**Underground warfare in the Gaza Strip and the military complexity of combating it**

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The past decades have seen the development of terrorist and guerrilla activity in the shallow subsurface of the Gaza strip. This began with small smuggling tunnels between the Egyptian and Gazan sides of the divided city of Rafah, which then became an underground route for the transit of goods and later for building diverse and effective networks for military engagement with Israel. This development is the result of a unique combination of historical, geological, geographic, political, and military factors. Gaza’s geographic and geological attributes provide an important infrastructure for this. Its shallow subsurface geology makes it possible to mine tunnels using basic tools and local geological knowledge. At the same time, these factors also pose significant difficulties for detecting subsurface spaces using close and remote geo-technological and military methods and systems.

The development of underground warfare in the Gaza strip has undergone many stages. For decades, Israeli decision makers failed to fully comprehend the reality and unique attributes of the underground threat and the importance of developing an effective, holistic toolbox of military, technological, and engineering solutions. This motivated Hamas’s military wing in Gaza to develop an underground network to serve logistically in its defensive and offensive engagement with Israel, since the 2000s and to this day.

This paper reviews the main elements and impressive evolution of the Gaza Strip’s subsurface exploitation for various combat purposes, the future implications of this exploitation, and the complexities of dealing with it from a military perspective.

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**Introduction**

The use of underground subsurface tunnels for military, defensive, and offensive purposes, as well as civilian uses, has been known for thousands of years in Israel and around the world.[[1]](#endnote-1) Throughout the State of Israel there is currently a variety of active subsurface systems alongside relics of such systems. These include ancient burial systems, historic water facilities, tunnels along the National Carrier pipeline and the Ashkelon-Eilat oil pipeline, as well as road and mining tunnels. Nowadays, in the modern age, the shallow subsurface is a well-developed, vital, and prevalent component of private and public buildings, parking lots, and infrastructure deployment.

 Israeli security forces have been dealing with the threat of tunneling and subsurface systems in the Gaza Strip since the peace treaty with Egypt took effect in 1982. Following the Al-Aqsa events in 2000, Israel increased its activity against the intensifying tunneling. This has involved tactical strikes, some of which have been strategically significant. Among other things, these strikes have included the detonation of an armored personnel carrier carrying explosives on the Philadelphi Route in Rafah (2004) and Israel’s tactical, political, and strategic campaign surrounding the kidnapping and return of Corporal Gilad Shalit (2006). Shalit was kidnapped through an invasive offensive tunnel as a result of Israel’s deficient tactical operational response and systemic failure in conducting the battle immediately after the kidnapping (it completely prohibited military entry into the Gaza Strip and prevented soldiers from firing at the retreating terrorist squad to stop the kidnapping in its tracks).

 Operation Protective Edge (in the summer of 2014) included successful offensive tactical actions by Hamas, who made use of the subsurface. Hamas squads used underground tunnels to penetrate Israel and attack Israeli soldiers. First Lieutenant Hadar Goldin was kidnapped and killed using an unknown tunnel at the end of the operation, and widespread use of the subsurface was utilized by various terrorist and guerrilla organizations to launch mortar bombs and steep-track rockets out of launching holes throughout all the stages of combat. As a result of the IDF’s inept conduct in regard to detecting and destroying these offensive tunnels, and its failure to curb steep-track firing from the Strip throughout the operation, Hamas gained strategic wins through underground combat.

 It was only in 2018, four years after Operation Protective Edge and 30 years since Israel’s security forces had begun to use geo-technological methods for dealing with the underground threat, that an impressive defensive and apparently effective obstacle system was deployed. This was done with the investment of vast sums of money and at the expense of agricultural lands belonging to the Jewish settlements surrounding Gaza. The system is directed solely at offensive tunnels. Israel’s security forces are also beginning to detect offensive tunnel sections that were not completely destroyed during Operation Protective Edge, as well as new tunnels that have since been created. They have been successful in effectively destroying tunnel sections and it appears this success is the result of operations by the special ground forces and recently established unique professional-divisional bodies (the “brain lab”).[[2]](#endnote-2)

 Much has been written about tunnels and underground warfare in the Gaza Strip. This mostly includes articles in the media and several papers published on academic and professional military platforms.[[3]](#endnote-3) Some were written in Hebrew,[[4]](#endnote-4) while international publications have focused on the political aspect of the field.[[5]](#endnote-5) Some of the publications are rife with weak attempts to present the use of Gaza’s subsurface as an innocent effort to deal with Israel’s military and political aggression. A comprehensive book about underground warfare and its legal and political implications has recently been published.[[6]](#endnote-6) However, the book does not approach the issue from a holistic perspective regarding the tunnels’ properties and the intricacies of combat. Likewise, no in-depth research has been conducted on the effect the Gaza Strip’s geographical and geological conditions have had on the development of the subsurface threat Israel faces. Moreover, there has been no public discussion regarding Israel’s security forces’ professional-organizational approach to developing reliable technological and geo-technological tunnel detection methods and the basic physical feasibility of doing so.

 This paper reviews the central elements of the subsurface and its development for building forces and warfare capabilities in the Gaza Strip and its surrounding area. It points to the complexities of combating the threat of subsurface exploitation and attempts to explain the professional and organizational reasons behind the IDF’s difficulty in coping with it. The paper presents an analysis of military, geological, and geographical knowledge alongside information published in the public media. In this context, the lack of physical access to the tunnels and incomplete scope of knowledge due to the high level of classification are inherent limitations.

**Professional Background**

***Human perception of subsurface tunnels and networks***

Subsurface tunnels and networks in the Gaza Strip are different from those we know from the civilian world. Tunnels are generally manmade shelters that mostly serve as hidden routes for various purposes. They are underground spaces containing gas or air and create a disruptive anomaly in the geo-mechanical and geophysical properties of the subsurface.[[7]](#endnote-7) Tunnels are generally dug in rocks or natural sediments (such as sand, dust, and river erosion) consolidated and strong enough to enable the mining of a reasonably stable space. For the most part, there are no tunnels in the subsurface layer of soil used for agriculture due to its shallowness, insufficient consolidation, and mechanical strength.

 As aforementioned, in most cases a tunnel is manmade. It has entry and exit points with a long route stretching between them that may branch out to spaces of various sizes. The entrance and exit openings can be vertical pits or sloping routes. Tunnels are commonly imagined as going along a single horizontal and fairly uniform route, as is the case with civilian tunnels. However, there are currently networks of tunnels of varying slopes in Gaza, and therefore tunnels should be presented in a more general and complex way - i.e. as underground systems.

