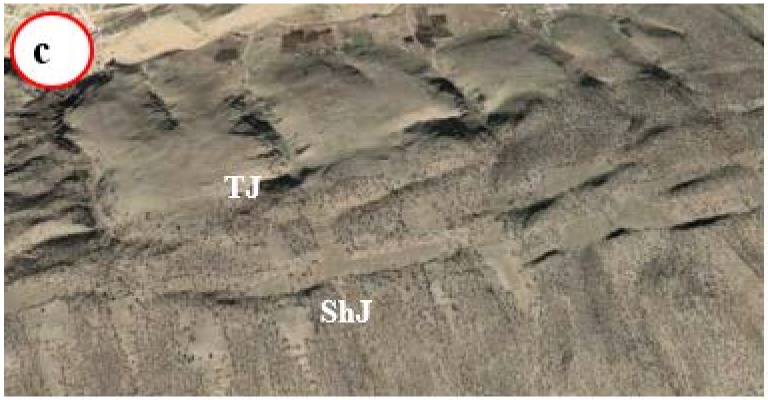


Figure 6. *Satellite Images of the Sinjar Anticline Showing Whale-back Shape, a) Western Part, b) Eastern Part, c and d) Tension Joints (TJ) and Shear Joints (ShJ). AAF= Abandoned Alluvial Fan, HB= Hogback, AnR= Anticlinal Ridge, ErR= Erosional Ridge. Valleys: CV= Cross-shaped, IV= Inclined (For Location, Refer to Figure 1)*




c
TJ
ShJ


d
ShJ
TJ

Discussion

The Sinjar anticline is an outstanding high amplitude anticline in the Low Folded Zone of the Outer Platform of the Arabian Plate, it is also part of the Zagros Fold Thrust Belt (Alavi 2004, Fouad 2015). The oldest exposed rocks in the core of the anticline belong to the Shiranish Formation of the Upper Cretaceous age (Sissakian and Fouad 2015); it is the second anticline (after Qara Chough anticline) within the Low Folded Zone with the Cretaceous rocks in the core.

The Sinjar anticline is an inverted graben (Fouad 2009, 2015) as many other southerly existing subsurface folds in the Jazira Plain, like Tayarat anticline (Fouad 2009). The inversion process has increased the deformation of the anticline, besides the lateral growth, which is a characteristic feature of most of the anticlines in the IKR (Ghafur et al. 2019, Sissakian et al. 2018 2020, 2021). Moreover, it has caused the Cretaceous rocks to be exposed in the core of the Sinjar anticline.

The intense structural deformation is clear along the southern limb of the Sinjar anticline (Figure 6), where the thick carbonate rocks of the Sinjar Formation form most of the limb. Although the northern limb is steeper than the southern limb, but the deformation is not clear. This is attributed to the type of the exposed rocks on both limbs and relief differences.

The long (2.6 – 3 km) steep, narrow and vertical valleys cross the anticlinal axis of the Sinjar anticline (Figure 6a) and run southwards. These valleys are most probably shear joints (Figure 6c and d), which are enlarged by gulley erosion and weathering. However, some of them, which run southwards directly crossing the anticlinal axis, they may represent water gaps which are abandoned due to the lateral and upward movements of the anticline.

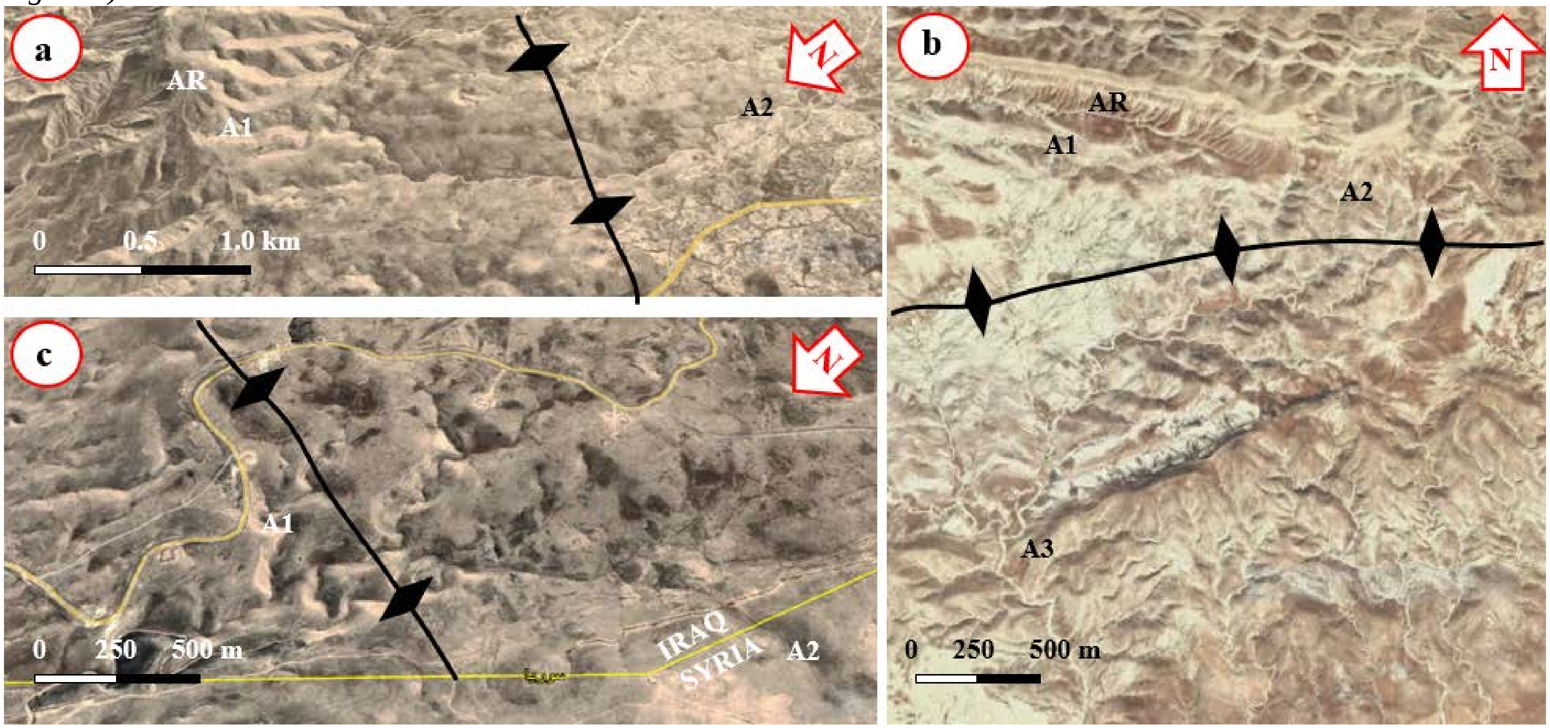
The constructed Neotectonic map (Figure 3) shows that the maximum upward amounts along the northern and southern limbs of the Sinjar anticline are 533 m and 517 m, respectively. Whereas the maximum downward amounts along the northern and southern limbs are - 405 m and - 266 m, respectively. The downward amounts along the northern limb are higher than those along the southern limb, this is attributed to: 1) Northern limb is steeper than the southern one, 2) There are many normal step faults parallel to the northern limb (Sissakian 2011), which increased the depth to the contact between the Fatha and Injana formations, and 3) The normal faults are active and continuously increasing the depth of the down thrown block; as indicated from the developed five stages alluvial fans (Sissakian 2011).

The interpreted geomorphological forms like different shaped valleys, abandoned alluvial fans, hogbacks are recognized only along the southern limb (Figures 4 and 5). This is attributed to the exposures of the hard carbonate rocks of the Sinjar Formation, and gentler dip as compared with the steep dipping beds along the northern limb.

Water gaps are also recognized along the western and eastern parts of the anticline only (Figure 7). This attributed to the exposure of the very hard carbonate rocks of the Sinjar Formation along the southern limb, where they form the bulk of the Sinjar Mountain, which is in whale-shape (Figure 6a and b). Moreover, the valleys run southwards just at the beginning of the anti-dip slopes of the northern limb (Figure 7a, b and c, Points A1 – A2 – A3). This attributed to the steeply dipping hard rocks, which form anticlinal ridges (Figure 7a and b, Point AR), where the valleys cannot cross the ridges. However, by continuous erosion and lateral growth of the Sinjar anticline, the valleys will be able to cross the developed anticlinal ridges.

The last recognized geomorphological form is the intense karstification of the exposed rocks of the Fatha Formation at the extreme western part of the Sinjar anticline within the study area (Figure 7c). This is attributed to the exposures of the gypsum and limestone beds within the Fatha Formation, which is characterized by intense karstification (Yacoub et al. 2012).

Figure 7. *Satellite Images of the Sinjar Anticline, a and c) The Western Plunge Area, b) The Eastern Plunge Area. Note the Water Gaps and the Intense Karstification in the Extreme Western Part of the Anticline (Caption c) (For Location, Refer to Figure 1)*



Conclusions

The Sinjar anticline shows clear structural and geomorphological indications for its lateral growth. Among those indications are water gaps, wind gaps, abandoned alluvial fans, different-shaped valleys, domes, plunges. The calculated Neotectonic movements indicate that the amount of the maximum upward movement along the northern and southern limbs of the anticline are 533 m and 512 m, respectfully. Whereas the maximum downward movements along the northern and southern limbs are – 405 and – 266 m, respectfully.

Acknowledgments

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Analysis of Air Temperature Trends as a Climate Change Indicator for Alexandria (Egypt)

By Tarek M. El-Geziry[*]

This work provides the results of the analyzed long-term trends for three air temperature categories, namely: average (T_{avg}), maximum (T_{max}) and minimum (T_{min}) on monthly, annual and seasonal bases for Alexandria. The aim was to examine possible climate changes in this famous City based on the results obtained from the analyzed trends. The study was based on examining (1) linear regression approaches, (2) trend magnitudes, (3) Mann-Kendall trend test and (4) extreme air temperature events. The air temperature data from Alexandria International Airport station were used over a period of 65 years (1957-2021). For all analyzed time series, the results showed statistically significant positive trends. The exception was for the monthly mean T_{max} during January, February and December (negative trends), and March (No trend). The H1 hypothesis prevails for the three temperature categories, on different basis. Over the period of investigation, both the annual mean T_{avg} and T_{min} rose at a rate of +0.02 °C/yr, while annual mean Tmax rose at a rate of + 0.008°C/ yr. In winter, the annual mean T_{avg} and T_{min} had increasing trends at a rate of +0.02 °C/yr. The winter T_{max} had a feeble increasing trend (almost constant), at a rate of only +0.0003 °C/yr. In summer, the three air temperature categories increased at a rate of +0.02 °C/yr, each. Extreme air temperature times were specified in this study on all bases for the three temperature categories. The findings of this study are thought to be a reliable indicator of the presence of climate change in Alexandria.

Keywords: *Alexandria, air temperature, climate change, trend analysis, extremes*

Introduction

The term ‘climate change’ refers to the alteration in the conditions of the climate brought on by long-lasting changes to one of its characteristics, generally lasting decades or longer (Masson et al. 2021).

Latitude, altitude, the tilt of the Earth's axis, temperature differences between land and sea, and topography all have a significant impact on the Earth's climate (Thapa et al. 2021). A growing body of scientific evidence suggests that the atmosphere of the earth has altered over time, signaling that the globe is warming (Masson et al. 2021; Thapa et al. 2021). Various anthropogenic activities that generate pollutants are mostly to blame for this change, with natural causes playing a smaller role (Jonathan and Raju 2017). Many indicators of climate change are evident around the world. This comprises but not limited to higher air temperatures, more drier areas, wilder weather with significant changes in rainfall patterns, increased ocean acidity, warmer seas, and quicker rates of sea-level rise (El-Geziry 2021; Tonbol et al. 2018).

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The most visible evidence of climate change is the significant rapid increase in air temperature observed in recent decades around the world (Arghius et al. 2020).

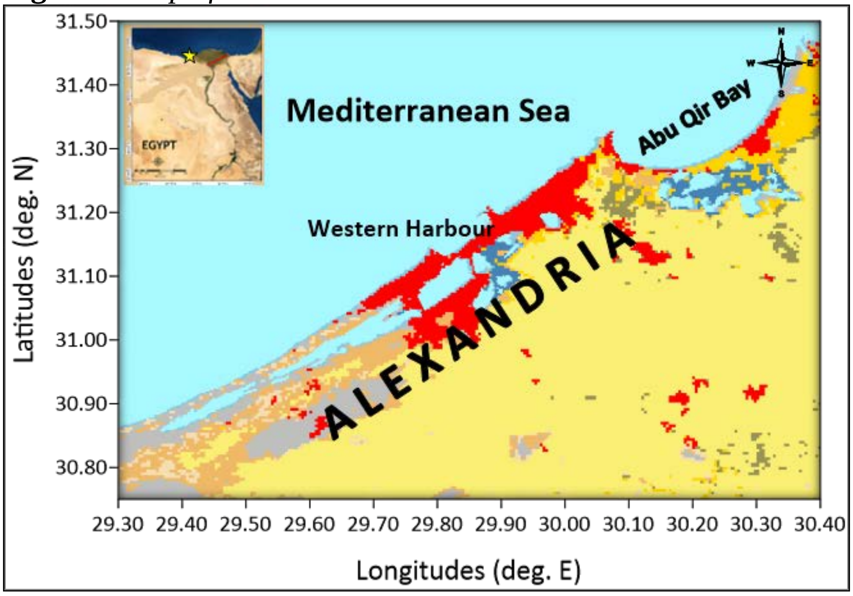
According to the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC 2013), global surface temperature data calculated using linear trend showed a 0.85 °C warming from 1880 to 2012. However, the spatiotemporal distribution of the increase in global air temperature is not uniform on Earth. The rise in air temperature varies by region, with the northern hemisphere experiencing a greater increase in air temperature (Bačević et al. 2020). Rising air temperatures may have various effects on various aspects of human life, particularly on human settlements, agricultural products, energy consumption, environmental and social processes and so on (Bonacci et al. 2021; Piticar and Ristoiu 2014). Temperature variations are significant for understanding the overall climatic structure (Atilgan et al. 2017) as well as determining the best planning adaptation techniques in a given area (Marin et al. 2014).

Several studies have looked at the temporal variability of temperature at various temporal and regional scales over the previous few decades, confirming a significant warming in the Middle East and North Africa (Eid et al. 2019; El Kenawy et al. 2015; 2009; Fontaine et al. 2013; Paeth et al. 2009). The air temperature trends and data from eight meteorological stations in the eastern Mediterranean basin were analyzed by Hasanean (2001), who found strong positive trends in Malta and Tripoli, and negative trends in Amman. Türkeş et al. (2002) examined mean, maximum, and minimum air temperature data in Turkey from 1929 to 1999. Their findings revealed patterns of variations in the long-term trends with time and locations, transition points, and crucial warming and cooling cycles. Maiyza et al. (2011) examined the changing behaviour of the mean monthly air temperature anomalies within the Levantine Basin and revealed a general decrease of 0.01 °C/yr from 1958 to 1990. They also came to the conclusion that the 70-year cycle has been one of the most important contributors to climate change in the southeast Mediterranean region after examining variations in air temperature, hydrography, and the phenomena of River Nile droughts. The Southern Levantine Basin's mean annual and monthly air temperature fluctuations and trends between 2007 and 2016 were examined by Tonbol et al. (2018). The hottest year in the area, according to their research, was 2010, while the coldest was 2011. Additionally, a general trend of rising mean monthly air temperature anomaly was revealed. Ibrahim et al. (2021) concluded that the frequency trend of marine heatwaves (MHW) in the eastern Mediterranean has increased by 1.2 events/decade between 1982 and 2020.

