
Research article

The Fall of the Syrian Regime: The End of Chemical Warfare in Syria

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Abstract

Background: The use of chemical weapons constitutes a serious violation of international humanitarian law and remains a persistent threat to public health and global biosecurity. Syria represents the most extensively documented case of state-level chemical-weapon use in the contemporary era, occurring despite near-universal prohibition under the Chemical Weapons Convention (CWC).

Methods: We conducted a retrospective descriptive analysis of documented chemical-weapon incidents in Syria between 2012 and 2020 using open-source investigative data from the Global Public Policy (GPPI), supplemented by reports from the Organization for the Prohibition of Chemical Weapons (OPCW) and United Nations mechanisms. Incident-level data were analysed to characterise temporal and geographic patterns, chemical agents, delivery mechanisms, attribution, and health outcomes.

Results: A total of 349 chemical-weapon incidents were documented, of which 334 were attributed to Syrian government forces. Chlorine accounted for the majority of incidents (67.4%), while sarin-related events comprised fewer than 5% but were responsible for over 80% of recorded fatalities. At least 1,900 deaths and approximately 18,600 injuries were reported. Incidents clustered spatially in Rif Dimashq and Idlib governorates and temporally in 2015, and persisted following Syria's accession to the CWC and the declared destruction of its chemical stockpile.

Conclusion: The Syrian case highlights limitations in chemical weapons verification and enforcement in active conflict settings and demonstrates the substantial public health impact of chemical exposures, even when infrequent. The collapse of the Assad regime in December 2024 has yet to eliminate chemical-weapons-related biosecurity risks, underscoring the need for sustained post-conflict oversight, integration of open-source intelligence, and strengthened international monitoring to prevent diversion and re-emergence.

Keywords: Syria, Assad, Chemical Weapons, Warfare

Introduction

The use of chemical-weapons represents one of the most serious violations of international humanitarian law and poses enduring risks to public health, regional stability, and global biosecurity. From antiquity to the present, there have been at least 121 instances of chemical-weapon use globally up to October 2023 (1). Despite the near universal prohibition of chemical weapons under the Chemical Weapons Convention (CWC), their use has persisted in

modern conflicts, exposing critical weaknesses in international non-proliferation, verification, and enforcement mechanisms. Among contemporary cases, Syria stands out as the most extensive and systematically documented instance of state-level chemical-weapon use since the late twentieth century (2-10), with profound humanitarian and regulatory implications.

Syria's chemical weapons programme emerged under Hafez al-Assad during the Cold War in the 1970's, reportedly through the acquisition of sulphur mustard and sarin from Egypt prior to the Yom Kippur War, and subsequently expanded through procurement of precursor chemicals, production equipment and munitions from multiple international suppliers (Germany, Czechoslovakia, the Soviet Union, China, and North Korea) (6, 11, 12). Human-rights violations, arbitrary detentions, extrajudicial killings, and suppression of opposition movements defined the Assad family's rule (13). Although some early allegations, such as the detection of chemical capabilities during the 1973 conflict or cyanide use during the suppression of the Muslim Brotherhood in Hama in 1982, remain unverified, international concern regarding Syria's chemical capacity intensified by the late 1980's, including United States export restrictions on chemical precursors in 1986 and further in 1987 (11, 14). By the early 1990's, Syria was reportedly producing VX and developing delivery capabilities, with multiple suspected production and storage sites identified (11). Throughout this period, the programme was publicly framed as a strategic deterrent against Israel (6, 12).

Following Hafez al-Assad's death in 2000, Bashar al-Assad consolidated power after a constitutional amendment lowered the minimum age for presidential eligibility (15, 16). Despite early portrayals as a reformist leader, governance remained characterised by repression and political control (17, 18). Prior to the 2003 United States invasion of Iraq, some intelligence and journalistic sources alleged that elements of Saddam Hussein's chemical weapons stockpile may have been transferred to Syria; however, these claims remain contested and unverified (11). Despite periodic elections, Assad's victories were widely regarded as fraudulent (19). Syria's weapons posture persisted amid regional insecurity, while social and environmental stressors, including a prolonged drought between 2006 and 2010, contributed to rising instability, exacerbated social unrest, driving rural migration, unemployment, and discontent (20, 21).