 There is some confusion regarding the distinction between tunnels and caves. Generally speaking, a cave is a space in a rock created through natural processes with an opening on the rock’s slope or precipice, with one central entrance. Caves have various geometrical shapes, sizes, and lengths. There are also some natural subsurface spaces with no entrance and exit openings that become exposed during mining activities. These, too, are caves. In light of the development and variety of the properties of underground spaces in the Gaza Strip, they can be defined as “spaces in the subsurface.”

***Primary uses of the subsurface***

Throughout the history of humankind, the subsurface has been exploited for military purposes mainly in relatively stationary conflicts and along borders, in order to cross geopolitical lines. In World War One, tunnels were dug under enemy positions. North Korea mined underground cross-border logistical tunnels hundreds of meters long in the rock layer leading to South Korea.[[8]](#endnote-8) In the Vietnam War, the subsurface was used for storage and refuge, as well as dynamic offensive movement and activity.[[9]](#endnote-9) Offensive subsurface caves were mostly operated in nonurban areas.[[10]](#endnote-10) In many cases, subsurface systems served the weaker or poorer side on the tactical and systemic level, one reason for this being its lack of control above ground. Escape tunnels mined from camps or houses using subsurface systems (such as sewage or infrastructure pipes) are a good example of this type of reality and are termed “clandestine tunnels.” The weaker party’s use of subsurface systems has often caused the stronger party to suffer many difficulties and casualties. It also served to prolong and complicate the battle, which ultimately ended with the stronger side gaining the upper hand.

 The use of tunnels involves many risks, as miners are well aware. Tunnels can become traps while they are being mined, lived in, fought in, and even as they are being destroyed. When mined without strict adherence to professional rules they become highly dangerous -- tens of young men and boys were killed when tunnels collapsed as they were being mined in the Gaza Strip.

***Perception difficulties***

Human beings walking on the face of the earth in a transparent three-dimensional space filled with air have perceptual difficulty when it comes to understanding the reality and implications of the shallow three-dimensional underground space beneath their feet. Tunnels are hidden and dark, and humans shy away from the subsurface. In many cultures, people are buried in shallow underground spaces just below the surface, a fact that perhaps creates a natural aversion to the subsurface dimension. Eerie, mystical images such as Hell and Hades are linked with the underground dimension, alongside expressions of sin and evil. On the other hand, the heavens are associated with faith, hope, deliverance, and fulfillment. However, big cities around the world have many artificial underground spaces and infrastructures (for trains, parking lots, drainage and sewage systems, etc.) and people generally feel quite comfortable in them. This is because they are accessible from the surface, are lit and ventilated, and do not require direct contact with rocks, soil, sediments, and the natural humidity.

 And yet, decision makers and the legal system give little attention to modern civilian subsurface systems, which is why the juristic aspect of their civilian and military nature remains vague.[[11]](#endnote-11) This allows non-state actors to make extensive use of them for aggressive and violent activities. Thus, for example, mining an offensive tunnel into the subsurface of a sovereign state is not perceived as a clear violation of sovereignty.

 An interesting phenomenon regarding the use of subsurface systems and the military response to it is the inconsistency of both the instigating and responding parties in formulating an underground combat doctrine and assimilating the lessons learned after the battle has ended.[[12]](#endnote-12) A possible explanation for this enigma is that for the instigating side, which is generally the weaker one, losing the battle does not allow or prompt a military and historical account of the events. On the other hand, for the winning side, the difficulties and complexities of engaging in subsurface combat (e.g. the length and nature of the battle, the casualties suffered, and the lack of an absolute victory) does not motivate it to write about and commemorate the rough ordeal of ending the battle.

***Classifying subsurface tunnels and systems***

There are currently three main types of subsurface systems in the Gaza Strip. This reality points to the complexity and sophistication involved in exploiting the Strip’s subsurface. Each system has a different purpose (see Table 1):

1. Smuggling tunnels
2. Offensive tunnels (see Figure 1)
3. Depth tunnels

The Gazan tunnels developed in the following order, with several variations for each type of tunnel (see Table 2).

The IDF’s Planning Division defined these tunnel types back in 2008, along with a fourth type: strategic tunnels or underground bunkers deep in enemy territory.[[13]](#endnote-13)

 Smuggling tunnels between the Gaza Strip and Egypt are an important economic axis for transferring goods and weapons as well as terrorists and guerilla activists; thus, they are used to build military forces in the Gaza Strip. The intensive use and large number of smuggling tunnels created the perception that they were mainly used for civilian purposes and that therefore there was no point in destroying them. Also certain geographers in academia, even up to Operation Protective Edge, held the view that these tunnels were of great economic importance and presented no military threat.[[14]](#endnote-14) Offensive tunnels include tunnels intended for detonating explosives under Israeli infrastructures (military posts, settlements, passageways) and mobilizing fighters to attack and kidnap Israeli soldiers and civilians within and without the Gaza Strip. Offensive tunnels are used to penetrate the surface within the State of Israel, an act that has not been known to be used against Egyptian police and military forces.

 We have very little visible information about subsurface systems deep in the Gaza Strip. These systems are several kilometers away from areas of tension with Israel and are located in orchards and groves and mainly in densely populated urban areas. There are command and control tunnels as well as combat tunnels connecting public buildings and residential ones. There are also dedicated tunnels and subsurface spaces for automatic and semi-automatic steep-track firing that require removing a camouflaged cover, and it is also likely that there are systems for other uses. These subsurface systems are difficult to detect with conventional methods involving imaging and deciphering aerial photographs, even if these are high-quality photographs taken from low altitudes with high resolution. Aerial attacks on subsurface systems for steep-track firing often do not lead to direct casualties among those firing the rockets, while inaccurate fire can harm children and civilians living nearby.[[15]](#endnote-15)

 There are three subsurface systems in the Gaza Strip that come together to create a strategic effect: the smuggling tunnels are crucial for managing the Gazan economy (and more accurately, Hamas’s economy) and building Hamas’s military force; the depth tunnels serve for command activity, storage, and tactical and strategic firing deep into Israel’s territory; and the offensive tunnels play a central role in Hamas’s ability to attack Israeli civilians and the IDF and constitute a psychological deterrent. In light of this, the Gaza Strip’s subsurface systems threaten and greatly influence the way the strategic, political, and military battle against Israel is managed, despite Hamas’s military inferiority in all aspects of the conflict other than the subsurface field.

***Tunnel mining and dimensions***

For years, up until Operation Protective Edge, combat soldiers and engineers created the impression that the Gazan tunnels were dug about 4–14 meters under the surface, despite rumors that were circulating back in 2005 (around the uprooting of Gush Katif) that there were tunnels about 30 meters deep. The assumption that the tunnels’ depth was fairly constant and within the range of 4–14 meters was supported by the seismic wave velocity measured in the shallow subsurface in the Kerem Shalom area.[[16]](#endnote-16) In that area, up to a depth of about four meters, wave velocity is relatively low, which is indicative of weak density and consolidation of sediments and buried soils (paleosols). From about 14 meters and below the wave velocity rapidly increases, indicating a higher density and probably consolidation caused by sediment compression under the weight of the sediments above. The increased strength and consolidation of the subsurface infrastructure could slow mining, make digging conditions more difficult, reduce digging quality, and affect the quality of the air underground. Since Operation Protective Edge there have been many reports about deeper tunnels, however, it is unclear whether their depth was measured during the operation. Over time, the Gazans have developed deep digging capabilities and improved their use of methods that support the mining process.