Egypt is regarded as one of the most susceptible countries to the long-term effects of climate change, which are exacerbated by an increase in the frequency and severity of extreme weather events. Egypt's water shortage is anticipated to worsen due to global warming, which will also spread to the semi-arid area and increase the strength and frequency of maritime storms (El-Geziry 2021). According to Zaki and Swelam (2017), Egypt has experienced regional changes in floods, droughts, and wildfires, as well as more intense and prolonged heat waves and less frequent and intense cold waves. A succession of heat waves have devastated the entirety of Egypt, with the heat waves of 2010 and 2015 killing over a hundred people who were exposed to extremely high temperatures that persisted for days, not just during the day but also at night (Mostafa et al. 2019). According to the results of Eid et al. (2019), seasonal and annual values of temperature exhibited a significant trend of increase over Egypt through the period 1960-2016.

Alexandria of Egypt is an ancient and important historical metropolis and cosmopolitan city on the Mediterranean coast. The City extends between latitudes 30.70°–31.34° N and longitudes 29.40°–30.10° E (Figure 1), and hosts 40% of Egypt's industrial activities (Abdel-Shafy et al. 2010; Abou-Mahmoud 2021). The coastline of Alexandria extends for about 75 km from Al-Hammam (west) to Abu Qir (east) (Abou-Mahmoud 2021). The City, which is one of the UNESCO world heritage sites, faces the risks from climate change, seen in so many phenomena: sea-level rise associated with flooding and erosion, increased air temperature, altered rainfall patterns, etc.

Figure 1. *Map of Alexandria*



Source: Author by using Surfer16® Software.

According to Hendy (2018) and Said et al. (2012a), Alexandria has only two seasons: a hot summer from April to September and a mild winter from October to March. The differences between seasons are primarily due to variations in daytime temperature and wind patterns. The average annual air temperature ranges from 14.0 °C in winter to 30.0 °C in summer (Hendy 2018; Mohamed and Beltagy 2009). Said et al. (2012b) determined an increasing rate of about 0.6 °C/decade in the mean annual air temperature in Alexandria over the period from 1979 to 2011. The City had three heatwaves in 1999, with temperatures exceeding historical averages on five days in April (> 26–30 °C), seven occasions in August (> 30 °C), and five occasions in November (>26 °C) (Said et al. 2012a). Tonbol et al. (2018), on the other hand, examined the air temperature behavior at Alexandria from 2007 to 2016 and found that Alexandria had a severe cold wave in winter 2010, when the observed air temperature dropped from 22.2 to 8.8 °C, over a 5-day period from December 11 to 15, 2010. El-Geziry (2021) calculated a mean annual air temperature of 20.8 °C for Alexandria over the period 1980-2019 and concluded a general trend of increase of 0.04 °C/yr (0.4 °C/decade) over the same period. He also showed that this rate varied from cold to warm seasons, being 0.08 °C/yr and 0.06 °C/yr, respectively.

The examination of extended records of meteorological data yields useful information, which aids in achieving a quantitative understanding of these two interrelated goals (Mohamed and Beltagy 2009). The study of temperature fluctuations is an indicator of climate change in the important city of Alexandria, with the goal of assisting decision-makers, interested in human services and development, in presenting projects that limit the problems with it. Therefore, the primary goal of this research is to investigate temperature variability, detect significant trends, and assess its increase over the last 65 years (1957-2021).

Data and Methods of Analysis

This study used data for average (T_{avg}), maximum (T_{max}) and minimum (T_{min}) air temperatures, on a monthly, annual and seasonal basis, recorded at the Alexandria International Airport Meteorological Station No. 62318 (31.22° N; 29.94° E) at 2 m below the mean sea level. The data covered 65 years of records from January 1957 to December 2021, with 0% missing data. The data was downloaded from the website: https://en.tutiempo.net/climate/ws-623180.html.
The obtained data sets were subjected to four types of analysis, as follows:

1. Linear Regression

Linear regression is a parametric criterion for determining the relationship between two or more dependent and independent variables that are linked by a causal relationship. With a 95% confidence interval, this test determines whether a linear relationship and trend exist between variables (Atilgan et al. 2017; Singh et al. 2015). Equation 1 depicts the linear regression equation:

$$Y = a + b\,X \qquad (1)$$

Where Y is the dependent variable (here is the air temperature), a is the slope coefficient, b is the interception and X is the independent variable (here is the time).

The linear regression test's significance is determined using a 95% confidence interval and a Student t-test (significance levels such as 5%, 1%) (Atilgan et al. 2017; Sneyers 1990).

2. Trend Magnitude

The slope size determines the value of the air temperature trend. There are three scenarios to consider: The trend is positive if the slope size is greater than zero; no trend if the slope size is equal to zero; and negative if the slope size is less than zero. The trend magnitude is calculated using the trend equation (Bačević et al. 2020; Gavrilov et al. 2015).

$$\Delta y = y(1957) - y(2021) \qquad (2)$$

Where Δy is the trend magnitude in degrees Celsius, y (1957) is the air temperature's value at the start of the period, and y (2021) is the air temperature's value at the conclusion of the period. There are three different options when it comes to trend magnitude: a) the trend is negative when Δy is greater than zero; b) when Δy is less than zero, the trend is positive; and c) when Δy is equal to zero, no trend exists.

3. Mann-Kendall Test

The Mann–Kendall (MK) test is a non-parametric test used to identify trends in time series data. It is one of the best methods for analysis that determines statistical significance through hypothesis testing. The MK trend test is used in long-term temporal data to detect statistically significant decreasing or increasing trends. This test is based on two hypotheses: the null (H_0) hypothesis, which assumes that there is no trend (the data are independent and randomly ordered), and the alternate (H_1) hypothesis, which elucidates significant rising or declining trends in data. The non-parametric MK test yields more accurate and reliable results than parametric tests (Kale 2017). The statistic formulas of MK test are given in the following Equations:

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn\ (x_k - x_i) \qquad (3)$$

Where the time series x_i is from i = 1, 2, ..., n-1, x_k is from k = i + 1, ..., n and n here is the number of months/years.

$$sgn(x_k - x_i) = \begin{cases} +1 & if\ (x_k - x_i) > 0 \\ 0 & if\ (x_k - x_i) = 0 \\ -1 & if\ (x_k - x_i) < 0 \end{cases} \qquad (4)$$

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\,(t_p - 1)(2t_p + 5)\right] \qquad (5)$$

Where t_p is the number of ties for the p^{th} value, and q is the number of tied values. Z_c is given as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & S < 0 \end{cases} \quad (6)$$

Where Z_c is the test statistic.

On the basis of a 5% significance threshold, if p-value is $\leq \alpha = 0.05$, the H_1 hypothesis is accepted, indicating a trend in the data. If p-value is $\geq \alpha = 0.05$, the absence of a trend in the data is shown, and H_0 is accepted (Arghius et al. 2020; Atilgan et al. 2017; Bačević et al. 2020; Kale 2017; Shadmani et al. 2012; Singh et al. 2015; Subarna 2017).

4. Extreme Air Temperature

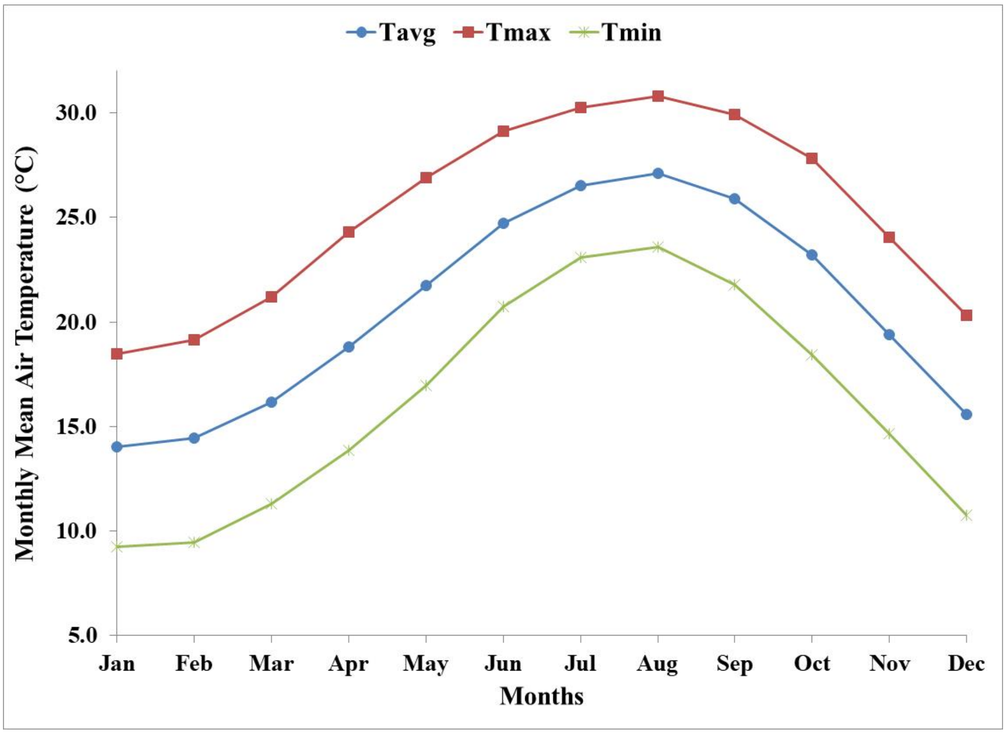
According to (ElBessa et al. 2021; Sridhar and Bhole 2015), an extreme air temperature event is defined as the event (record) calculated as Mean±2*SD, where SD is the standard deviation.

Results

Linear Regressions

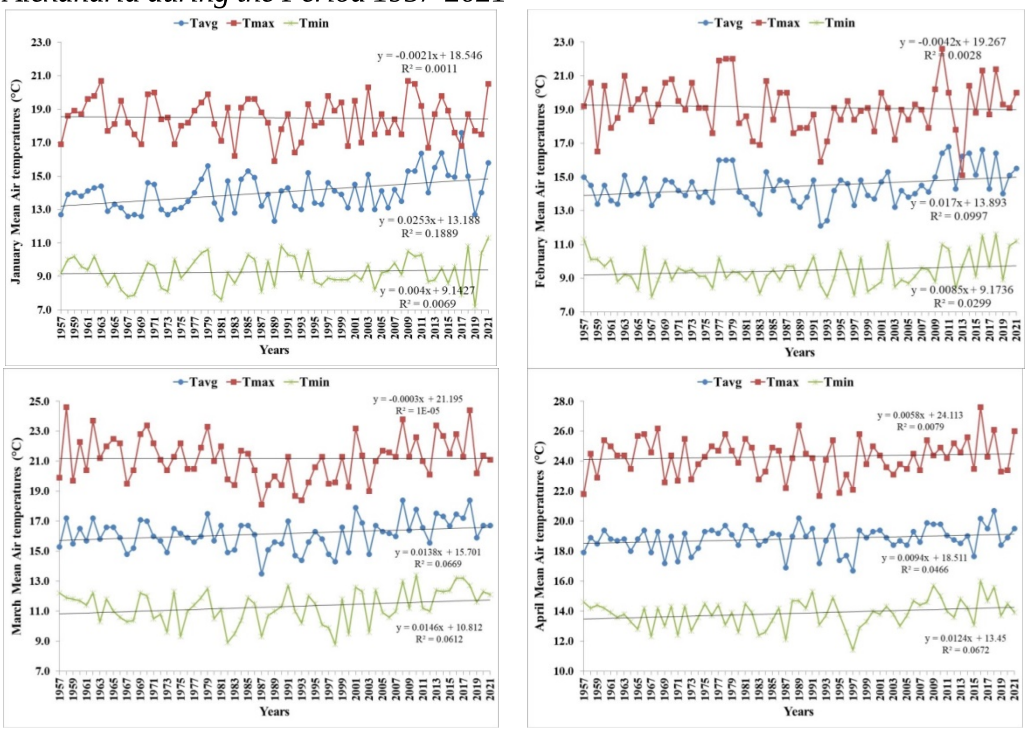
The monthly mean air temperatures for the three recorded parameters (T_{avg}, T_{max} and T_{min}) are shown in Figure 2. The mean annual T_{avg} was 20.6 °C, while that of T_{max} and T_{min} was 25.2 °C and 16.2 °C, respectively. January was the month of lowest monthly means with values of 14.0 °C, 18.5 °C, 9.3 °C for T_{avg}, T_{max} and T_{min}, respectively. On the other hand, August was the month with the highest monthly means with values of 27.1 °C, 30.8 °C, 23.6 °C for T_{avg}, T_{max} and T_{min}, respectively. Figure 3 depicts the trends of the monthly mean air temperatures (T_{avg}, T_{max} and T_{min}) for Alexandria over the period 1957-2021, using the parametric linear regression approach. As shown, the monthly T_{avg} had a general trend of increase for all months, with different rates over the period of interest. The lowest rate occurred in April (+0.009 °C/yr), while the highest occurred in September (+0.029 °C/yr). The monthly T_{max} behavior varied over the period of investigation with three different trends: decreasing trend occurred in three successive months (December-February) with the lowest trend of -0.004°C/yr in February and December and a maximum of -0.002 °C/yr in January. March was a month of almost no change in the trend of T_{max} over the period of interest, with a trend as low as -0.0003 °C/yr. The positive trends of the monthly T_{max} extended from April to November, with the lowest rate of +0.005 °C/yr in April and November, and the highest of +0.024 °C/yr in September. The monthly T_{min} followed the same trend of increase detected for the monthly T_{avg}, but with different rates over the period of interest. The lowest rate was in January (+0.004°C/yr), while the highest was in October (+0.0036 °C/yr).

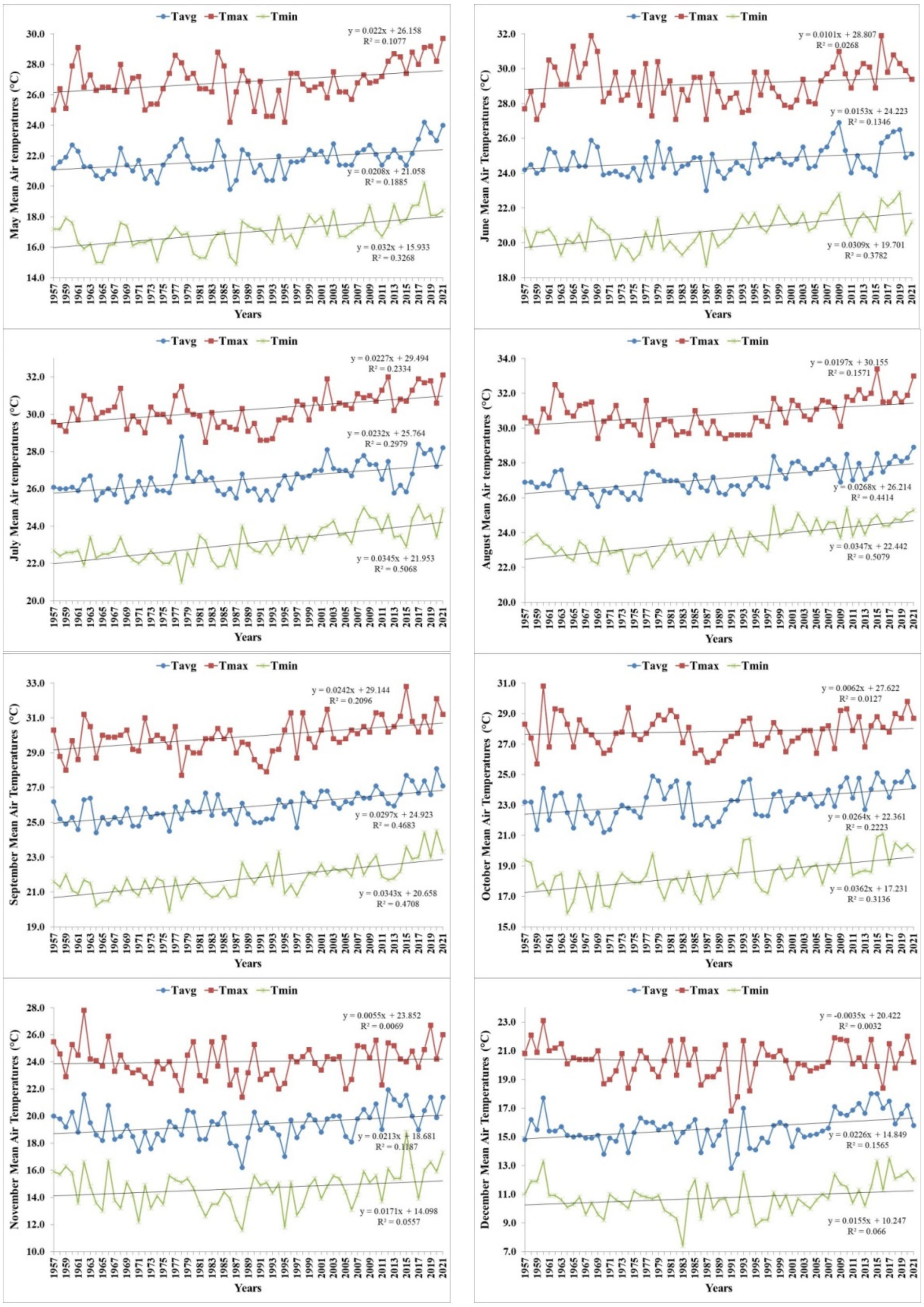
Figure 2. *Monthly Mean Air Temperatures over Alexandria during the Period 1957-2021*



Source: Author.