In March 2011, mass protests over mounting grievances over corruption, repression, and lack

of political freedom escalated into a multi-actor civil war involving domestic factions and substantial international involvement (19-22). Inspired by the Arab Spring uprisings in Tunisia, Yemen, and Egypt, demonstrators in Deraa demanded reform after the arrest and torture of Syrian schoolboys who had written pro-democracy graffiti (22). Security forces responded with lethal force, triggering nationwide protests and armed resistance (21). The conflict rapidly escalated into a full-scale civil war involving multiple rebel factions and foreign actors. Regional and international powers, among them Iran, Turkey, Russia, Israel, and the United States, became directly or indirectly engaged (21). By January 2012, an estimated 5,000 civilians and protestors had been killed, and in August 2012, the United States declared chemical-weapon use in Syria a "red line" (20, 23).

From 2012 onwards, chemical weapons were repeatedly documented in attacks affecting civilian populations, occurring across urban neighbourhoods, besieged enclaves, and contested frontlines (20, 24). Syria acceded to the CWC in 2013 and, under the supervision of the Organization for the Prohibition of Chemical Weapons (OPCW), declared and removed its chemical arsenal; however, subsequent investigations and reporting indicated continued chemical-weapon incidents after the declared disarmament, raising concerns regarding undeclared stockpiles, residual precursors, and verification limits (25-28).

The collapse of the Assad regime in December 2024 transformed, but did not eliminate, chemical-weapons-related biosecurity risks, shifting them from state-controlled arsenals to post-conflict oversight and diversion challenges (27-30). Against this backdrop, this study examines documented chemical-weapon incidents in Syria between 2012 and 2020 using open-source investigative data from the Global Public Policy Institute (GPPI) (24), supplemented by international monitoring reports, to inform understanding of patterns of use, associated health impacts, and implications for chemical weapons governance and post-conflict risk reduction.

This study aimed to describe the scale, temporal and geographic distribution, and health impacts of documented chemical-weapon incidents in Syria

during the civil war, and to situate these findings within the context of international chemical disarmament and post-conflict biosecurity risk. Specifically, it examined patterns of chemical agent use and attribution, characterised casualty profiles, and contextualised chemical-weapon events in relation to major military offensives and siege operations to inform chemical weapons governance and non-proliferation efforts.

Methods

Study Design

We conducted a retrospective descriptive analysis of documented chemical-weapon incidents in Syria using open-source investigative data. The study was designed to synthesise incident-level information on chemical-weapon use, health outcomes, and operational context, rather than establish causal relationships or infer intent.

Data Sources

The primary data sources were the GPPI database of chemical-weapon incidents in Syria (24), which compiles and systematically codes reports from open-source investigations, including non-governmental organisations, United Nations mechanisms, media reporting, and forensic analyses. The dataset includes incident-level variables such as date, time, location, suspected chemical agent, delivery method, attribution, casualty counts, and confidence classification. Data from GPPI were supplemented with publicly available reports from the OPCW and the United Nations investigative mechanisms to contextualise disarmament processes and post-conflict assessments.

Incident Classification and Attribution

Chemical-weapon incidents were classified according to GPPI's evidentiary confidence framework as credibly substantiated, established, or comprehensively confirmed, reflecting increasing levels of corroboration and investigative certainty. Attribution to perpetrators was based on GPPI's synthesis of available evidence, including witness testimony, medical and environmental sampling, munition analysis, and consistency with documented operational patterns. Incidents attributed to Syrian Government Forces, non-state actors, or

unidentified perpetrators were analysed separately.