**Geographical and geological conditions and their effect on subsurface activity**

***Geology***

The development of the subsurface in the Gaza Strip stemmed from a combination of several geographic conditions. Substantial parts of the Gaza Strip have excellent physical conditions for digging subsurface systems. Over time, its location in the southeast corner of the Mediterranean Sea on the fringes of the global desert strip led to the development of an intersection between various sediments carried by the wind, chiefly Aeolian (windborne) sand. Sand from the beach or North Sinai dune field and thin dust came from the west, mainly North Africa, created a mixed infrastructure of loam and dust that accumulated and developed over time into a geological slice in the shallow subsurface built of layers of consolidated sand. The geotechnical properties of this layer make tunnel mining very easy.

 The topography of the Gaza Strip is dictated by sandstone ridges that until 50,000 years ago had been amassing as elongated dunes along the edges of the seashore. This coincides with the general location of the ancient Mediterranean seashore, which in certain places was located more to the East, and in others more inland compared to its present-day location.[[17]](#endnote-17) These elongated dunes were very different from those we currently see today along Israel’s coastal plain, which makes them difficult to imagine. Three sandstone ridges sprawl along the Gaza strip, parallel to the shoreline, reaching an altitude of up to 90 meters above sea level (see Figure 2). The solidity level of the sandstone, which is the only natural stone in the Gaza Strip, is inconsistent, but it is generally not very solid.[[18]](#endnote-18) There have been no reports or evidence of smuggling tunnels mined in sandstone, at least not until Hamas took over the Strip in 2007. Apparently, this is due to the inconsistent consolidation and relatively high solidity of the rock in certain places compared to ancient soils.[[19]](#endnote-19) In light of the development of the smuggling tunnel industry after 2007, it is likely that tunnels or tunnel segments have also been mined in sandstone.

 Between and around the sandstone ridges are valleys filled with a slice of several meters of sediments that include Aeolian sand and dust as well as ancient weathered and washed-out products from the sandstone ridges.[[20]](#endnote-20) These sediments contain a substantial and varied sandy component and the consolidation comprises lime (calcium carbonate) originating from dust and remnants of tiny marine animals swept to land along with the sand from the seashore. The soil developed through a process of sand precipitation followed by dust precipitation. Cycles, often spanning thousands to tens of thousands of years, during which the soil developed as a result of invading sand or loess soil (a sediment made up of thin sand, silt, and dust), occurred alternately (during periods with stronger winds than we currently experience) and created an underground slice comprised of layers of ancient buried soils (paleosols). These buried soils solidified over time under increasing cumulative pressure as sediments continued to amass on the surface and liquefied lime solidified.[[21]](#endnote-21) Nowadays, there are practically no amassed sediments of sand and dust on the surface.

 The further south in the Gaza Strip, the fewer sandstone ridges. The sandy component of the sediment increases (compared to the dust) in the valleys between the ridges and the plains in the southeastern area of the Strip,[[22]](#endnote-22) where the slice of buried sandy soils reaches a depth of no more than 15 meters. In the northeastern area of the Strip, the sediments mainly contain loess sediments (that cover the Be’er Sheva-Netivot area) with a larger clay and silt component compared to the southern area of the Strip. The loess layer also contains ancient soils with a substantial amount of lime. The ancient soils containing sand and loess consolidated in lime are very convenient for tunnel digging, and the more solid layers of lime make it possible to stabilize the tunnel walls while they are being mined.

 The western part of the Gaza Strip is covered with fields of unconsolidated sand plains and dunes extending from the seashore. Previous studies conducted on similar dunes in Israel’s coastal plain show that in terms of the interaction between the sand dunes and archeological sites in Gaza, a substantial amount of this sand spread and accumulated around the Byzantine era (about 1400–1700 years ago). According to these findings, it is possible that the dunes only developed around the 19th century.[[23]](#endnote-23) As the sand is unconsolidated, there is almost no tunnel mining in this sediment. However, initial mining attempts were made in the early 2000s, possibly by unprofessional diggers.

**The importance and impact of drainage systems, surface water, and groundwater in the Gaza Strip**

Since the dawn of history, life and the extensive agriculture in Gaza have been based on utilizing high groundwater. The groundwater level gradually approaches the surface towards the sea (west) from a depth of about 70–100 meters in the East to one meter in the West near the shore.[[24]](#endnote-24) The Gaza Strip has hundreds of wells, the depth of which has been increasing over time, especially since advanced pumping systems have come into use. This has caused the groundwater level to go down and has harmed the quality of the water.[[25]](#endnote-25) The groundwater level is relatively close to the surface in the valleys between the sandstone ridges, where fertile thin-grain soils spread out and most of the wells in the Strip are located. These wells have provided the infrastructure for life in the past and present. There are no known tunnels mined in the groundwater in the Strip and the IDF’s working assumption has been that no tunnels will be mined in this area. It is worth noting that smuggling tunnels on the border between Mexico and the United States in the San Diego area were dug in groundwater.[[26]](#endnote-26) In the 20th century, the high groundwater near the shore (one to two meters deep) was used for agriculture by digging in the sand almost down to the groundwater level and pumping the water out of a shallow hole using simple mechanical methods. In the Gaza Strip, this method is known as “Muasi agriculture” and seems to have developed along the coastal plain of Israel in the ancient Islamic period, approximately one thousand years ago.[[27]](#endnote-27)

 The natural drainage system in the Gaza Strip is also unusual and is dictated by the sandstone ridges and invading sands. Nowadays, only the Besor stream, also known as “Wadi Gaza” in the Strip, which drains about 3,000 square kilometers of the Negev’s northwest area, runs across the entire center of the Strip into the Mediterranean Sea[[28]](#endnote-28) (see Figure 2). The sandstone ridges (or ancient dune ridges back then) blocked water channels and diverted them towards the Northeast[[29]](#endnote-29) and periodic invasions of shallow sands from the sea over hundreds and thousands of years blocked ancient drainage systems.[[30]](#endnote-30) For this reason, aside from the Besor stream basin, the shallow underground slice of the Strip also has very few elements from streams, such as pebbles, which can make mining and stabilizing tunnel spaces difficult.[[31]](#endnote-31)

The invasion of sands and dune fields expanding northeast of the shoreline over the past 2000 years has had very little influence on the drainage systems. The progression of sands and dunes pushed some of the streams north and blocked the channel passages in the sandstone ridges. As a result of these processes, there are some blocked channels in the north and center of the Gaza Strip (aside from the Besor stream).