Figure 3. *Linear Regression Trends of the Monthly Mean Air Temperatures over Alexandria during the Period 1957-2021*



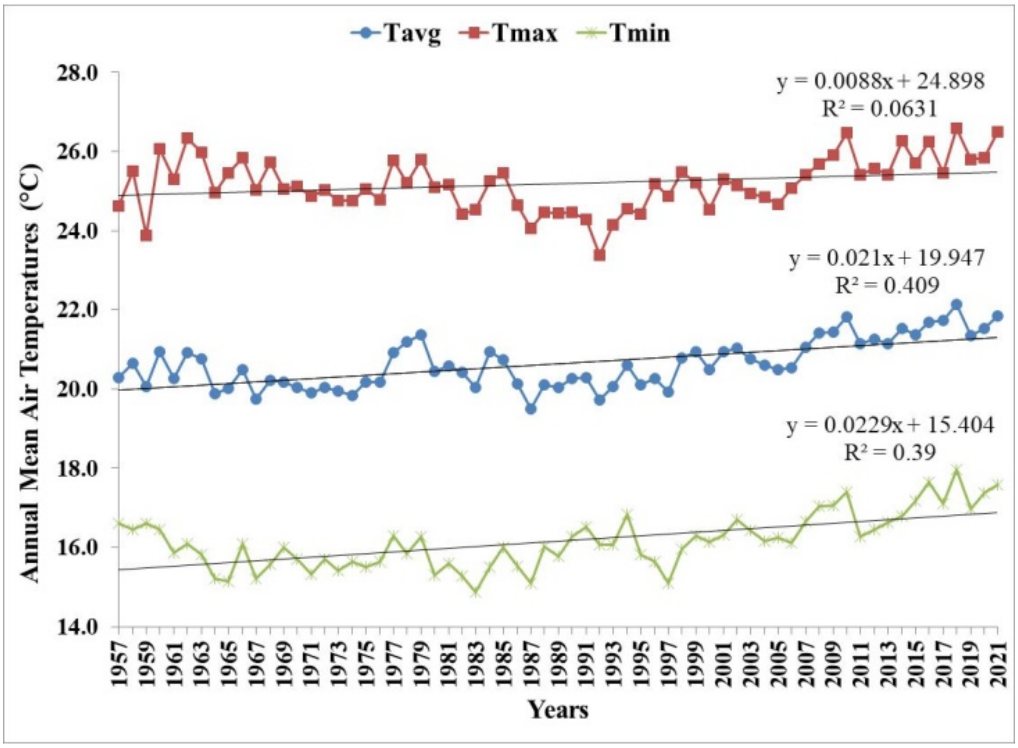


Source: Author.

The annual T_{avg} varied between 19.5 °C in 1987 and 22.1 °C in 2018, with an overall mean of 20.6 °C, over the period 1957-2021. The annual T_{avg} variations revealed an increasing trend over the period of investigation, with a rate of +0.02°C/yr. The annual T_{max} fluctuated between 23.4 °C in 1992 and 26.6 °C in 2018, with a T_{max} mean value of 25.2 °C, over the period of examination. The T_{max}

annual variability showed an increasing trend with a rate of +0.008 °C/yr over the period 1957-2021. Lastly, the annual T_{min} ranged between 14.9 °C in 1983 and 18.0 °C in 2018, with an overall mean of 16.2 °C, over the study period. The annual T_{min} trend of variation revealed an increasing trend over the period 1957-2021 with a rate of +0.02 °C/yr. The mean annual variations of the three air temperatures over Alexandria are depicted in Figure 4.

Figure 4. *Annual Mean Air Temperatures and their Trends over Alexandria during the Period 1957-2021*



Source: Author.

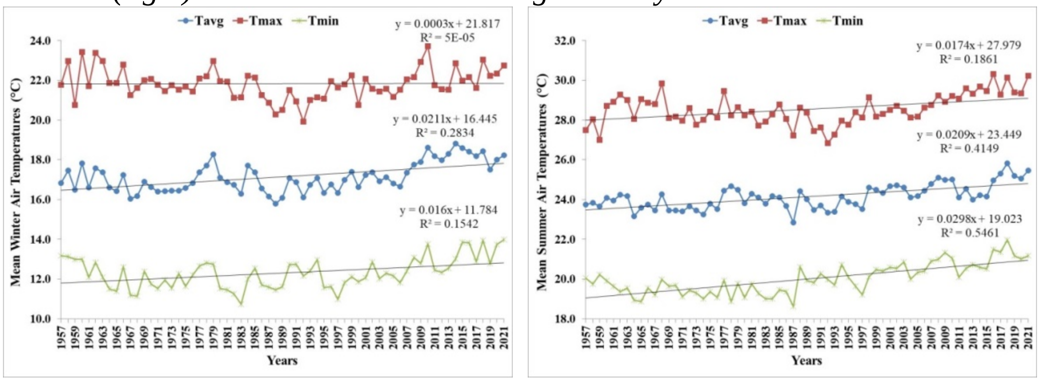
Alexandria exhibits two seasons over the year: a mild winter from October to March and a hot summer from April to September. The three examined air temperatures fluctuate and vary from one season to the second. In winter, the annual mean T_{avg} fluctuated over the period 1957-2021 between 15.8 °C in 1988 and 18.8 °C in 2014, with an overall mean of 17.1 °C. The trend of annual mean winter T_{avg} fluctuations reflected an increasing trend with a rate of 0.02 °C/yr. The annual mean winter T_{max} ranged between 19.9 °C in 1992 and 23.7 °C in 2010, with a winter mean of 21.8 °C, over the investigated period. The winter T_{max} had a feeble increasing trend (almost constant) over the period 1957-2021, with a rate of +0.0003 °C/yr. Lastly, the annual mean winter T_{min} varied between 10.7 °C in 1983 and 14.0 °C in 2018, with an overall average of 12.3 °C, over the period of interest. The increasing trend of the annual mean T_{min} in winter occurred with a rate of +0.02 °C/yr.

In summer, the annual mean T_{avg} varied between 22.9 °C in 1987 and 25.8 °C in 2018, with an overall mean of 24.1 °C, over the period 1957-2021. The warm

T_{avg} showed an increasing trend with a rate of +0.02 °C/yr. The hot annual mean T_{max} fluctuated between 26.8 °C in 1992 and 30.3 °C in 2016, with a mean of 28.5 °C, over the study period. The warm T_{max} had an increasing trend of +0.02 °C/yr. Lastly, the annual mean T_{min} in summer varied between 18.6 °C in 1987 and 22.0 °C in 2018, with a mean of 20.0 °C, over the study period. The annual mean T_{min} in summer showed an increasing trend with a rate of +0.02 °C/yr.

The seasonal fluctuations in the three air temperature parameters and their trends of variation are shown in Figure 5.

Figure 5. *Seasonal Mean Air Temperatures over Alexandria in Winter (left) and Summer (right) and the Their Trends during the Study Period*



Source: Author.

Trend Magnitudes

Using Equation (2), the monthly mean trend magnitudes for the three air temperatures in this study were calculated. The results are shown in Table 1. The calculated magnitudes are consistent with the concluded trends of monthly mean variations. This can be detected from the positive magnitudes for the T_{max} in January, February and December, the zero value for T_{max} in March and the negative magnitudes for the 12 months for T_{avg} and T_{min}. From these magnitudes, one can conclude the larger alterations in the behavior of change for the T_{min} than for both T_{avg} and T_{max}. Table 2 shows the annual mean trend magnitudes of the three examined air temperatures over Alexandria during the period 1957-2021. The obtained negative magnitudes confirm the positive trends of variations concluded for the three air temperature parameters over Alexandria during the study period. Table 3 shows the seasonal mean trend magnitudes of the three examined air temperatures over Alexandria during the period 1957-2021. The seasonal mean T_{avg} had the same magnitude of -1.4 °C in both winter and summer, reflecting the positive increasing behavior over the study period. The mean T_{max} did not change during winter, having 0.0 °C magnitude. The negative magnitudes of the seasonal mean T_{min} during both winter and summer revealed its seasonal positive trend of increase.

Table 1. *Monthly Mean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021*

	T_{avg}		T_{max}		T_{min}	
	Trend Equation	ΔT_{avg}	Trend Equation	ΔT_{max}	Trend Equation	ΔT_{min}
Jan	y = 0.0253x + 13.188	-1.6	y = -0.0021x + 18.546	0.1	y = 0.004x + 9.1427	-0.2
Feb	y = 0.017x + 13.893	-1.1	y = -0.0042x + 19.267	0.2	y = 0.0085x + 9.1736	-0.6
Mar	y = 0.0138x + 15.701	-0.9	y = -0.0003x + 21.195	0.0	y = 0.0146x + 10.812	-0.9
Apr	y = 0.0094x + 18.511	-0.6	y = 0.0058x + 24.113	-0.3	y = 0.0124x + 13.45	-0.8
May	y = 0.0208x + 21.058	-1.3	y = 0.022x + 26.158	-1.4	y = 0.032x + 15.933	-2.0
Jun	y = 0.0153x + 24.223	-0.9	y = 0.0101x + 28.807	-0.7	y = 0.0309x + 19.701	-1.9
Jul	y = 0.0232x + 25.764	-1.5	y = 0.0227x + 29.494	-1.5	y = 0.0345x + 21.953	-2.2
Aug	y = 0.0268x + 26.214	-1.7	y = 0.0197x + 30.155	-1.3	y = 0.0347x + 22.442	-2.3
Sep	y = 0.0297x + 24.923	-1.9	y = 0.0242x + 29.144	-1.6	y = 0.0343x + 20.658	-2.2
Oct	y = 0.0264x + 22.361	-1.6	y = 0.0062x + 27.622	-0.4	y = 0.0362x + 17.231	-2.3
Nov	y = 0.0213x + 18.681	-1.3	y = 0.0055x + 23.852	-0.4	y = 0.0171x + 14.098	-1.0
Dec	y = 0.0226x + 14.849	-1.4	y = -0.0035x + 20.422	0.3	y = 0.0155x + 10.247	-1.0

Source: Author.

Table 2. *Annual Mean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021*

	Trend Equation	ΔT (°C)
Annual Mean T_{avg}	y = 0.021x + 19.947	-1.4
Annual Mean T_{max}	y = 0.0088x + 24.898	-0.6
Annual Mean T_{min}	y = 0.0229x + 15.404	-1.5

Source: Author.

Table 3. *Seasonal Sean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021*

	T_{avg}		T_{max}		T_{min}	
	Trend Equation	ΔT_{avg}	Trend Equation	ΔT_{max}	Trend Equation	ΔT_{min}
Winter	y = 0.0211x + 16.445	-1.4	y = 0.0003x + 21.817	0.0	y = 0.016x + 11.784	-1.0
Summer	y = 0.0209x + 23.449	-1.4	y = 0.0174x + 27.979	-1.1	y = 0.0298x + 19.023	-1.9

Source: Author.

Mann-Kendall Non-Parametric Test

The results of the MK test for the monthly mean trend identification at a significance level of 0.05 are given in Table 4. As shown, T_{avg} and T_{min} showed an increasing trend over the entire period of investigation. However, T_{max} showed a mixture of increasing, decreasing and null trends. These results confirm those obtained using the linear regression approach and the calculated trend magnitudes.

Table 4. *The MK Test Results for Air Temperatures on a Monthly Mean Basis*

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Jan	308	2.52	+	171	-2.52	-	296	2.42	+
Feb	314	2.56	+	174	-2.56	-	301	2.45	+
Mar	303	2.48	+	131	1.93	No	291	2.38	+
Apr	266	2.0	+	168	2.48	+	255	1.97	+
May	338	2.76	+	187	2.76	+	325	2.65	+
Jun	238	2.0	+	132	1.98	+	228	1.98	+
Jul	307	2.52	+	151	2.22	+	295	2.42	+
Aug	327	2.67	+	181	2.67	+	314	2.56	+
Sep	303	2.48	+	168	2.48	+	291	2.38	+
Oct	309	2.52	+	171	2.52	+	182	1.98	+
Nov	190	1.98	+	165	2.43	+	297	2.09	+
Dec	287	2.12	+	159	-2.34	-	276	2.03	+

Source: Author.

The MK test was applied to examine the annual mean trends of air temperatures over the period of investigation. Significant trends were increasing for the three examined parameters (Table 5). As shown, trends are statistically significant at 99% significant level for both T_{avg} and T_{min}, while this drops to a significant level of 95% for T_{max}.

Table 5. *The MK Test Results for Air Temperatures on an Annual Mean Basis*

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Annual Mean	938	5.3	+	361	2.03	+	905	5.11	+

Source: Author.

The results of the MK test for the two seasons, mild winter and warm summer, affecting Alexandria are shown in Table 6. The significant level of both T_{avg} and T_{min} was 99%, while that of T_{max} was 95%.

Table 6. *The MK Test Results for Air Temperatures on a Seasonal Mean Basis*

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Winter	260	3.82	+	101	1.46	No	251	3.68	+
Summer	363	5.34	+	140	2.04	+	350	5.14	+

Source: Author.

Extreme Air Temperatures

The statistics of the monthly mean air temperature to examine the monthly extreme values are shown in Table 7. The entire set of mean monthly T_{avg} showed extreme mean high air temperature (mean+2*SD) except for October. Also, monthly mean T_{avg} associated with extreme low air temperature (mean-2*SD) appeared all over the monthly set except for January, July, September and October. The extreme high monthly mean T_{max} appeared for the entire monthly set but for January and the extreme low monthly mean T_{max} existed for the entire monthly set but for the three successive months: June, July and August. On the other hand, the extreme high monthly mean T_{min} occurred in the entire monthly set but in March, and the extreme low monthly mean T_{min} did not appear in February, May and September.