The line separating Israel and the Gaza Strip (based on the 1949 Armistice Agreements) and the border between the Gaza Strip and Egypt cut across landscape components with various geological slices, which impacts the geotechnical effort required to mine tunnels in the various areas. Along the Gaza Strip-Egypt line, digging is difficult along a 2-kilometer segment of unconsolidated sands south of the shore. In the southeast part of the Strip is a wide sandy plain that is a continuation of the Kerem Shalom plain in Israel, which is used extensively for agriculture. The subsurface layer under this sandy plain provides the most convenient infrastructure for digging tunnels. In this space, and mainly since the IDF’s withdrawal from the Gaza Strip, smuggling tunnels to Egypt as well as many attack tunnels to Israel have been dug. These include the Gilad Shalit tunnel, the tunnel that was used to attack the Kerem Shalom tower at the start of Operation Protective Edge, and the Hadar Goldin tunnel that was used at the end of Operation Protective Edge. Here, along the Philadelphi Route from the south of Rafah to the Kerem Shalom passage, the smuggling tunnel industry evolved in the open.[[32]](#endnote-32)

Between the center of the Strip and Israel, sandstone ridges and creeks flowing from the Besor stream make it difficult to dig long invasive attack tunnels. Stretching out north of the Besor stream basin, in the Nahal Oz passage area, is an even-leveled valley created by the Erez stream, which is one of the creeks branching out from the Shikma stream. The valley and its creeks are filled with a slice of ancient soils created by loess sediments and sediments containing more clay. The northern border between Israel and Gaza in the Netiv HaAsara area is similar to the southern line in the Rafah area, however, the sandstone ridges are more developed and the sediments in the valleys have a thinner component. These sediments are convenient for tunnel mining and indeed tunnels have been mined in this area since the IDF’s withdrawal in 2005, although many of them have been blocked by the IDF.

**Development stages and characteristics of underground combat in the Gaza Strip**

The stages of underground combat activity in the Gaza Strip have been dictated by geopolitical conditions, a different perception of reality on each side, the intensity of the ongoing security situation, and the response to underground threats on Israel’s security forces.

 In most cases, each stage served as a preliminary stage to the one that followed. The stages also had a big impact on the nature of the battle initiated by each side. All these stages focus on the Gazan side, which initiated the activity, aside from the last stage, which is when Israel became determined to address the threat that had already been realized and which continues to increase and present a challenge (see Table 2):

1. **The early days – 1982–1994:** Mining and operation of smuggling tunnels in the divided city of Rafah that enable the passage of family members and a few goods. Although the tunnels are not used for terrorist purposes, Israel begins to take an interest in geotechnical solutions[[33]](#endnote-33) and approaches civilian companies in search of tunnel detection methods.
2. **The development stage – 1994–2000:** During these years there is a rise in the number of tunnels used for smuggling goods and weaponry between Egyptian Rafah and Gazan Rafah, which is now controlled by the Palestinian Authority under the Oslo Accords. During this period the Philadelphi Corridor, which is about 200–250 meters wide and separates Gazan Rafah from Egyptian Rafah, remains under the control of the IDF above ground, while tunnels are being mined and operated beneath it.
3. **The first intensification – 2000–2004:** The smuggling of weaponry and tunnel mining in Rafah increases following the El Aqsa events in 2000 (see Figure 4). As a result of the IDF’s preparations to invade the Strip as part of Operation Protective Shield, the smuggling tunnel pits in Gazan Rafah become well-hidden in houses, often under furniture and cradles. The IDF performs ground operations to detect tunnel openings and achieves partial success, while being subject to international criticism for causing damage to civilian homes.[[34]](#endnote-34) Israel’s security forces amplify their engagement with civilian companies in an attempt to find a geo-technological solution.

The IDF develops and implements large-scale engineering activity with an aim to detect and destroy tunnels. This includes drilling, underground explosions, and building a tenoning wall four meters deep and about eight meters high along the Philadelphi Corridor. The explosions cause damage to some of the tunnels, mainly in the section that passes under the corridor. Once a dent in the ground is created by an explosion, the engineering team reports that the tunnel has been destroyed without checking and verifying this by penetrating the subsurface. The explosion activity takes place without any knowledge of the cumulative effect it has on the properties of the subsurface and surface area. Underground spaces might develop and collapse, becoming a trap for IDF forces, particularly heavy combat vehicles operating on the ground. The tenoning wall is only four meters deep, apparently due to budget restrictions,[[35]](#endnote-35) and allows tunnels to be dug deeper. At the same time, it protects the IDF’s movement behind the wall and keeps it hidden from houses in Gazan Rafah. The Engineering Corps also operates a tunnel team that penetrates the tunnels and conducts basic documentation. In 2004 the team is given formal status and is expanded into a unit known as SMOR (a Hebrew abbreviation of “Weapon Stashes and Tunnels”).

The IDF places the Engineering Corps in charge of the subsurface area. The corps does not map the subsurface in terms of its geology and geo-engineering to understand the characteristics of the tunnel mining medium, or how the geological structure affects the explosions and what geotechnical methods should be used. As part of its attempts to deal with the situation, the Engineering Corps digs a “Philadelphi-simulating site” in the agricultural area in the northeastern part of the Negev. This activity is unregulated and unplanned and no professional geological survey is done to check whether and to what extent the geological slice at the site resembles that in the Rafah area. The IDF does not examine the way tunnels are mined using the manual means Gazans have at their disposal, but uses mechanical means to dig in the simulation site. Many experiments are conducted at the site, mainly using geophysical solutions created by civilian companies. The site’s proximity to military bases and civilian settlements does not enable an examination of the effect explosions have on tunnels.

The activity in the Philadelphi Route yields partial and unmeasured results while wreaking massive engineering havoc on the corridor and its margins, destroying tens of homes on the margins of Rafah, and damaging the shallow subsurface. This topographical change, alongside changes in the mechanical properties of the top part of the slice, led to the formation of huge puddles of water in the winter. In certain places, water trickled into the tunnels and caused them to collapse. At this stage, the IDF does not work toward acquiring accurate quantitative knowledge regarding existing tunnels and those that have been destroyed, and despite its many efforts, smuggling through tunnels continues. The Egyptians do nothing to prevent the smuggling, which begins in Egypt and Sinai, nor do they cause any damage to tunnel pits in open fields, which are usually covered with very simple lids (made from tin or wood). The Israeli government makes no demands of Egypt to stop the smuggling and the IDF carries the burden.

1. **Thriving and exploiting the success – 2004–2005:** Following the massive engineering activity above ground along the Philadelphi Corridor, Hamas begins to realize that Israel has no effective solution to the threat it presents. Hamas increases and develops its subsurface activity and launches a series of explosions under IDF stations and posts using attack tunnels.[[36]](#endnote-36) These attacks create a psychological deterrent to IDF soldiers. Posts, camps, and settlements are evacuated as soon as soldiers or civilians report hearing mining sounds underground, even without any intelligence, engineering, or geo-technological verification of the situation.

IDF officials understand that there is no effective solution to both types of active tunnels. Commander in Chief Moshe Ya’alon appoints the experienced geologist, Colonel (Res.) Yossef Langotsky, to prepare a comprehensive position paper on the subject. Langotsky goes through the IDF’s many units dealing with the field (the Administration for the Development of Weapons and Technological Infrastructure, the Engineering Corps, the Intelligence Corps, Southern Command, the Gaza Division, and others) and submits a detailed report. However, the pressure of preparing for the Disengagement and the end of the commander-in-chief’s term cause the issue and findings to be addressed and handled in an extremely limited way.[[37]](#endnote-37) Langotsky sends many letters to decision makers in the security forces and the government regarding the matter, but receives feeble responses, if any at all.

The psychological effect caused by the attack tunnels seems to be one of the catalysts for the hasty military and civilian withdrawal and evacuation of the Jewish settlements in the Gaza Strip in the summer of 2005 (the Disengagement Operation). While the Israeli security forces agree in principle that disengagement is advisable, some voices call to preserve the Philadelphi Corridor as a means for gaining future control, even if only partial, over the Gaza Strip’s continuing and intensifying arming through an ever-increasing number of tunnels.

1. **Israeli neglect of arming in Gaza – 2005–2007:** Israel’s security forces shirk responsibility for the Gaza Strip following its unilateral withdrawal and the Disengagement Operation. The hope and assessment of Israeli decision makers and senior IDF officers are that the army will not return to the Gaza Strip and that there is no need for a lot of infrastructural intelligence about the Strip in general and the tunnels in particular. The Defense Ministry’s research and development efforts toward finding a solution to the subsurface threat are perceived as being less relevant once the Philadelphi Corridor is abandoned. However, after the IDF abandons the corridor, the smuggling tunnels along the Philadelphi Route between Gaza and Egypt grow bigger and their deployment expands. Goods and weapons are transferred through them uninterruptedly and concrete is used to construct the tunnel walls, unlike in the past, when only wood was used (see Figure 4). The Gaza Strip continues to arm itself through the tunnels, and as a result, Israel’s policy tends toward strictly overseeing the entry and exit of goods through the crossings it controls (thereby bolstering Hamas’s “siege” propaganda). This arming enables Hamas to develop its own independent production of weaponry and threaten Israel with the possibility of a prolonged and rather ongoing battle involving steep-track firing using mortar shells and Qassam rockets aimed at Israeli settlements.

In addition, attack tunnels to Israel are mined along the separation line. The IDF easily and effectively blocks this new effort through focused invasive operations on the margins of the Strip. However, after several months this operational activity is brought to an end, mainly due to political reasons, leading to the redevelopment of invasive attack tunnels. A tunnel about one kilometer long is dug and used as part of a combined attack inside Israel at the Kerem Shalom area, and soldier Gilad Shalit is kidnapped and smuggled to Gaza through it only one year after the Disengagement Operation.

1. **Becoming established – 2007–2009:** In the absence of a solution to the tunnel threat or any type of response on the part of Egypt, and following the successful kidnapping of Gilad Shalit, subsurface warfare in Gaza continues to expand uninterruptedly. This leads Hamas to develop a holistic approach to warfare using its subsurface systems. The subsurface deep in the Strip is used for positioning steep-track firing stations and tunnels are dug to access firing stations, weapon storage centers, and command headquarters. The vigilance of IDF field intelligence officers uncovers steep-track firing launch pits, however it is difficult to detect all the stations.

The smuggling tunnels grow bigger and large amounts of weapons and goods from Egypt are transferred through them. There is increased awareness around the world and in Israel regarding the free use of smuggling tunnels, which is considered legitimate in some circles in Israel. The tunnels are perceived as an economic bypass and supplementary means of transferring goods, which is limited through regulated crossings leading to Israel for security reasons. Hamas builds attack tunnels leading to Israel under a shroud of secrecy while implementing a high level of compartmentalization within the organization.

The State Comptroller Report for 2007 points out the security forces’ failings and calls for the establishment of an entity within the IDF to investigate and direct the handling of the subsurface threat. Such an entity is established and presents two results of its research, however, due to internal prioritization of resources allocation this entity is dismantled several months later. In the Gaza War at the start of 2009, the IDF partially damages attack tunnels and depth tunnels in conquered territories. Israel decides not to conquer the Philadelphi smuggling tunnel area, which allows arming of the Gaza Strip to continue.

1. **The second intensification – 2009–2014:** In the absence of an effective Israeli response to the tunnel threat and as part of the lessons learned from the Gaza War, Hamas’s exploitation of the subsurface shifts to strategic levels and there is a huge increase in all types of tunnels being mined. About 35 attack tunnels are mined, some of which penetrate hundreds of meters into Israel. It is only in 2013, and quite accidentally, that Israel detects an attack tunnel in its territory for the first time. Hamas develops a subsurface combat doctrine and a social culture evolves around the diverse subsurface systems: children in summer day camps in Gaza visit the tunnels and couples getting married get their pictures taken underground. The full scope of the Gaza Strip’s underground system is only uncovered during Operation Protective Edge. This is due to the Israeli security forces’ failure to prevent steep-track firing toward civilian targets in Israel, the lack of a holistic technological response, the encumbered process of detecting and destroying operational tunnels, and the lack of strategic and tactical combat for dealing with the subsurface threat. The lack of accurate intelligence about the Hadar Goldin tunnel located at the margins of Rafah at the end of the operation seems to illustrate the professional gap the IDF and other intelligence bodies have in the field. This, despite the tunnel pit opening being adjacent to a makeshift tower (which was observed from Israel’s territory and through aerial photographs), and appearing as an anomaly in its environment with a heap of dirt at its base - a typical sign of tunnel waste.
2. **Israel and Egypt’s awakening - 2014–2018:** As part of the lessons learned from Operation Protective Edge, Israel gradually invests substantial resources in building professional units comprising geologists and engineers to construct an extensive subsurface barrier and operational combat doctrine for the IDF’s various arms. The Egyptians also begin destroying tunnels and preventing subsurface activity in the Rafah area, for instance by flooding it with seawater. Israel’s success forces Hamas to change the nature of its attacks, and as of the time of writing this paper (August 2018) Hamas has shifted to demonstrations involving both civilians and terrorists and guerilla activists along the Israeli West Bank barrier, sending explosive balloons and firing into Israel.