Table 7. *Statistics of the Monthly Mean T_{avg}, T_{max} and T_{min} in Alexandria during the Period 1957-2021*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly T_{avg} (°C)	14.0	14.5	16.2	18.8	21.7	24.7	26.5	27.1	25.9	23.2	19.4	15.6
SD (°C)	1.1	1.0	1.0	0.8	0.9	0.8	0.8	0.8	0.8	1.1	1.2	1.1
Extreme High T_{avg} (°C)	16.2	16.5	18.2	20.5	23.5	26.3	28.1	28.6	27.5	25.3	21.7	17.7
Extreme Low T_{avg} (°C)	11.8	12.4	14.2	17.2	19.9	23.2	24.9	25.6	24.3	21.1	17.1	13.5
Mean Monthly T_{max} (°C)	18.5	19.1	21.2	24.3	26.9	29.1	30.2	30.8	29.9	27.8	24.0	20.3
SD (°C)	1.2	1.5	1.5	1.2	1.3	1.2	0.9	0.9	1.0	1.0	1.2	1.2
Extreme High T_{max} (°C)	20.8	22.1	24.1	26.7	29.4	31.5	32.0	32.7	31.9	29.9	26.5	22.6
Extreme Low T_{max} (°C)	16.1	16.2	18.3	21.9	24.4	26.8	28.5	28.9	28.0	25.7	21.6	18.0
Mean Monthly T_{min} (°C)	9.3	9.5	11.3	13.9	17.0	20.7	23.1	23.6	21.8	18.4	14.7	10.8
SD (°C)	0.9	0.9	1.1	0.9	1.1	0.9	0.9	0.9	0.9	1.2	1.4	1.1
Extreme High T_{min} (°C)	11.1	11.3	13.5	15.7	19.1	22.6	24.9	25.4	23.7	20.8	17.4	13.0
Extreme Low T_{min} (°C)	7.5	7.6	9.1	12.1	14.9	18.8	21.3	21.8	19.9	16.0	11.9	8.5

Source: Author.

The extreme annual mean temperature is calculated as 20.6±2*0.6. Only 2 years, 2018 (22.1 °C) and 2021 (21.9 °C), out of 65 recorded extreme high annual mean T_{avg} in Alexandria from 1957 to 2021. No extremely low annual mean T_{avg} was recorded over the entire period of investigation. On the other, the extreme annual mean T_{max} is derived as 25.2±2*0.7. 2018 (26.6 °C) was the only year to record extremely high annual mean T_{max}, and 1992 (23.4 °C) was the only year to record extremely low annual mean T_{max}. The extreme high annual mean T_{min} was recorded in 3 years: 2016 (17.7 °C), 2018 (18.0 °C) and 2021 (17.6 °C), with no extreme low annual mean T_{min} detected over the whole period of interest. This T_{min} extremes were derived as 16.2±2*0.7.

The extreme seasonal mean air temperatures in the two seasons affecting Alexandria are associated with associated the equations 17.1±2*0.7 (winter) and 24.1±2*0.6 (summer) for T_{avg}, 21.8±2*0.7 (winter) and 28.6±2*0.8 (summer) for T_{max}, and 12.3±2*0.8 (winter) and 20.0±2*0.8 (summer) for T_{min}. Results revealed no extreme low T_{avg} winter temperatures during the study period. However, 3 years had extremely high T_{avg}: 2010 (18.6 °C), 2014 (18.8 °C) and 2015 (18.6 °C). Two extremely hot T_{avg} summer years were detected: 2018 (25.8 °C) and 2021(25.5 °C), and one extremely low of 22.8 °C (1987). The winter high extreme T_{max} was detected in 3 years: 1960 (23.4 °C), 1962 (23.4 °C) and 2010 (23.7 °C), while the summer had only one extreme cold year with 19.9 °C in 1992. 2015 and 2021 were he two years of the extremely high T_{min} in Alexandria over the period

1957-2021, of 13.8 °C and 14.0 °C, respectively. Only 1983, with as low as 10.7 °C record, was detected as extremely low summer T_{min} over the period of interest.

Discussion

It is critical to investigate the effects of climate change and to consider the outcomes of various climate change projects. Temperature variation is one of the most essential and crucial metrics of global climate change. Most climate models predict a rise in temperature by the end of the twenty-first century (García-Ruiz et al. 2011). It has been reported that rising temperatures may be linked to global warming (Chen and Xu 2005).

It is worth mentioning that this study is the first to examine the long-term behavior of T_{max} and T_{min} air temperatures in Alexandria in details. Therefore, there is no base study to compare the present findings of these two parameters. However, many previous studies have examined the variations in T_{avg}, and the present findings will be thoroughly compared and discussed considering results from these previous research.

In this study, the monthly pattern of air temperature change in Alexandria was demonstrated, with January having the lowest monthly means of 14.0 °C (T_{avg}), 18.5 °C (T_{max}) and 9.3 °C (T_{min}) and August having the highest of 27.1 °C (T_{avg}), 30.8 °C (T_{max}) and 23.6 °C (T_{min}). For T_{avg}, these findings are consistent with the findings of Hamed (1983) who declared January (13.7 °C) and August (26.1 °C) as months of highest and lowest monthly means over the period 1951-1980. Also, Mohamed and Beltagy (2009) showed the lowest monthly mean of 14.1 °C in January and the highest of 26.5 °C in August over the period 1958-2008. Results of Eid et al. (2019) revealed that January is the month with the lowest monthly mean (13.0 °C) and August of the highest (26.9 °C) over the period 1960-2016.

On a mean annual basis, this study revealed annual mean values of 20.6 °C, 25.2 °C, and 16.2 °C for T_{avg}, T_{max} and T_{min}, respectively. This is in agreement with the results of Said et al. (2012a, b) who calculated an annual mean T_{avg} of 20.6 °C, over the period 1974-2006. However, this is higher than the annual means of 20.3 °C (Mohamed and Beltagy 2009) over the period 1958-2008, and of 20.3 °C (Hendy 2018) over the period 1974-2006. This is, meanwhile, lower than the annual mean of 20.8 °C calculated by Shaltout et al. (2013). This difference in the calculated annual mean may be attributed to the different time spans of calculations or to the variant data sources.

The current study of long-term trends in air temperature variations reported that Alexandria experienced an annual increasing rate of +0.02 °C for its annual mean T_{avg}. This is consistent with the rate calculated by Mostafa et al. (2019) for Alexandria (+0.02 °C/yr) during the period 1960-2010. However, this rate is lower than the +0.06 °C/yr by Said et al. (2012a, b) for the period 1979–2011, the +0.04 °C/yr calculated by ElBessa et al. (2021) from 1979 to 2018 and by El-Geziry (2021) over the period 1980-2019. This is also lower than the +0.056 °C/yr rate calculated by Tonbol et al. (2018) for the period 2007–2016 in the Southern

Levantine. Meanwhile, the current pace is higher than Hendy (2018)'s estimate of +0.01 °C/yr for Alexandria from 1979 to 2016.

The results of this study revealed that the year 2018 as the year of maxima for the three examined air temperature categories. This is consistent with the results of El-Geziry (2021). Mohamed and Beltagy (2009) declared 2002 as the year of maximum annual mean over the period 1958-2008, and Hendy (2018) declared 1974 for the period 1974-2016.

The significance of increasing trends in the present study is in a very good agreement with those of Eid et al. (2019) who declared that the annual and seasonal air temperatures in Alexandria have significant increasing trends with 95% confidence.

Seasonal variations of both cold and warm T_{avg} affecting Alexandria revealed an increasing trend of +0.02 °C/yr, each. This is lower than the rates calculated by El-Geziry (2021) over the period 1980-2019, of +0.08 °C/yr (cold) and +0.06 °C/yr (warm). This difference may be attributed to the different data periods.

From an extreme perspective, results revealed no extreme low T_{avg} over the period of interest. 2018 and 2021 were the years of extremely high T_{avg}. Eid et al. (2019) declared 3 years of extremely low T_{avg} in Alexandria: 1967, 1983 and 1989, over the period 1960-2016. They also showed 3 years of extremely high T_{avg}: 2010, 2014 and 2016. On a seasonal basis, no low winter extreme event occurred in this study, and three years were recorded as extremely high: 2010, 2014 and 2015. 2010 and 2018 were the two years of extremely high winter T_{avg} (ElBessa et al. 2021) over the period 1979-2018. They recorded 1983 and 1992 as the years of extremely low winter T_{avg}. Summer extremely high T_{avg} years were 2018 and 2021 (present study) and 2010 and 2015 (ElBessa et al. 2021). The extremely low summer T_{avg} year, on the other hand, was in 1987 in the two studies.

Conclusion

Temperature data from 1957 to 2021 were used in this study to determine temperature variability and trends in Alexandria. Based on the analysis of the (T_{avg}), (T_{max}), and (T_{min}) data series, it is possible to conclude that the temperature of the area reflected general higher temperature variability, on different bases: monthly, annual and seasonal. A significant increase in air temperature was seen in all-time series when the trend equation, trend magnitude, and MK trend test were applied to the three considered air temperature categories in Alexandria. Hypothesis H_1 is highly common, and there is a minute chance that it will be rejected. Monitoring and analyzing the climate extremes in Alexandria should be the focus of future research. It should also be noted that the trend analysis was carried out using the parameters from the available station in the city territory. The presence of microclimate differences in Alexandria is influenced by a number of elements, including the degree of urbanization, topography hypsometry, hydrographic objects, and flora. Extreme climate events (aridity, drought - an unfavorable situation in agriculture), human health repercussions, and the decrease or even extinction of terrestrial and marine ecosystems are just a few of the socio-economic impacts of climate change. For these reasons, this study highly recommends additional automatic weather stations to cover the large surface area of the City in order to monitor the required parameters for excessive analysis, which by the end, may guide the decision-makers to the actions needed to perform convenient mitigation and adaptation plans.

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Using Pixel Counts to Measure Accuracy and Confidence in Representations of Mental Maps

By Andrew T. Johnson[*]

Mental imagery and cognitive maps are difficult to study because these are so subjective and not easily observable. This exploratory study uses pixel counts to measure accuracy and confidence related to mental imagery. In this study 35 fifth grade students received an outline map of the continental United States on a standard-sized sheet of paper and asked to write state abbreviations as large as possible being 100% confident that the abbreviations would be within the boundary of the respective states. The response sheets were scanned. Adobe Photoshop was used to calculate pixel counts of the area of the abbreviations within and outside of the respective state boundaries. The ratio of In and Out pixel counts provided a measurement of Accuracy, while a ratio of In and Total State pixel counts provided a measurement of Confidence. More abbreviations were attempted for US states that had one or more sides present on the US outline map. The girls showed greater accuracy and higher confidence across all conditions. Similarly, there was a linear relationship between the number of reference sides and the confidence outcomes. The results provide proof of concept that pixel count measurements provide value to measuring mental imagery and spatial cognition.

Keywords: *mental imagery, cognitive maps, spatial cognition, accuracy, confidence index*

Introduction

Historical reference to mental imagery can be found in the Greek tradition with the account of Simonides using the Method of Loci to recall attendees who were killed by a collapse of a banquet hall by visually imagining where they were seated. More recently, cognitive psychologists have taken on the task of quantifying mental imagery. Some mental imagery processes are similar to visual processing (Kosslyn et al. 1978, Shelton and Gabrieli, 2004, Shepard and Metzler 1971). However, there are also systematic distortions within mental maps (Moar and Bower 1983, Thorndyke 1981, Taylor 2005, Tversky 1997, 2000).

Geography is the study of nature and relative arrangement of places. In the United States, fifth-grade students are expected to know the states that comprise the nation (Missouri Department of Elementary and Secondary Education 2016). Furthermore, Moore and Boehm (2011) argue that geography knowledge is vital for a person’s politico-economic understanding and should be taught in grade school. Geography for school-aged children includes not only knowledge of the states, but the visual shape/ representation connected to the states. This includes identifying the names of states, information about the state, e.g., capital, prominent

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cities, area location, etc., as well as storing visual characteristics of the state to locate it on a map.

Literature Review

Maps are not only at the center of geography, but they influence the development of spatial cognition (Gauvain 2000). Maps are universal tools of thought and transcend cultures, as such their role is history is well established (Gauvain 2000). Mental images are not always accurate, but rather portray a world as a person perceives it to be. Moeser (1988) explored cognitive mapping of nursing students in a five-story hospital by having them draw out the floor they typically trained on in the hospital. Moeser found the even after two years of experience nursing students failed to form a global cognitive representation of the hospital. Moeser concluded that internalized cognitive representations are not automatically created and that motivational factors play a key role. If there is a value to building a cognitive map, the individual will do that.

The work of Marchette et al. (2011) used undergraduate participants at Johns Hopkins University to identify buildings on their Homewood campus and test out judgments of relative direction (JRDs). They found support that their participants organized and referenced their memory of campus from a particular point of reference, e.g., North-as-up. Additionally, having participants imagine the campus from another point of reference hindered performance. Marchette et al. (2011) findings provided evidence for the importance of point of reference, but avoided examining any gender effects in their study.

Several studies have examined sex differences for males and females. Chumney and Zinser (2011) examined the performance of undergraduates on identifying several geographical aspects of the United States. Participants were asked to label US states and major cities on outline maps, locate major cities, and reproduce state boundaries on an US outline map. The males and females varied in their performance. The male undergraduates displayed a performance advantage in some of the tasks, e.g., map-labelling and fragmented state identifications, and in context-dependent tasks of the United States. They point out in their article that the geographical limitations (coming from one region of the US) of their participants make their results difficult to generalize to other adults. Furthermore, they speculate that gender differences may be driven by experiences in grade school (Chumney and Zinser 2011).

Vecchi and Girelli (1998) explored gender difference across four experiments in visuo-spatial abilities by using 2D and 3D matrices of varying sizes and asking adult participants to complete specific tasks. For example, in Experiment 1 participants were played sets of direction statements and asked to indicate the final position on a 2D matrix or 3D cube. Males outperformed females in 2D and 3D tasks as well as active tasks across most of the interference manipulations Passive storage tasks did not show evidence for a male advantage (Vecchi and Girelli 1998).

Beatty and Troster (1987) collected data for over 1,800 undergraduates across five studies and several institutions. They asked participants to list locations within the US they had visited and to identify physical features, e.g., lakes, rivers, mountains, and locate cities on outline maps for regions of the United States. Their findings indicated that the male undergraduates outperformed their female counterparts on the tasks. However, the differences were not particularly robust. The males located places on a map of the United States more accurately than females. Overall, gender differences accounted for a range variance between 7% to 31% (Beatty and Tröster 1987). Are these sex differences present at the grade school level? If so, this may provide evidence that boys and girls may benefit from different instructional strategies to remove this difference (Beatty and Tröster 1987).

Current Study

The literature on spatial cognition and mental imagery has featured mostly research on adults and has revealed varying results. There is sufficient evidence that supports that individuals process and respond to mental representations similarly to actual visual stimuli (Kosslyn et al. 1978, Shepard and Metzler 1971). However, there have been conflicting results related to whether males and females handle mental manipulations differently. A previous study of mine (Johnson and Griffith 2016) investigated these topics through the use of a fragmented test of US states applied to grade-school students. Fifty fifth-grade students were given an outline map of the US and a fragmented test of US states. Each state set (44 of 48 continental US states) featured four-sized versions. One of the versions was scaled to fit in an outline map of the US given to each student. The fifth graders were instructed to label the state and use their mental imagery to choose which of the four selections was the appropriate size. For this phase of the study, the students answered a little over 31 of the 44-state size-estimations and identifications. The boys attempted significantly more states than the girls. The boys had higher accuracy for naming the states presented. However, for the accuracy of estimating the correct size, there was no difference between the boys and girls.

Additionally, there was a strong positive correlation between mean number of correct size estimation and mean number of correct state identifications. Those students who had higher numbers of correct state identifications also had higher accuracy of correct size estimations. There was also a strong positive correlation between percent accuracies (percent correct for size estimations and identifications). In other words, students who had a high percent of correct estimations also had high accuracy for state identifications.

The study reported in this article presents the second phase of the Johnson and Griffith (2016). In Phase 2 the students were asked to fill in the US outline map with state abbreviations. We were interested in examining the performance of boys and girls and how they would be able to perform and how “on target” their abbreviations would be. While Phase 1 involved identification of US states and imagining which state selection fit the outline map, Phase 2 involved more specific location of states with an added measurement of confidence. Participants can report confidence of mental images and mental maps, but how accurate are these ratings? Is there a way to objectively quantify mental map confidence? Self-report data may be flawed (King et al. 1980, Moore and Healy 2008) so more objective measurements are necessary. Several researchers have quantified many aspects of visual images/mental maps (Chumakov et al. 2021, Aram et al. 2019, Gardony et al. 2015, ELIAN (www.seldage.com)) and automated calculations such as point counts, line length, area, speed, duration, orientation, pen pressure, hesitations, etc. However, in many instances, these applications rely on human/expert programming.

In this study we are examining a performance measure of confidence. Instead of directly asking students to rate their confidence for each abbreviation attempt, we proposed framing the task to students to draw their abbreviations being 100 percent confident that they would place the abbreviations within the state boundaries. Then we apply pixel counts to calculate areas and derive a confidence measurement. We are interested in exploring how well they will do on this and whether any gender differences will be present.

Method

Participants

A total of 35 fifth-grade students (22 girls and 13 boys) from a Midwestern USA suburban grade school participated in this study.

Procedure

Each of the participants were given an answer sheet, outline reference map of the United States on a standard 8.5” x 11” sheet of paper formatted in a landscape position, and the test booklet in a class context. The study was conducted in two phases. Phase 1 consisted of completion a fragmented test of 44 continental states of the United States with two state sets per half page. The state set consisted of four choices varying from 40% to 160% of the actual state size that corresponded with the outline US reference sheet. Participants were told for each state set to write down the state abbreviation on the answer sheet then select one of the four choices that would accurately fit the reference outline using their mental imagery.

After Phase 1, Phase 2 consisted of having participants using the outline reference map of the US (see Appendix). They were asked to write state abbreviations in capital letters, e.g., MO, on an outline map of the US “as large as possible being 100% sure that the abbreviations would fall within the boundaries of the states (see Appendix for an example). A reference sheet with the abbreviations of the US states was provided. Phase 1 results were presented previously (Johnson and Griffith 2016). The results presented in this paper are for Phase 2.

Materials

We prepared the stimuli by first separately scanning the individual reference map sheets (300 dpi – black and white). Next, within Adobe Photoshop, a layer consisting of the outline US map with state boundaries was added to each individual map sheet. Following this, the Magnetic Lasso tool within Photoshop was used to wrap around the edges of each state abbreviation to make the most regularized shape possible. Using the Histogram outputs, pixel count totals were recorded for each abbreviation. An additional pixel count measurement was taken for abbreviations that were partially inside the appropriate state boundary. Then the pixel count measurements of the state abbreviation total and state abbreviation total within the state boundary were entered into a Google Form. The Google Form consisted of: The Participant Identification number, Sex, State Abbreviation, Pixel Count total, Pixel Count In (state boundary). A separate look-up table with US state pixel count totals was used to calculate Confidence (operationalized as Abbreviation pixel count Total/Abbreviation pixel count within the state boundaries). Accuracy was calculated as State pixel count Total/Abbreviation pixel count within the state's boundary. US states were sorted into groups related to the number of sides that are referenced on the outline map. An example of a three-sides state is Florida. Washington is an example of a two-sides state, whereas its neighbor Oregon is a one-side state example. Examples of zero-reference side states are Missouri, Kansas, Iowa, Nebraska, etc. - ones that are found away from the outside US Continental boundary line. A total of four states were classified as three-sided and five others as two-sided. Twenty-one states were classified as one-sided states leaving the remainder of 18 continental states as zero reference-sided.

Results

Our main research question examined the accuracy of depicting state abbreviations within the respective states and the confidence of the depiction reflected by the size of the state abbreviations. We were also interested in how measurements of accuracy and confidence would differ across the number of reference-sided states. Finally we were interested in investigating whether any sex differences were present.

On average females attempted 19.1 state abbreviations (Range = 3 to 40). On the other hand, males attempted 16 abbreviations on average (Range = 3 to 41). On average the females and males attempted a similar number of state abbreviations across state reference sides groupings, however the average attempt percentage declined across the number of state reference sides. For zero reference sides the mean attempts for females and males are 36.12% and 37.65%, respectively. This slightly increased for one and two reference sides (1 Side 38.74% Female; 39.19%, Male; & 2 Sides 46.59% Female, and 46.15% Male, refer to Figure 1). Finally, the females and males attempted more abbreviations for three reference-sides states – 61.36% and 57.69%, respectively (refer to Table 1). These averages indicate that states with perceptual cues on the outline map were easier to respond to. Moreover, the five of the six top attempted states contained two or three reference sides: Florida, Texas, Washington, Maine, and Michigan (For a listing of the states and the total attempts, see Table 2).

Figure 1. *Mean Number of Abbreviations Attempts across Gender and Number of Reference Sides*

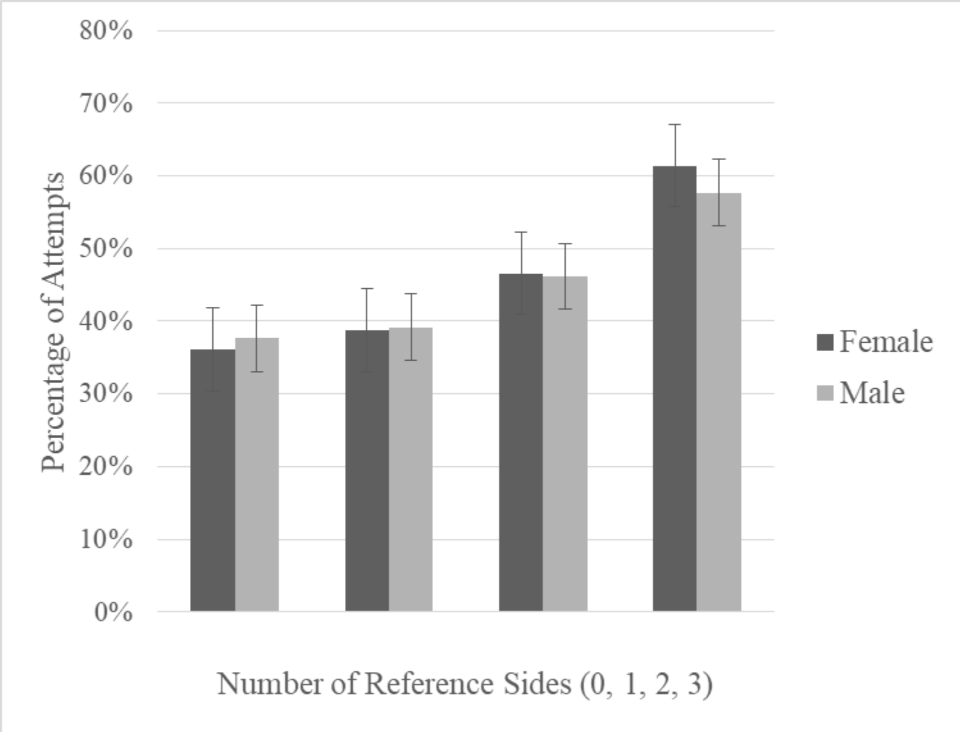

Table 1. *Average Attempt Percent for the Top Three States Attempted Across the Number of State Reference Sides*

Number of Reference Sides	Highest State/ Percentage	Second Highest State/ Percentage	Third Highest State/ Percentage
0	OK / 68.57%	CO & NV / 54.29%	MO / 51.43%
1	CA / 91.43%	AZ / 68.57%	MT / 60%
2	TX / 94.29%	WA / 88.57%	MN & WI / 51.43%
3	FL / 97.14%	ME / 82.86%	MI 71.43%

We used Abode Photoshop to calculate the pixel counts for the state abbreviations within (In) the respective state boundary and outside (Out) of the respective state boundary. Taken together the In and Out pixel counts (In/Out ratios) provide a measurement of Accuracy. The lower the Out-pixel counts are, the more accurate the estimate is. Overall, the mean state In/Out ratios ranged from 583627.900 (TX) to 0.051 (RI). (For a listing of the all of the continental US states and the Mean and Standard Deviations for In/Out total attempts, see Table 2). The outcomes for Texas are outliers because Texas is significantly larger than the other US continental states. The bottom border of Texas easily provides perceptual cues for depicting an abbreviation. Nevertheless, the data for Texas were included in this study. Aside from Texas and the outcomes for Arizona and Washington, the ratios for the remaining states are one digit or less.

Table 2. *Total Number of Abbreviation Attempts, Means and Standard Deviations for the Ratio of Pixel Counts within the State Boundary to Pixel Counts Outside of the State Boundary, and Ratio of Pixel Counts within the State Boundary to Total Pixel Counts of the State Across States*

	Ref Sides	Attempts	In/ Out Pixel Count Ratios		In/ State Total Pixel Count Ratios	
State	**N**	**N**	**M**	**SD**	**M**	**SD**
AL	1	13	2.544	4.940	0.080	0.091
AR	0	13	4.208	10.166	0.119	0.110
AZ	1	24	15.740	40.779	0.169	0.180
CA	1	32	1.816	5.503	0.157	0.148
CO	0	19	1.199	3.154	0.076	0.127
CT	1	5	0.134	0.300	0.145	0.199
DE	1	4	1.951	3.902	0.297	0.595
FL	3	34	2.189	4.256	0.181	0.144
GA	1	10	1.651	2.554	0.099	0.076
IA	0	14	1.029	1.841	0.151	0.137
ID	1	20	1.423	1.673	0.114	0.148
IL	1	17	2.172	4.049	0.132	0.187
IN	0	8	0.083	0.222	0.040	0.070
KS	0	17	1.566	4.163	0.076	0.095
KY	0	16	2.280	2.280	0.081	0.092
LA	1	20	7.002	9.163	0.187	0.126
MA	2	4	0.030	0.060	0.025	0.055
MD	0	5	0.429	0.959	0.102	0.229
ME	3	29	2.428	8.589	0.238	0.119
MI	3	25	8.794	25.347	0.236	0.155
MN	2	18	4.238	8.454	0.193	0.144
MO	0	18	2.357	3.460	0.155	0.122
MS	1	18	7.434	17.212	0.152	0.150
MT	1	21	4.719	12.875	0.126	0.088
NC	1	13	2.503	3.534	0.119	0.150
ND	1	14	4.133	10.199	0.113	0.108
NE	0	16	3.035	10.291	0.083	0.171
NH	0	5	0.052	0.116	0.026	0.058
NJ	3	9	1.119	2.765	0.138	0.237
NM	1	20	0.916	2.490	0.079	0.091
NV	0	19	1.879	5.661	0.099	0.080
NY	1	20	3.334	8.385	0.172	0.125
OH	1	16	0.111	0.354	0.210	0.151
OK	0	24	1.511	1.511	0.088	0.117
OR	1	17	3.329	8.291	0.189	0.146
PA	0	13	1.568	3.638	0.113	0.167
RI	1	9	0.051	0.153	0.115	0.346
SC	1	11	1.027	1.027	0.177	0.245
SD	0	12	1.730	2.418	0.160	0.140
TN	0	13	1.419	1.419	0.114	0.173
TX	2	31	583627.9	3248432	0.156	0.140
UT	0	10	3.518	9.957	0.106	0.089
VA	1	15	2.540	8.575	0.120	0.159
VT	1	10	0.452	0.803	0.138	0.211
WA	2	31	10.100	28.636	0.236	0.146
WI	2	18	2.543	9.985	0.110	0.129
WV	0	9	0.286	0.553	0.084	0.120
WY	0	13	2.554	6.601	0.063	0.081

In, Out, and Total Pixel Count Outcomes

We used a two-way between-subjects ANOVA to test any main effects and interaction of Gender and Number of Reference Sides on counts of pixels In, Out of state boundaries, and Total of pixel counts for abbreviations.

For the three-pixel count measurements (In, Out, Total) there were significant differences for Gender. For the In measurement, Females had significantly more pixel counts in their abbreviations, $F(1,666)=8.457$, $p=0.004$, partial $\eta 2=0.013$. Similarly, Females had more pixel counts in the their abbreviations that fell outside on the respective state boundaries, $F(1,666)=8.813$, $p=0.003$, partial $\eta 2=0.013$. Not surprisingly, Females also had more Total pixel counts in their abbreviations, $F(1,666)=13.495$, $p\sim 0$, partial $\eta 2=0.02$. Refer to Table 3 for Means and Standards for the In, Out, and Total measurements across Gender.

Table 3. *Means and Standard Deviations of Pixel Counts within and without State Boundaries as a Function of Gender and Number of Sides Referenced on the Outline Map*

			M	SD	N
In	Male	0	5854.82	6424.079	91
		1	7060.99	11218.264	109
		2	17446.91	23799.815	23
		3	7097.03	4813.746	29
		Total	7577.50	11459.68	252
	Female	0	7766.10	9810.431	142
		1	11743.37	13768.702	183
		2	24596.90	31449.206	39
		3	8750.84	6985.559	51
		Total	11222.64	15317.192	415
	Total	0	7019.64	8681.943	233
		1	9995.49	13054.537	292
		2	21944.48	28853.817	62
		3	8151.34	6303.793	80
		Total	9845.46	14087.716	667
Out	Male	0	4882.12	5109.069	91
		1	3713.30	5291.369	109
		2	4722.30	6634.953	23
		3	1732.55	4969.844	29
		Total	3999.52	5383.325	252
	Female	0	11132.50	12220.617	142
		1	5877.66	8195.041	183
		2	5186.77	9646.249	39
		3	2540.63	4836.646	51
		Total	7200.68	10044.238	415
	Total	0	8691.36	10499.036	233
		1	5069.73	7313.954	292
		2	5014.47	8596.151	62
		3	2247.70	4869.579	80
		Total	5991.25	8720.539	667
Total	Male	0	10799.42	5627.932	91
		1	10953.73	12125.961	109
		2	25569.57	25751.065	23
		3	8829.59	5519.090	29
		Total	11987.55	12456.987	252

	Female	0	18962.75	14084.222	142
		1	17620.86	14037.48	183
		2	29783.67	33674.817	39
		3	11284.41	8613.554	51
		Total	18444.33	16913.074	415
	Total	0	15774.49	12197.359	233
		1	15132.10	13720.322	292
		2	28220.37	30818.68	62
		3	10394.54	7691.821	80
		Total	16004.88	15688.001	667

The ANOVA results also yielded significant results for the In, Out, and Total pixel counts for the Number of Reference Sides, In $F(3,666)=17.544$, $p{\sim}0$, partial $\eta 2=0.074$; Out $F(3,666)=11.578$, $p{\sim}0$, partial $\eta 2=0.05$, and Total $F(3,666)=17.495$, $p{\sim}0$, partial $\eta 2=0.072$. Utilizing Tukey post-hoc comparison significant differences were found between 2 Reference Sides and 0, 1, 3 Side conditions ($p{\sim}0$) for In measurements. No other significant comparisons were indicated. For Out of State pixel counts and 0 Side condition, there were significant differences between the 0 and 1 Side conditions ($p{\sim}0$), 0 and 2 ($p=0.01$), and 0 and 3 conditions ($p{\sim}0$). For Out of State pixel counts and 1 Side condition, there was an additional significant difference between the 1 and 3 Side conditions ($p=0.035$). The Total pixel count measurement the Tukey post-hoc comparison revealed significant differences between the O and 2 Side conditions ($p{\sim}0$), the O and 3 Side conditions ($p=0.027$), the 1 and 2 Side conditions ($p{\sim}0$), and the 2 and 3 Side conditions ($p{\sim}0$). Finally, the ANOVA results yielded a significant result for the interaction of Gender and Number of Sides on Out of state pixel counts $F(3,666)=3.913$, $p=0.009$, partial $\eta 2=0.018$. Females drew larger abbreviations for the 0 Reference Side states than the Males.