**Basic human-geographical conditions for the development and implementation of subsurface warfare**

***Determining the international borderline without considering the geographical conditions***

Beyond the various aforementioned circumstances enabling subsurface warfare development, some major political-geographic background factors contributed to forming the conditions for subsurface system development in the Gaza Strip. The first reason was the political decision made under the peace agreement with Egypt to declare and entrench the Rafah-Taba line as an international border. The Rafah-Taba line was established as an arbitrary separation line that the British conquerors forced upon the Ottoman rule in the Land of Israel in 1906,[[38]](#endnote-38) without considering the geographical conditions existing between the southeast corner of the Mediterranean Sea and the top of the Gulf of Aqaba. This line became the borderline between Israel and Egypt under the 1949 Armistice Agreements. While Israel possessed the Sinai Peninsula during 1976–1982, this line became blurred as the city of Rafah and its population expanded on both sides of the line. Upon signing the peace treaty with Egypt, the Rafah-Taba line was revived and implemented for the first time as the formal international border between Israel and Egypt, despite that it clearly did not follow a topographical line, making it difficult to effect control on both sides. The line led to the artificial division of Rafah, causing families to split apart. Later on, this line provided a convenient space for thousands of African infiltrators to cross from Egypt into Israel (from the 1990s until 2013). Among other reasons, this was due to a lack of Israeli control over the line (also due to legal reasons) and Egypt’s poor control over Sinai.[[39]](#endnote-39) Decades later, the infiltrations finally led Israel to build a complex barrier along the border at a cost of over NIS 1.5 billion between 2010–2013.[[40]](#endnote-40)

 Some of the effects of turning the Rafah-Taba line into an international border were known in advance. Toward the division of Rafah in 1982 under the peace treaty with Egypt and in light of the splitting of families between the Egyptian and Gazan sides, Israel proposed that Egypt take full control over the city in return for other territory. Egypt vehemently refused despite the Israeli public’s strong support of the notion.[[41]](#endnote-41)

 Rafah’s division and the difficulty of moving between Egypt and the Gaza Strip made it very hard for families to get together. This new reality led to the digging of the first tunnels in the 1980s,[[42]](#endnote-42) mainly by Gazan well diggers. At first, the tunnel pits were based on well pits; well diggers who knew the shallow geological structure of the Strip and how to dig in this layer added a horizontal burrow that connected between Egyptian Rafah and Gazan Rafah.

 Determining the new borderline along an unnatural topographical route involves many challenges. A similar geopolitical situation exists along the Israel-Lebanon border as a result of Israel’s unilateral withdrawal in 2000, which raises concerns regarding invasive attack tunnels being created in this area. As the infrastructure of the border with Lebanon is mainly built of marine carbonate rock (lime, chalk, and dolomite) which is generally hard, tunnel mining is possible, however it requires much more resources compared to the Gaza Strip. Therefore, it is reasonable for Hezbollah to mine tunnels in order to achieve significant strategic targets, such as a combined ground and underground invasion intended to take control of areas in the Galilee.

***Unilateral withdrawal behind the separation line/borderline opposite the built-up area of a violent non-state entity***

Following the IDF’s unilateral withdrawal from the Gaza Strip as a result of the Oslo Accords in 1994, its unilateral withdrawal from the Lebanon security strip in 2000, and its complete withdrawal from the Gaza Strip in 2005 (the Disengagement), a new reality developed around populated areas in Israel, as part of which the IDF had no control over activity taking place beyond the separation line/border. The territories Israel withdrew its control from shifted to the hands of non-state Muslim actors comprised of terrorist and guerilla organizations, among others, and not an organized army. The presence of violent actors near the separation lines and in built-up areas (cities, towns, and villages) made it very easy for these entities to organize their defense and attacks against Israel and to mine, access, and operate subsurface systems.[[43]](#endnote-43) Israel’s failure to consider geographical conditions as these entities were becoming established along the separation line, with no security strip, may have stemmed from a political and military optimism. Undoubtedly, it stemmed from a misunderstanding or disregard of the significance of the subsurface threat developing in Gaza. However, psychological and practical hostility toward Israel increased in these areas, contrary to the predictions of Israeli intelligence officials and decision makers. Israel’s withdrawal did not lead to the long-awaited recognition by the other side; rather, it served as physical evidence that Israel withdrew in response to the violence directed at its forces. Thus, in the absence of natural topographical barriers between Israel and its enemies, excellent conditions were created for exploitation of the subsurface by various terrorist and guerilla actors.

***Efficient military control on the ground***

The development of subsurface threats following the withdrawal from Gaza in 2005 also stemmed from Israel’s optimal military control above ground planned and deployed around the Gaza Strip. The IDF forces above ground forced Gazan organizations to develop aerial and subsurface means of defense and attack. A report by the military disengagement administration in 2005 emphasized that the IDF was prepared for ground operations outside the Gaza Strip, but that it had no solutions for aerial and subsurface threats.

**Dealing with subsurface threats**

***Components of dealing with subsurface threats***

The tunnel threat comprises many aspects that make it difficult to arrive at a political, geo-technological, and–military-operational solution. These include the tunnel operators (an organization), the planners (professionals), the managers and diggers, digging equipment, tunnel opening property owners, various and changing physical properties along the space/tunnel, the properties and nature of the air in the space, and the range of geotechnical and geophysical properties of the sediment/soil layers above and around the underground space. These all vary between geographical areas, tunnel types, and the quality of the means tunnel operators have at their disposal. In attempting to find an effective solution to the various tunnel threats, consideration must be given to most of the components and variables mentioned above, and changes to do with them must be monitored periodically based on the tunnel properties and technological, military, and political developments. This understanding is critical for developing a solution against the threat (Table 2 summarizes the main approaches and provides examples of each).

 Understanding the significance of the information regarding each component requires dedicated professionals in each field. To gain an understanding of the physical properties of the subsurface, research should be conducted by engineering geologists and geophysicists specializing in the shallow geological slice. Detailed intelligence is required in order to know who the tunnel diggers are and what methods they use. When provided with intelligence on tunnel digging, intelligence officials must interpret and specify the methods and engineering and geological nuances involved in subsurface mining.

***Methods for detecting tunnels and spaces in the subsurface***

Methods for detecting subsurface systems include the physical detection of tunnel components and activity around or within the tunnel. In enemy territory, this often needs to be conducted remotely, as physical detection of the tunnel itself is not possible because it is hidden underground. Therefore, efforts are directed at detecting mining signs such as the building of hiding structures, changes in the attributes of the soil, and mounds of dirt indicative of mining in the subsurface of the area; this requires experienced geomorphologists. Tunnel detection includes all stages of tunnel development and construction: mining openings and burrows, stabilizing the tunnel walls, tunnel usage, and tunnel maintenance. Detection efforts can only be directed at a single tunnel segment or opening. There are many detection methods and they will not be discussed in detail here. The lack of an approach and inability to implement geo-technological methods above the tunnels (e.g. ground-penetrating radars) make detection all the more difficult, and remote detection is complicated due to lively civilian activity around the tunnels.