In/ Out State and In/ State Total Pixel Ratios Outcomes

We used a two-way between-subjects ANOVA to test any main effects and interaction of Gender and Number of Reference Sides for In/Out State pixel count ratios and In/State Total pixel count ratios. For the In/Out ratios and In/State Total ratios there were significant differences for Gender. For both measures, there was a main effect of Gender for In/Out Ratio $F(1,666)=5.881$, $p=0.016$, partial $\eta 2=0.009$, In/State Total Ratio $F(1,666)=7.575$, $p=0.006$, partial $\eta 2=0.011$.

There were main effects for Number of Sides for both measures, In/Out Ratio $F(1,666)=3.857$, $p=0.009$, partial $\eta 2=0.017$, and In/State Total Ratio $F(1,666)=8.096$, $p{\sim}0$, partial $\eta 2=0.036$. The Ratios for 2 Reference Side states (principally Texas) elevated both ratios (refer to Table 4).

Tukey post-hoc comparisons revealed significant differences were found for In/Out Ratio between 2 Reference Sides and 0, 1 Side conditions ($p{\sim}0$) and between 2 and 3 Reference Side conditions ($p=0.003$). No other significant comparisons were observed. For In/State Total Ratios, there were significant differences between the 0 and 1 Side conditions ($p=0.038$), 0 and 3 ($p{\sim}0$), and 2 and 3 conditions ($p=0.039$). Finally, the ANOVA results yielded a significant result for the interaction of Gender and Number of Sides only for In/Out Ratios $F(3,666)= 4.051$, $p=0.007$, partial $\eta 2$=0.018. Males had significantly lower In/Out Ratios for 2 Reference Side states than the Females.

Table 4. *Means and Standard Deviations for In/Out Pixel Ratios and In/State Total Pixel Ratios across Gender and Number of State Reference Sides*

			M	SD	N
In / Out Ratio	Male	0	2.888	13.135	91
		1	3.716	10.977	109
		2	1.582	6.249	23
		3	3.948	17.530	29
		Total	3.249	12.323	252
	Female	0	1.976	7.196	142
		1	3.872	15.771	183
		2	150.468	643.543	39
		3	4.250	13.224	51
		Total	17.046	200.033	415
	Total	0	2.332	9.930	233
		1	3.814	14.153	292
		2	95.236	513.094	62
		3	4.141	14.819	80
		Total	11.834	158.036	667
In / State Total Ratio	Male	0	0.091	0.096	91
		1	0.116	0.180	109
		2	0.120	0.118	23
		3	0.188	0.130	29
		Total	0.116	0.146	252
	Female	0	0.125	0.154	142
		1	0.167	0.166	183
		2	0.160	0.157	39
		3	0.231	0.168	51
		Total	0.160	0.164	415
	Total	0	0.112	0.136	233
		1	0.148	0.173	292
		2	0.145	0.144	62
		3	0.216	0.156	80
		Total	0.143	0.159	667

Discussion

Measuring mental imagery is challenging. Chronometric studies (Kosslyn et al. 1978) and mental-rotation studies (Shepard and Metzler 1971) have significantly contributed to the understanding of mental visual imagery. More recent work (Friedman and Montello 2006, Friedman et al. 2002, Kerkman et al. 2003) has advanced the literature with implementing thoughtful measurement approaches. This study adds to the existing literature through the novel application of pixel counts to measure area. Pixel count calculations may also be used to create an index of confidence that does not rely on self-report.

The results from this study indicate that using mental imagery to make estimations is influenced by perceptual cues. The fifth-grade students attempted more abbreviations for states with sides on the outline map. There were no differences between the boys and girls for their abbreviations attempts across reference sides. Abbreviation accuracy was higher for states with sides referenced on the outline map. For the most part the boys and girls performed similarly across the reference-side states except that girls significantly outperformed boys for 2-reference sided states, more specifically for Texas. The girls were significantly more accurate than the boys. Moreover, the girls drew the abbreviations for Texas significantly larger than the boys.

Confidence as measured by the ratio of total pixels of the abbreviations to the total of pixels of the respective state. Similar to the accuracy measure, there was a linear relationship between the number of reference sides and the confidence outcomes. Having only one side referenced on the outline map improved the ratio of in-state pixel counts to the state pixel total. The highest ratios were in the states with three sides referenced on the outline map. Having a perceptual cue boosted confidence. The girls had higher confidence ratios across all four reference side conditions. This includes the zero-reference side condition where no perceptual cues were available. These outcomes call attention to mismeasures of female mental visuo-spatial cognition like previous research (Kerkman et al. 2000).

This study provides a proof of concept that pixel count measurements provide value to the area of mental imagery. The advantage of using a map of the continental United States is that the states can be sorted into different groups depending upon the number of reference sides on the outline map. That allows for useful comparisons. Overall, the boys and girls had a wide range of the abbreviations attempts (from 3 to 40/41) and the girls attempted more state abbreviations on average than the boys. The results for the average state abbreviations attempted show a distinct linear decline in attempts both in the boys and girls. Just over a third of the zero-referenced states were attempted while just under two-thirds of the 3-referenced sides states were attempted.

Furthermore, there were no significant differences between the boys and girls for the abbreviation attempts across referenced-side state groups. This indicates that the boys and girls found the task difficult especially for the internal states where there were no perceptual cues to the location of the state. This is particularly interesting because the participants were tested shortly after they completed their segment on states of the United States – learning about locations, capitals, and other information, e.g., state bird and motto. These results underscore that semantic memory and visuo-spatial memory operate independently (Shelton and Yamamoto 2009).

There were limitations in this study. The US states vary in size, spatial position, and the number of sides that are present on an outline map. The irregular outline afforded sets of comparison state side-referenced groups. An advantage of this is that comparisons may be made between states with no perceptual cues to states with one, two, and three perceptual cues (sides referenced). Then there is Texas. Texas is so large and the perceptual cues are so salient that the abbreviation pixel counts overshadowed the other states for the accuracy measure. Texas was the second most-attempted abbreviation after Florida. We debated removing the Texas data from analysis, but decided that those results were valuable to include. Nevertheless the post-hoc comparisons significances for accuracy and number of reference sides were due to the Texas data. The girls took advantage of perceptual benefits of Texas and drew significantly larger abbreviations than the boys and scored higher accuracy.

We did not include independent self-report measurements for confidence. While self-reported confidence measurements could be used to compare with our performance measure of confidence, self-report confidence may be inaccurate (Moore and Healy 2008). Adding in this estimate would add time and potentially distract from the activity. This study utilized a low-technology approach of paper and pencil with the fifth-grade students. The activity seemed like a game to many of them. Going forward, as this approach moves from exploratory to explanatory, it may be helpful to formalize data collection by online or application-based testing where more technological features may be implemented. If the task was programmed to allow participants to use a mouse or stylus to draw in the area, an easy way to indicate self-report confidence would be to allow participants to use color for confidence, e.g., blue for cold (low confidence) to red (high confidence). This could be correlated with the performance measurement of confidence.

A game or online application (a gamification approach) could offer players higher points for using more mental imagery, e.g., zero-reference side states. This could promote more attempts and could be used as a manipulation to observe response bias effects. For example, if the within-the state area reaches a certain value or if there is no area of the abbreviation outside of the state boundary, players earn bonus points. Perhaps, participants can provide different sizes of abbreviations, for example, a 95% Confident estimation and a 75% Confident estimation.

Moving forward, there have been significant development in software applications to analyze drawings and mental maps, e.g., Wallon's (n.d.) ELIAN; Chumakov et al.'s (2021) Creative Map Studio; Aram et al.'s (2019) Aram Mental Map Analyzer; and Gardony et al.'s (2015) Gardony Map Drawing Analyzer, yet all of these program rely on extensive programing focused on specific types of drawing outputs. Nevertheless, these examples demonstrate that automated scoring and analysis of drawings is possible. Perhaps it would be beneficial to apply this approach to more regularized maps/contexts other than using the continental United States with its idiosyncratic state shapes. Having regularized "states" or areas can simplify measurements. Additionally, having the testing materials based solely on using the United States is severely delimiting for generalizing the results.

Conclusions

Studies like the one presented provide a novel strategy to examine the accuracy and confidence of mental imagery and spatial cognition. Direct measures of confidence have been elusive and we offer performance-based solution. Furthermore, our study demonstrates that perceptual cues improves accuracy and increases confidence. Applying these strategies to online applications will connect to a broader population and take advantage of principles of gamification to motivate responses. Furthermore, the development of computational analysis programs show promise to automate the complexities and variations of hand-drawn maps.

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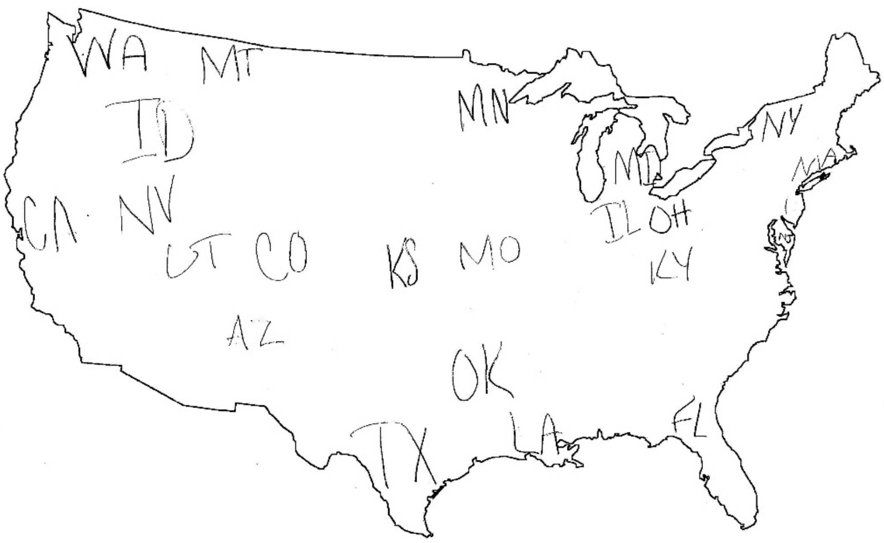
Appendix

Blank Outline Map of the United States

Outline Map Sample with US State Abbreviations



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Metacognitive Failures of Preservice Mathematics Teachers ın Problem Solving

By Zeyneb Betül Kaya & Ibrahim Kepceoglu±*

Metacognitive success is one of the factors that positively affects problem solving skills. Identifying metacognitive failures in the problem-solving process is also important in recognizing the factors that will inhibit metacognitive success. In this study, it is aimed to reveal metacognitive failures of pre-service mathematics teachers in the process of given mathematical problems. The present research on investigated metacognitive failures of pre-service teachers in the process of problem solving is modelled as case study. Data collection was carried out in clinical interviews were conducted with the preservice teachers who were predicted to obtain rich data in accordance with the purpose, using the "think aloud" interview technique, among these pre-service teachers. As a result of the analysis of the data and field notes obtained from the clinical interview voice recordings, 8 different metacognitive failure behaviors were encountered; including "metacognitive mirage" two times, "metacognitive blindness" three times and "metacognitive vandalism" three times.

Keywords: *metacognitive failure, preservice teacher, mathematics education*

Introduction

In contemporary education system, it is important for the students to reach the right information by doing research, to use this information, to manage their own mental process and to gain high level mental skills. In order to be successful individuals in academic and social field, students must have be aware of their own learning style and develop appropriate learning strategies. Metacognition is also important as the knowledge acquired by the student about his own learning. In the previous studies with students in elementary school, the use of metacognitive skills in problem solving process have been investigated in quantitative and qualitative ways (Aydemir and Kubanç 2014, Jacobse and Harskamp 2012, Swanson 1992, Şengül and Işık 2014). According to the results obtained from these studies, the students with metacognition successfully exhibited metacognitive behaviors in the process of problem solving. On the other hand, the relationships between metacognition and problem solving success have been also conducted with secondary and university students (Bakioğlu et al. 2015, Başol et al. 2014, Kapa 2001, Kiremitçi 2011, Yıldırım and Ersözlü 2013). According to the results of these studies, a significant relationship has been found between metacognition and problem solving success. In addition, gaining metacognitive skills to students increased the success in problem solving.

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In contrast to above researches, in this study, it is aimed to reveal metacognitive failures of pre-service mathematics teachers in the process of given mathematical problems. In mathematical metacognitive processes; Metacognitive failure situations have not been studied in different forms, except for not using useful information and lack of control behavior (Goos 2002, Stacey 1992). As explained below, defining metacognitive failures is important in mathematical problem solving processes. Also, nearly any study has been conducted about this subject in literature except Goos (1997, 2002), Ng (2010), Stillman (2011), Huda et al. (2016, 2018), Surya (2019) and Faradiba and Alifiani (2020) in which the term “metacognitive failure” is defined.

Literature Review

Metacognition

Conceptualizations of metacognition have expanded over time within educational psychology and mathematics education. Despite the extensive theoretical and empirical literature on metacognition, there is no consensus definition of the construct. Metacognition was first defined by Flavell (1976) as “one’s knowledge concerning one’s own cognitive processes and products or anything related to them” (p. 232). Flavell (1976, 1979) described several aspects of metacognition, including metacognitive knowledge and metacognitive experiences, as well as the monitoring, regulation, and orchestration of cognitive processes. Soon after Flavell (1976) introduced the term, metacognition, Brown (1978) reviewed existing research on related phenomena, describing several aspects that later came to be recognized as aspects of metacognition, including planning, checking and monitoring, and knowing when and what you know. In summary, metacognition refers to the psychological structures, knowledge, events and processes that are involved in the control, modification and interpretation of thinking itself (Wells and Hatton 2004). A good understanding of the concept of metacognition is possible by explaining its relationship with the concept of cognition. Cognition is defined as the functions and working processes of the brain used in the mental activities of individuals such as attention, perception, understanding, interpretation, discrimination, making sense of information, and reasoning (Bacanlı 2002, Ömeroğlu and Kandır 2005). During the realization of these tasks in cognitive processes, the responsibility for managing the tasks belongs to metacognition. Metacognition refers to a series of processes that an individual uses to monitor ongoing cognition in order to effectively control his or her behavior (Desoete and De Craene 2019, Rhodes 2019, Veenman et al. 2006). Metacognitive activities that occur in the individual occur either before cognitive activities or during cognitive activities. Metacognition includes information about the strategies that an individual uses to fulfill cognitive tasks, as well as self-monitoring and evaluation skills while performing these tasks (Desoete and Veenman 2006, Schoenfeld 2016). When the studies on metacognition are examined (Aşık and Sevimli 2015, Özsoy 2011), metacognition is structurally under two headings as metacognitive knowledge and metacognitive control.

Metacognitive knowledge refers to an individual's knowledge, strategy, beliefs, and cognitive awareness of a task or problem situation. Knowing the solution strategies and solution ways of how to solve a problem correctly, that is, knowing the procedures of a task and being aware of the situation of being able to do this task is within the scope of metacognitive knowledge. Although Flavell (1979) suggested that person, task and strategy variables constitute metacognitive knowledge, Paris et al. (1984) argued that metacognitive knowledge can be organized as declarative, procedural and situational knowledge. These three types of knowledge have often been discussed and expanded upon in later metacognitive studies. In general, metacognitive knowledge refers to individuals' awareness of their own knowledge of their strengths and weaknesses, and includes tasks, strategies, and knowledge related to the achievement of a particular task.

Metacognitive control is defined as an individual's ability to use his/her metacognitive knowledge to fulfill cognitive tasks and to manage cognitive processes (Desoete et al. 2019, Flavell 1979, Özsoy 2008). Metacognitive control skills were examined under four headings: estimation, planning, monitoring and evaluation. It shows that metacognitive control skills have an important place in the learning processes of the individual, as he monitors and evaluates the cognitive processes of the individual and can organize these processes by choosing appropriate strategies according to different situations.

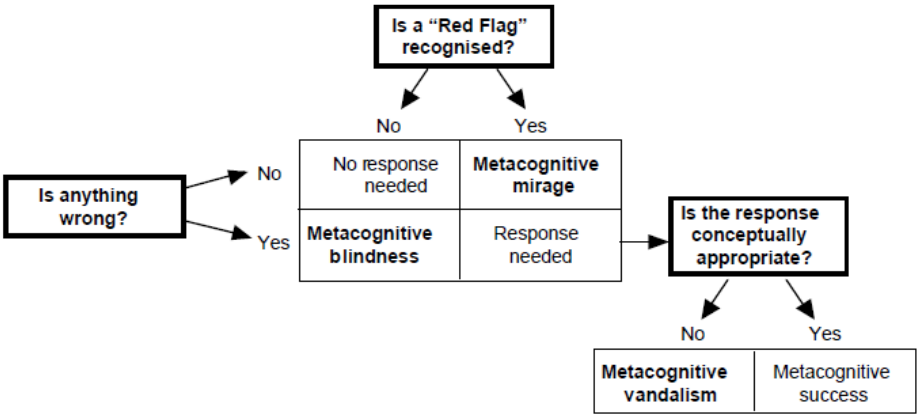
The frameworks outlined by researchers in educational psychology are very similar to the processes of mathematics problem solving as described by Polya (1945), and Garofalo and Lester (1985). The works of these mathematics researchers and educators contextualize regulation by studying how students regulate their thinking during problem solving situations. Previous studies investigating the impact of metacognition on problem solving have shown that people with metacognitive skills perform better in problem solving environments (Balcı 2007, Özsoy 2008, Pilten and Yener, 2010, Bagçeci et al. 2011, Oğraş 2011, Memnun and Akkaya 2009, Kanadlı and Sağlam 2013, Aydurmuş 2013, Azak 2015, Yıldız and Güven 2016, Kaplan et al. 2016, Demir 2016, Lester 1994, Lester et al. 1989). However, as much as the presence of metacognitive behaviours is crucial for favourable problem solving outcomes (Hessels and Hessels-Schlatter 2010), researchers have found that the quality of the nature of metacognitive interactions (Stillman and Galbraith 1998) is just as important.

Metacognitive Failure

The term "metacognitive failure" is firstly defined by Goos (1997, 2002). This term indeed is related to "red flags". Metacognitive red flags can occur at critical junctures where the problem solvers are faced with important decision making pertaining to the success or failure of their attempts. Thus, purposeful, conscious, and at times drastic actions (e.g., pausing for reflection, backtracking, re-doing the problem in another way) may be warranted to change problem solving pathways. Nonetheless, subsequent metacognitive regulatory behaviours (or the lack of them) in reaction to red flag situations also play a large role in savaging or sabotaging the problem solving situation. Goos (1997, 2002) identified three red flag situations in her study of group collaborative problem solving process: (a) lack of progress, (b) error detection, and (c) anomalous or strange results. According to Goos (1997, 2002), red flag situations are distinguished from routine monitoring behaviours (e.g., assessment of knowledge, approach, outcomes) which served to confirm that the problem solving process is on the right track.

Goos (2002) identified three types of metacognitive failures displayed by problem solvers in reaction to red flags. These are described by the metaphors of “blindness”, “vandalism”, and “mirage”. Metacognitive blindness occurs when a problem solver did not notice his or her likelihood of impending failure in solving the problem, opting for instance to continue with an inappropriate approach. Metacognitive vandalism comes into play when problem solvers decide to take destructive action to deal with a deadlock situation (e.g., changing the conditions of the problem so as to suit the fixed mindset of the problem solver). Metacognitive mirage takes place when problem solvers mistakenly change course of actions upon perception of difficulties which in fact do not exist. These metacognitive failures types is schematized in Figure1.

Figure 1. *Metacognitive Success and Failure Scenarios*



Source: Goos 2002, p. 9.

Methodology

Research Design

The present research on investigated metacognitive failures of pre-service teachers in the process of problem solvingis modelled as case study, which is a qualitative study method.

The case study explores a case or event that the researcher cannot control based on the “how” and “why” questions (Şimsek and Yıldırım 2011). From this point of view, case study methodology was found suitable with the aim of the current research because the aim of this study is to investigate the behavior of pre-service teachers in the process of problem-solving according to the metaphor defined by Goos (2002) and to reveal these behaviors 'how' and 'why' occurred.

Participants

The study group of the research is 5 second grade preservice teachers from Kastamonu University, Department of Elementary Mathematics Education. The study group was selected in accordance with criterion sampling, which is a purposive sampling method. Purposive sampling enables the studying of cases, which are thought to have rich information (Patton 2002). The criterion for the selection of these pre-service teachers to participate in the present study was they are considered to be sufficient for the problems to be given because they completed the required courses and additionally they took course in "problem solving and posing" last semester.

Data Collection Tools

The data collection tool was prepared for requiring knowledge and reasoning skills. In order to prepare, firstly, some problems about metacognition and metacognitive failure in the literatüre were examined. Two expert opinions were taken from the field of mathematics education to determine whether the data collection tool are valid and reliable. As a result of the evaluation of these opinions, the data collection tool consisting of 4 open-ended problems was prepared.

The data collection tool was applied to 5 pre-service teachers in clinical interview sections. They were asked to explain the problems they had in the solution processes, explain the reason of the strategy they chose and not delete them when they thought they made a mistake, but instead continue explaining why they changed their minds. Clinical interviews give opportunity to "enter the persons' mind" considering individual difference and their mathematical understanding (Newell and Simon 1972). For this purpose; the participants were expected to solve the problems in the text by using 'think aloud' method (McKeown and Gentilucci 2007). When the thoughts of the pre-service teacher are not explanatory, the researcher asked the leading questions like"Can you explain what you understand about the problem?", "Why did you choose this strategy?" and "What do you think about your solution? Can you explain it?". During the clinical interview, voice recording and field notes were taken.

Analysis of Data

For the data analysis; data tool collection, voice recording and field notes was analyzed based on descriptive analysis. In the descriptive analysis, the data is first described systematically and clearly (Çepni 2014). Afterwards, descriptions are explained according to the conceptual framework of the research, interpreted and cause-effect relations are examined and some conclusions are reached (Çepni 2014). In the research; the data were analyzed according to the metacognitive failure structures, which is described by Goos (2002), whose themes were is "metacognitive blindness", "metacognitive mirage" and is "metacognitive vandalism". In terms of the confidentiality of the research, clinical interviewed participants in the study were coded as PST.1, PST.2, PST.3, PST.4 and PST.5.

Ethical Considerations

The real names of the pre-service teachers participating in the research were hidden and each of them was given a pseudonym. With the permission of the teacher candidates, the interviews were recorded on a voice recorder. After the interview, the transcription of the records was completed and the transcripts were sent back to them for review and approval.

Findings

In this section, the findings obtained in the research are included. As a result of the analysis of the data and field notes obtained from the clinical interview voice recordings, 8 different metacognitive failure behaviors were encountered; including "metacognitive mirage" two times, "metacognitive blindness" three times and "metacognitive vandalism" three times. As stated in the research problem; in this research, it was aimed to show in detail how and why the pre-service teachers exhibited metacognitive failure behavior in the process of problem solving. Accordingly in the findings of the research, one for each the sample presented and discussed about each different metacognitive failure behavior.

Metacognitive Mirage

The first open-ended question where PST1 has encountered a metacognitive failure is as follows:

> *Problem1: You are given101 identical-looking balls and a two-sided scale. One of the balls is of a different weight, although you don't know whether it's lighter or heavier. How many weightings of the scale at least you must use to determine whether it's lighter or heavier?*

The process of solving this non-routine problem that PST1 had never met during the interview is shown below:

> *PST1: So, it sounds like two. At least ... is the probability that it will be the least? (02: 00)*
> *R: How many times will be measured but for a final result?*
> *(She thinks again on the question)*

While PST1 was first reading the question, she considered the problem as a probabilistic problem but gave up the idea with the use of the exact result of the researcher.

R: Tell me what you understand about the question. (03: 12)
PST1: There are 101 balls. One is different as weight, but the image is the same and we need to measure it with a scale.
R: What is asked?
PST1: How many times we need to be weighed in order to find out for sure. 51… I say then
R: How did you find it?
PST1: I make group of 50 balls divided into two groups. 50 as I have 50 measurements in that way, then the last one of the measurements I've made a measure before I thought I would find this way.
R: Do you want to think again? The question is that you are not asked to find the ball itself, only to find out whether it is heavy or light.

PST1 gave a wrong answer by choosing the wrong strategy at 04:00. While she only needed to determine whether the different balls were heavier or lighter than the others, she tried to determine the ball itself by applying 51 measurements. Again, she gave up the way to solve the problem again by repeating the desired.

PST1: Ok ok! I found it. I can split any ball, for example 50 to 50 measurements. Either 50 different balls or one ball will be left out. For example, the ball outside will be different when it is equal. I take one ball from the group (50 balls in the balance) and put the other ball (the ball outside) and I think I'll find it that way. (07: 30) (new idea)
R: So what happens when it's not in balance?
PST1: Can we tell if it is light or heavy? What if we took one of the pans and put them in 25 and then weigh them… but how can we understand from here? (new idea)
[Thinks about the problem situation for a while. (09: 54)]
PST1: We cannot detect it
R: Why?
PST1: For example, the pan is out of balance. Either there is a light ball here (above the scale of the scale) or heavy (here below the scale of the scale). We can't determine which one.

At 07:00, PST1 put forward a "new idea" that could lead to the solution of the problem. In her strategy on 2 probabilities, she followed a correct way of thinking in case of probability (2 weighing operations to determine if the ball is heavy or light).In the event of a possibility, although she was actually on the right track, she could not decide how she could make a determination from there and felt that her strategy was wrong. After thinking for a while;

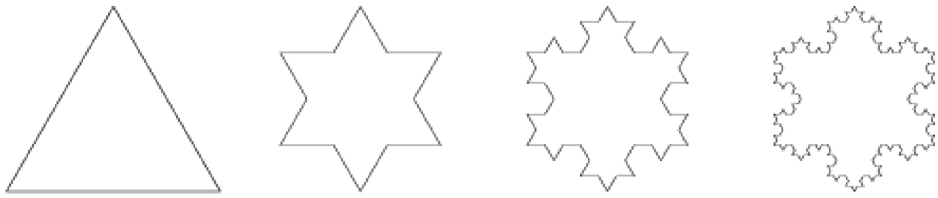
PST1: Then I leave this solution. The first thing I'm saying is 51 because the same thing will come out here.
R: Are you sure about the answer?
PST11: I'm not quite sure, but that's the way I do it.

PST1 thought that she had encountered an anomalous result that is "red flag" "contradictory" warning sign that she had been dealing with a problem she had not encountered before and was not sure of what she understood and knew about the problem. The strategy she was using was unreasonable and did not meet the conditions of the problem. She abandoned the useful strategy to solve the problem. Afterwards, she failed to provide the correct answer to the problem by continuing her old strategy which was wrong. PST1 exhibited a "metacognitive mirage" by detecting a red flag warning sign that does not exist even though there was no error in the problem solving and therefore abandoning a strategy suitable for the solution in the solution process.

Metacognitive Blindness

In this section, the solution process of PST2 in a pattern problem (Figure 2) is discussed. In the question, Koch snowflake pattern was used and the shapes and fields formed in the first two steps were given and the area of the next step and the number of triangles formed in the iteration of k and the area of one of these triangles were asked.

Figure 2. *Koch Snowflake Pattern*



Source: Goos 2002, p. 9.

The solution process of PST2 in the shown pattern problem is as follows: When PST2 encountered the problem, he thought about the problem for about 3 minutes.

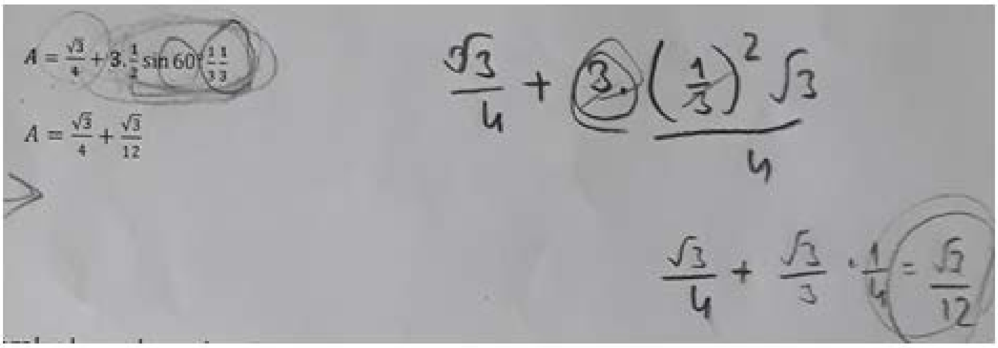
> *R: What do you understand from the question? Can you tell me?*
> *PST2: It thought as a pattern. In step 3 this field will already be. Other than that, I need to find the last addition.* [After a little more thought at 04:00.]
> *PST2: It would be ridiculous, but I didn't understand where this 12 came from. (Number of triangles added in Step 2)*
> *R: You need to find it.*

When he first read the question, he noticed that there was a pattern question and that the area of the previous step was preserved from the text given in the question. But because he didn't carefully examine what was given in the steps in the question, he didn't realize that 12 in step 2 was the last 12 added triangles. If he had studied more carefully what was given in step 1, he could have noticed that three triangles were added and the coefficient 3 in the field formula would speed up the solution process.

> *PST2: "$a^2 \sqrt{3} / 4$" is already the formula of the area of the equilateral triangle. So here he is I thought it could be used, I did not fully understand why it used the sinus formula.*
> *R: You can do whatever you want.*

PST2, by applying the area formula, has reached the same conclusion as given in the question (Figure 3).

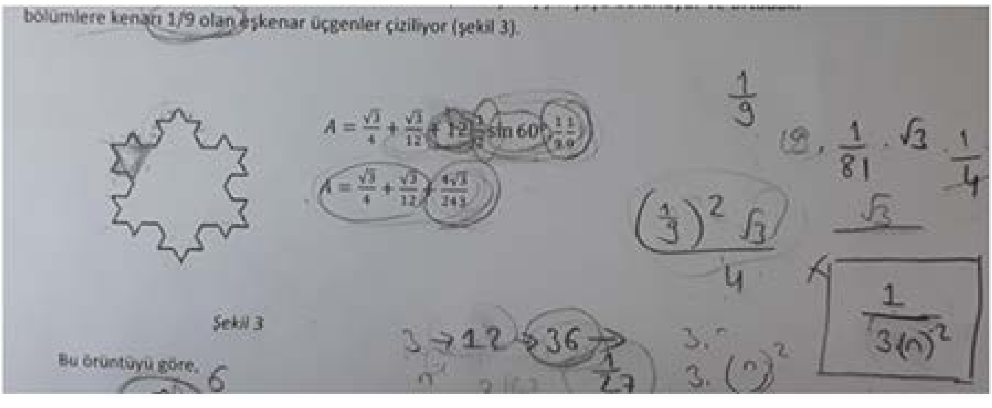
Figure 3. *The Calculations of PST2*



PST2: The pattern will now be 1/3, 1/9 and 1/27. In other words, $1/(3.n)^2$ is used in the pattern (07: 00)
R: What is this formula you found?
PST2: The formula in which the pattern advances If $a = 1/3^n$ then I think 1/27 would be in the third step.