***The challenge of providing a technological solution***

As far back as 1990, detection of the Rafah tunnels was defined as a top security priority.[[44]](#endnote-44) Until recently no geo-technological tunnel detection solution had been found. Perhaps the search for such a total and comprehensive solution was misguided from the start, as the difficulty involved in detecting tunnels or digging activity has been known throughout the world for decades.[[45]](#endnote-45) Despite this reality and the state comptroller’s recommendation,[[46]](#endnote-46) no professional body has been established within Israel’s security forces that includes experienced professionals in the field for the purpose of providing a combined organizational and geo-technological solution.

 Several aspects are involved in the challenge the security forces have to deal with:

* **The perceptual-organizational aspect:** The IDF, and particularly the intelligence bodies, do not place enough importance on the surface and soil when attempting to learn about the enemy’s tunnel infrastructure.[[47]](#endnote-47) Up until recently, and especially since Operation Protective Edge, there seems to have been a shift in the security forces’ understanding of the importance of the structural elements of the soil in the context of military activity.
* **The professional aspect:** Geology professions are not well-known among the general population and the average person has no understanding of them. As a result, the significance of geological and geo-engineering issues is generally far from the minds of decision makers in the field of security.[[48]](#endnote-48)

***The feasibility of tunnel detection***

In certain cases, tunnel detection is possible using geotechnical and geophysical methods of close sensing using sensors and systems deployed on the ground. The soil has many geo-mechanical (engineering) and geophysical properties that vary in each environment (slice) of the tunnel and affect the type and quality of geo-technological solution required. This means that the success of a certain method in one area, for instance a ground-penetrating radar, does not predict similar success in another area. For years, this insight had not been assimilated among military decision makers, who upon partial success in a specific environment immediately demanded that the solution become operational throughout the entire Strip before conducting a comprehensive examination of the system.

**Geotechnical methods**

Geo-mechanical properties of the soil include, among other things, shear coefficients, Poisson coefficients, soil stratification, and soil moisture.[[49]](#endnote-49) Geotechnical tunnel detection methods include drillings and digs that are mostly guided by ground engineers or engineering geologists. In the IDF, engineering officers conduct geotechnical activity.

 Digging to the depth of a tunnel requires clearing vast amounts of sediments and soils and creating physical access in order to investigate the tunnel. The deeper into the subsurface the dig goes, the wider it becomes due to safety reasons (creating steps, generally at a height of about 2.5 meters). This involves the disposal of large volumes of matter. Digging that damages the tunnel can also cause the tunnel space to collapse, thereby hiding it from the digger. For this reason, many of the digs to find segments of the tunnel used to kidnap Gilad Shalit failed. The method of drilling into the ground is faster and less detrimental to the environment, however it only provides localized information, and so detecting a space in the subsurface requires many drillings.

**Geophysical methods**

Geophysical methods are based on wave dissemination as it is recorded on a sensor placed close to the tunnel area, mostly above ground. These methods make it possible to scan a slice of the subsurface from above ground without damaging the soil.[[50]](#endnote-50) The scientific infrastructure of these methods is based on five types of waves spreading through the subsurface that differ in terms of their time of creation, velocity, range, and other properties only professionals know about. Only an experienced geophysicist would be capable of leading detection attempts using these methods. However, the IDF has not recruited nor trained such professionals.

 Geophysical methods attempt to detect anomalies in underground spaces or activity taking place between the layers of buried sediments and soils. As each soil has many properties, including its electrical conductivity, dielectric coefficient, and magnetic susceptibility, attempts can be made to discover disturbances by monitoring changes and anomalies in the way active electromagnetic transmissions return from the subsurface, characterizing and interpreting them. The sensors’ detection ability depends on the electrical properties of the soils and the level of anomaly. To discover underground spaces or underground movement, anomalies must be discovered through the active transmissions of electromagnetic or acoustic-seismic waves created by digging activity.[[51]](#endnote-51) As all the waves arrive at the same sensor, it is very difficult to separate between the various wave types and identify an anomaly stemming from a dug space and not from a natural subsurface phenomenon. It takes an experienced and highly skilled professional to perform this task.

 Geophysical methods and the methods used to interpret the findings must be adapted to changes in tunnel properties. It is difficult to discover a tunnel of small dimensions relative to the depth and wavelength it transmits. The tunnel dimensions up until the Disengagement Operation were small, mostly about one meter in diameter, which made them very difficult to detect using geophysical methods. The increase in size of the tunnel slices and the fact that tunnels are strengthened using concrete or metal beams could make them easier to detect with geophysical methods. However, the fact that they are dug deeper makes detection more difficult.

**Summary and a view to the future**

The development of the subsurface in the Gaza Strip was made possible due to several background conditions:

1. A lack of in-depth analysis regarding the implications of determining national borderlines without considering the geographical conditions dictated by reality.
2. A lack of understanding that failure to effectively deal with the extensive subsurface activity in an ongoing manner, even if this activity initially involved smuggling goods and not weaponry, led to increased exploitation of the subsurface dimension and the development of a combat doctrine on the Gazan side.
3. Israeli security forces officials’ lack of understanding regarding the complexity of the subsurface medium prevented professional and organizational development that may have provided the IDF with effective methods for dealing with the tunnels, long before Operation Protective Edge.

However, it seems that nowadays the IDF is dealing with the attack tunnels along the Gaza-Israel border in a much more effective and professional way and preparing itself professionally in terms of both defensive and offensive action in anticipation of subsurface conflicts in other arenas. Coping with depth tunnels as an infrastructure for command and control and steep-track firing into Israel are no less critical and require other research and working methods.[[52]](#endnote-52)

The tunnel threat in the Gaza Strip does not pose an actual strategic threat to the State of Israel, yet it does have threatening strategic implications, for several reasons:

1. The tunnels have enabled massive smuggling of weapons into the Strip, which allowed Hamas to build its forces and become a military threat.
2. The attack tunnels caused Israel to launch a ground war (Operation Protective Edge) without being operationally prepared to deal with the subsurface threat in a comprehensive manner.
3. During Operation Protective Edge the IDF did not succeed in limiting steep-track firing, a substantial part of which was launched from subsurface spaces.
4. The release of terrorists in return for kidnapped Corporal Gilad Shalit increased the terrorist threat to Israel.

It appears that the subsurface threat, especially its psychological component, alongside other terrorist threats, served as a lever for the IDF’s withdrawal and the evacuation of Israeli settlements from the Gaza Strip.

Subsurface combat has become an integral part of guerrilla warfare against Western countries.[[53]](#endnote-53) The success and development of the subsurface in the Gaza Strip since the early 2000s has been a significant component of this regrettable trend. It now appears that exploiting the subsurface in battles between non-state actors and Western countries may leak and expand into urban areas in Western countries in the near future. Today, it is quite clear that decision makers should carefully consider the possibility of subsurface threats before making political and military decisions related to the geographical properties of the combat zone.

**Tables and figures**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Tunnel type** | **Start date** | **Characteristics** | **Purpose** | **Comments** |
| Smuggling | ~1982 | Hidden entrance and exit pits, mainly on the Gazan side of RafahA pit in a field in Egyptian territory | Smuggling of:\* Goods and commodities that are not transferred through Israel or Egypt\*Weapons and supporting materials\*Guerilla/terrorist organization activists to and from the Gaza Strip | For decades the Egyptians took very action against this phenomenon |
| Offensive – cross-border/separation line | 2004 | Shallow entrance and exit pits in fields/buildings and a small space under the target for attack | \*Attacking IDF soldiers or civilians in camps, settlements, or open lands\*Kidnapping soldiers and civilians | Huge psychological effect |
| Depth | 2007 | Entrance from buildings or hidden surfaces in open lands, orchards, and groves.A lot of branching | \*Command and control in the hands of Hamas leadership and senior commanders in a hidden area\*Surprise attacks on the IDF and tactical hiding.Diverse, effective, and protected steep-track firing | Relatively hidden |

Table 1. Main types of subsurface systems in the Gaza Strip.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Observation and ground control over tunnel mining spaces** | **Physical prevention of access to existing tunnels** | **Political pressure to limit the construction and activation of subsurface systems** | **Precise detection** **of tunnel pits and routes** | **Detection** **of signs of tunnel digging and activation** | **Detection** **of tunnel digging /activity** | **Intelligence research on people / activists** |
| Expanding the security strip inside the Gaza Strip | Trench possibly filled with water to weaken the ground. Digging up to the tunnel route | Effective pressure on neighboring entities (Egypt) | Geophysical methods on the surface above the tunnels | Remote sensing using airborne sensors and satellites to gauge:precise topography, changes in the surface temperature, spectra (color shades), changes in gravity and magnetism | Geophysical methods (geophones) deployed on the surface above (or in shallow trenches for bringing in devices) or perpendicular to the tunnel axis | To locate the tunnels’ entrance points |
| Command of ground observation systems (combat intelligence collection) | Deep iron walls (tenoning) | Pressure on tunnel operators or their opponents | Localized invasive methods above tunnel routes: cone penetration testers with dedicated sensors or drillings | Analysis and decoding of periodic aerial photographs. Automatic change detection system based on a series of aerial photographs |  | To detect those initiating, managing, digging, and operating the tunnels |
| Evacuation of the hostile population in suspect areas | Precise explosion of route segments or pits, or structural explosion of suspected tunnel areas from the ground /air | Pressure on the sovereign in Gaza |  | Parapsychological methods (e.g. dowsing pendulum)  |  |  |
| Fleeing or evacuation of soldiers and civilians | Activist arrests |  |  |  |  |  |
| Localized / broad-scale operational actions |  |  |  |  |  |  |

Table 2. Main approaches to combating subsurface threats.

**Text for Figure 1:**

**Subsurface:**

* Depths
* Properties
* Processes

Settlement

**Israel**

IDF post

Shallow approximation canal for detection devices

**Attack tunnel**

**Border/separation line**

**Security strip**

**Resting and logistics cells**

Soil dispersion in fields

**Enemy**

Warehouse for hiding soil

**Hiding/steep-track firing tunnels**

Houses

Figure 1. A schematic slice of an invasive attack tunnel with partial depth tunnel components (current as of 2014, processed based on Roskin, Gavish, Roskin, and Lipshitz, *A Professional-Organizational Suggestion*).

**Text for Figure 2**

Netiv HaAsara

The Gaza metropolitan area

Wadi Gaza

The Mediterranean Sea

Khan Yunis

The ruins of Gush Katif

Rafah

Egyptian Rafah

Egypt

The Kerem Shalom area

The Philadelphi Corridor

The Israel-Egypt borderline

Geomorphic legend

Loess soil

Brown clay soil

Sandy loess

Loess sand

Sandy soil above loess

Dunes and dune plains

Sandstone ridge axis

Km]

Figure 2: A map of the main types of soils and central elements in the Gaza Strip (processing: Joel Roskin, based on Dan, Raz, and Koyumdjiski, *Soil Survey Manual*).

|  |  |  |
| --- | --- | --- |
| **Tunnel attributes and relative dimensions** | **Geopolitical event** | **Attributes of tunneling development** |
| **Smuggling** | **1982** | **International recognition of the Rafah-Taba line as a border****Egyptian concession of Gaza/the Rafah Crossing** | **Well diggers expand wells into tunnels and smuggle family members** |
|  | **1993–1994** | **The Oslo Accords – Rafah is handed to the Palestinian Authority** | **Smuggling of goods and drugs** |
| **Attack** | **2000** | **Attack on Jerusalem**(The El-Aqsa Intifada) | **Smuggling of weapons****Acceleration of weapon smuggling** |
|  | **2004** | **Statement of intent to disengage from Gaza** | **Inferno tunnels****Posts/passages** |
|  | **2005** | **“The Disengagement”****Military withdrawal and destruction of Jewish settlement in the Gaza Strip** | **Inferno/kidnapping tunnels across the Gaza-Israel border****“Quality tunnels”: Gilad Shalit and his concealment** |
|  | **2007** | **Battle of Gaza****Hamas takes control of Gaza****Security lockdown in Gaza** | **Underground fortification and expansion of smuggling** |
| **Depth** | **2009** | **The Gaza War** | **Firing from an underground range** |
|  | **2011** | **Gilad Shalit is brought back in return for thousands of terrorists** | **Expansion of underground fortification and attack tunnels** |
|  | **2014** | Operation Protective Edge | **Substantial damage to attack tunnels alone by the IDF** |
|  | **2018** | **Summer of kites and fence demonstrations** | **Significant IDF deployment against attack tunnels and detection** **of several tunnels** |

Figure 3. Tunnel development stages and political and strategic events (source: Joel Roskin)

**Text for Figure 3:**

Y axis: Number of tunnels X axis: Year

Top to bottom:

Evaluated number of smuggling tunnels –Katif.net

Smuggling tunnels detected by an Egyptian government ministry

My evaluation of the rise in the number of tunnels

The IDF’s History Department evaluation of the number of tunnels]

Figure 4. The rate of smuggling tunnel development in the Gaza Strip (data from various sources)

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