When calculating one edge of the triangles formed in each step (a = (1/3) ^ n) PST2 made an error applying to the field formula (Figure 4). He did not notice that the formula found was incorrect because it did not check whether the general formula it found provided the previous steps (error detection). PST1 then tried to find the area of the shape formed in Step 3.

Figure 4. *The Calculations of PST2*



R: What do you think?
PST2: It had given the same result before (a ^ 2 √3 / 4). Like it gives again.
R: How?
PST2: In the previous example, we found equilateral triangles with 1/3 edge. We also find triangles that are 1/9 with the following formula ($(1/9)^2$) √3 / 4) (evaluation)

He applied his formula and saw that the result was different from the one given in the question.

PST2: Oh, that didn't come out, actually.

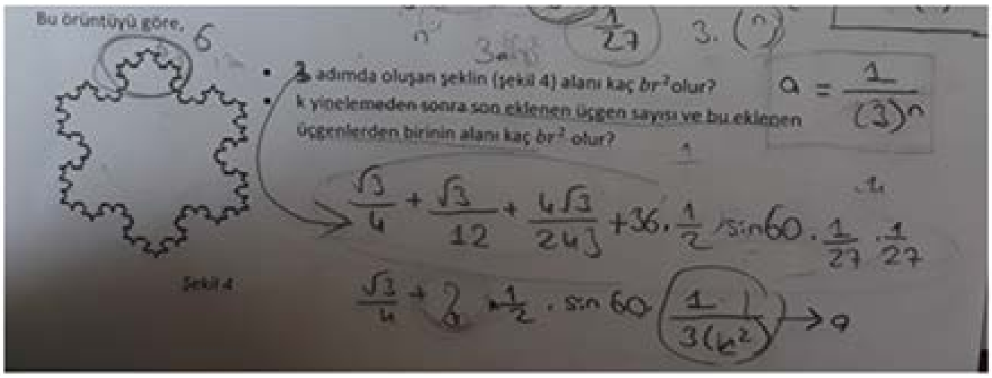
The first time he applied the equilateral triangle field, he reached the correct result because he unknowingly multiplied the area by 3, but when he found the area of a single triangle in Step 2, he encountered an "anomalous result" and realized that he needed to "error detection".

PST2: How many of these triangles do I have that have a triangle whose edge is 1/9? 18 yes I used the number of triangles here (the solution he used for step 1).
R: How did you find 18 triangles? (Evaluation)
PST2: So there were 3 triangles, 3 triangles were made again, I thought it would be 18 because it has 6 corners; but I could not make sense of the relationship between 3 and 18. (evaluation)

After thinking a little [at 17:00];

PST2: Actually, I always thought it was 3 triangles, but it's part of the big triangle, these two triangles are added later. 12 triangles. Then… (doing its operations) .. here (Step 3) 6-12-18… 36 (new idea)
R: How did you find it?
PST2: now that 2 triangles are added to each corner, and that's where the 12 comes from. Here again 2 of these triangles are added to the edge and there are 6 in each corner is 36 I found here. The shape of the shape formed in step is in this way. (Figure 5)

Figure 5. *The Calculations of PST2*



PST2 reassessed the problem solution because he did not find a relationship between the triangles numbers 3 and 18, and realized red flag "error detection" checking for error, he found that the number of triangles added in the figure was actually 12 and showed a successful metacognitive movement. Then, when he calculated the number of triangles formed in step 3, he thought that 48 triangles should be added because he thought that only the last formed triangles were divided into three identical parts, not the whole edge of the shape and 36 triangles would be added. If he had followed the steps in the figures, he would have achieved the right result.

> *PST2: I'm trying to figure out what these 3 12 and 36 patterns look like, but it doesn't, unfortunately (lack of progress) (22: 00)*
> *After considering the question for a certain time;*
> *PST2: Sorry I couldn't find it*
> *R: Is the number of triangles added?*
> *PST2: Yes. I couldn't find the pattern of the added triangle number.*
> *R: Why? Where could you have made a mistake?*
> *PST2: I don't know I couldn't relate*
> *R: Well you couldn't find the number of triangles added. What could be the area of one of the last added triangles?*
> *PST2: I need to find it here, so I need the coefficient at the beginning (number of added triangles) I can't find it either*

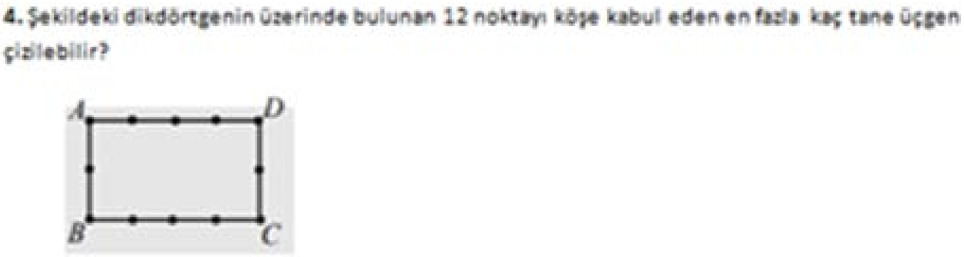
PST2 gave an incorrect answer in the first stage of the problem because he found the number of added triangles 36 in step 2, which he found during the solution process. Then he could not find the number of triangles that would occur in the iteration because he could not find a relationship between the number of added triangles (3 and 12). At this stage, PST2 encountered a "lack of progress" which is red flag but ignored the "error detection" that it had successfully provided in the previous solution steps. If he had noticed this red flag and checked his operation and re-examined the given data (for example the figure in step 3), he would have been able to detect the error at this stage and successfully solve the problem.

In the previous process, PST2 also incorrectly created the field formula of the triangle and did not validate the general formula it obtained and ignored the red flag of error detection. In the second part of the problem, he thought that he could not solve the question because the number of triangles added to find the last added triangle area did not need to be known. It has been observed that PST2 has "metacognitive blindness" behavior due to the fact that it does not notice the red flags that appear at different moments (at 7:00, 17:00 and 22:00) and that it should review the problem process again and therefore fail to solve the problem.

Metacognitive Vandalism

This section discusses the solution process of a combination problem (Figure 6).

Figure 6. *The Combination Problem (Question in English: How Many Triangles can be formed by using 12 Points as One of Their Corners)*

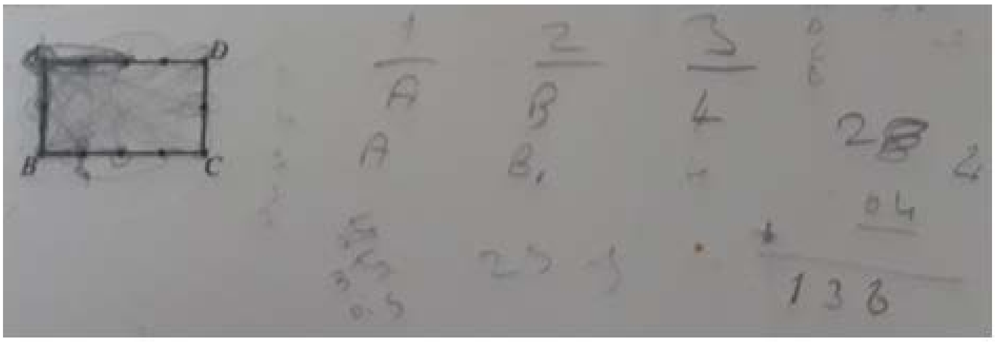


The solution process of PST3 in the illustrated problem is as follows:

PST3: I often find these questions counting quickly, but this may not be the question.
R: Do you want to apply?

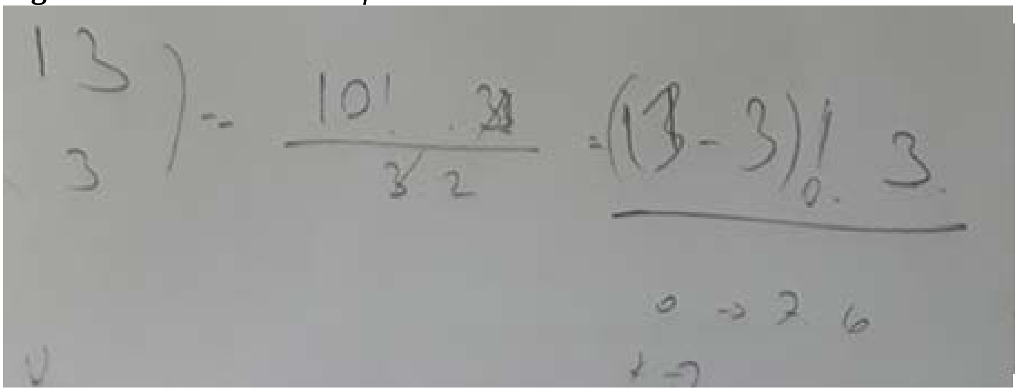
ST3 tried to solve the question by using the counting method, but as he said, the counting method was not an appropriate method for this question. At the end of the solution, the PST3 encountered an “anomalous result” (Figure 7).

Figure 7. *The Calculations of PST3*



R: The result you found is not correct. As you said, the counting method is too long for this question. Can you solve this question any other way?
PST3: I can do anything. I get all three states in combination, but those that don’t work for us (linear dots) take them out of all these three. (new idea)
R: How to do?
PST3: I have 13 points. 3_combinations of 13… something like this (Figure 8)

Figure 8. *The Calculations of PST3*

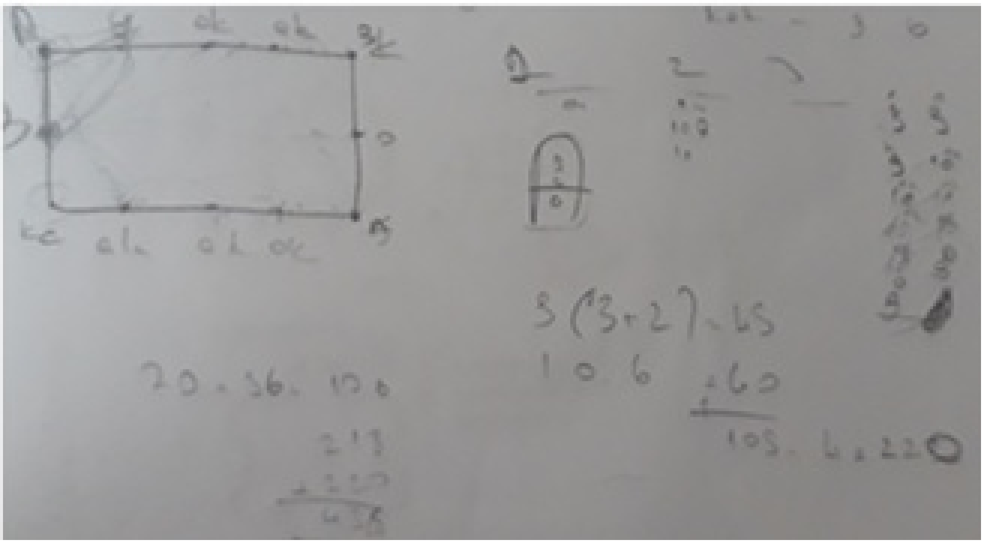


When searching for a new solution for the question, PST3 proposed a “new idea” that could lead him to the right answer, but because he did not examine the question carefully. He took the 12 points given as 13 points and made a wrong application because he remembered the combination formula incorrectly. As the result of his transaction would be a very large number, PST3 was unable to continue the operation and was encountered a lack of progress (at 03: 28).

> *R: Are you sure you are doing the right operation?*
> *PST3: No, I made a mistake somewhere. It wasn’t supposed to happen. (reviews) I'll do it again by counting.*

PST3 recognized the red flag “lack of progress” at 03: 22, but when he “error detection” he decided to apply the method he had previously tried and failed instead of trying to understand the question and detecting the errors in the solution. He decided to apply the counting method with reference to different corners this time, after a long period of struggle, 13:55 minutes reached the following solution (Figure 9).

Figure 9. *The Calculations of PST3*



R: Your answer is not correct again. Where could you have made a mistake? Could you use another solution?
PST3: I don't know, but I would try to find it again by counting.

PST3 knew that counting would not be the right strategy when faced with the problem and did not reach the right result when he first used it (Figure 7). Then, the preservice teacher who noticed a "new idea" using the right strategy did not read the question carefully and misused the combination formula once again caused a faulty solution (Figure 8).

Even though he noticed the "lack of process" red flag indicating that something was wrong in his solution, he chose to use the counting method, where the probability of finding the right result was rather poor, rather than giving correct feedback and correcting the wrong points. As a result, it was seen that he noticed red flag but could not give correct feedback and because it was easier for him to solve the problem, he chose the wrong strategy and displayed "metacognitive vandalism".

Conclusion and Implications

As a result of the data analysis obtained from the study, preservice teachers may display some metacognitive failures in problem solving sessions where they over-looked a "red flag" indicating a calculation error (blindness), responded to a lack of progress "red flag" by imposing an irrelevant conceptual structure on the problem (vandalism), and imagined an anomalous result "red flag" in mistakenly rejecting a correct answer (mirage). Especially they mostly show metacognitive blindness when they are weak in metacognitive problem-solving behaviors such as carefully analyzing the instructions given in the problem understanding what is desired in the question and using the right strategy. The metacognitive blindness exhibited by PST2 was caused by ignoring the "error detection" red flags in the second stage. This result is similar to the findings of the studies in the literature (Goos 2002, Huda et al. 2016, Surya et al. 2019). The metacognitive mirage behavior occurs when they work to solve a problem that they have not encountered before, that the solution does not know exactly the appropriate strategy and that they do not have sufficient level of judgment to prove the correctness of their solutions or strategies. In the example of PST1, the candidate thought that there was an "anomalous result" warning sign or red flag in his answer because he was not sure about the solution strategy that could reach the correct result, and exhibited a "metacognitive illusion" by abandoning the useful strategy. This finding is similar to the result of the study conducted by Goos (2002) in which metacognitive successes and failures based on collaboration were examined with high school students. Metacognitive vandalism behavior occurs mostly when they are trying to solve the problem with similar problems in the past by trying to apply the strategy to solve the problem in order to facilitate the solution to the current problem or even though he is not sure of the appropriate strategy because he is not sure of the appropriate strategy. In the PST3 example; although the red flag "lack of progress" caused by the wrong solution strategy was noticed, not being inclined to the correct solution strategy caused the continuation of the strategy that was not suitable for the solution of the problem. As a result, the preservice teacher did not get the correct answer. The result obtained in terms of giving devastating feedback to the "Lack of progress" red flag is Huda et al. (2016) and Goos (2002) can be said to be in line with the findings.

Huda et al. (2018) stated that lack of metacognitive assessment may cause metacognitive failure. In this sense, handling a similar study together with the metacognitive assessment dimension may provide richer results regarding the causes of metacognitive failure. Finally; in the study of Goos (2002), a study in which metaphors of metacognitive failure were introduced, was conducted with collaborative groups. A similar study to be carried out with pre-service teachers can reveal whether the cooperative learning environment will prevent metacognitive failures.

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