Variables and Analysis

For each incident, we extracted information on geographic location (governorate), date, chemical agent involved, delivery mechanism, number of fatalities, and number of injured individuals into Microsoft Excel. Descriptive analyses were performed to summarise incident counts, temporal trends, spatial distribution, and agent-specific patterns. Case fatality ratios were calculated where sufficient casualty data were available. Chemical-weapon incidents were descriptively contextualised within major military offensives and siege operations to examine temporal concurrence, without inferring causality or strategic intent. The distribution of attacks was mapped using ArcGIS Pro.

Results

Documented Chemical-Weapon Use in Syria (2012-2020)

This section describes the scale, attribution, and temporal distribution of documented chemical-weapon incidents in Syria between 2012 and 2020, based on open-source investigative data.

The first reported use of chemical weapons attributed to the Syrian government forces occurred on 23 December 2012 in Homs, resulting in the deaths of six people in a rebel-held area (14). In response to escalating international condemnation, Syria acceded to the CWC on 14 October 2013 following airstrike threats from the United States. However, Syria, under the supervision of the OPCW, had already declared and surrendered its chemical weapons arsenal, reportedly destroying approximately 1,100 metric tonnes of sarin, VX, and sulphur mustard agents, along with associated delivery systems (25, 26). By June 2014, the OPCW certified the destruction of Syria's declared stockpile.

Despite this formal disarmament process, documented chemical-weapon incidents continued to be reported. According to multiple independent investigations and Global Public Policy Institute (GPPI) data, a total of 349 chemical-weapon incidents were documented: 334 attributed to Syrian government forces, eight to the Islamic State of Iraq and the Levant (ISIL), and seven to unidentified actors (*Table 1*) (24).

Within the GPPI dataset, these 334 regime-attributed incidents are coded by confidence level: credibly substantiated (n = 110), established (n =

69), and comprehensively confirmed (n = 155), reflecting varying degrees of evidentiary verification.

Table 1: Chemical-weapon incidents, reported fatalities, injuries, total casualties, and case fatality ratios (CFR) attributed to Syrian government forces by governorate, 2012–2019 (24)

Governorate	Attacks	Attacks %	Killed	Injured	Casualties	Casualties %	CFR %
Rif Dimashq	95	28.4	1552	13164	14716	71.6	10.5
Idlib	72	21.6	130	2052	2182	10.6	6
Aleppo	47	14.1	67	1062	1129	5.5	5.9
Hamah	46	13.8	123	1511	1634	7.9	7.5
Damascus	42	12.6	23	509	532	2.6	4.3
Homs	11	3.3	28	220	248	1.2	11.3
Dayr Az Zawr	10	3	5	51	56	0.3	8.9
Dar'a	9	2.7	7	35	42	0.2	16.7
Lattakia	1	0.3	0	4	4	0	0
Unknown area	1	0.3	0	24	24	0.1	0
Totals	334	-	1935	18632	20567	-	-

Chemical Agents, Delivery Mechanisms, and Casualty Profiles

This subsection summarises the chemical agents involved, delivery mechanisms, and associated casualty patterns across documented incidents.

Across all documented chemical-weapon incidents, at least 1,900 fatalities and approximately 18,600 injuries were reported, yielding an estimated 20,500 casualties of varying confidence levels (24). Barrel bombs were implicated in 39% of reported incidents, of which delivery mechanisms could be identified (24).

By chemical agent, chlorine accounted for the majority of reported incidents (67.4%), followed

by unidentified chemical substances (27.5%), sarin (4.8%), and BZ (0.3%). Although sarin-related incidents comprised fewer than 5% of total documented events, they accounted for more than 80% of all recorded fatalities (Table 2). Air-delivered munitions were reported in 41% of incidents, ground-based delivery in 11.7%, with the delivery mechanism remaining undetermined in 47.3% of cases (24).

Case fatality ratios (CFRs) varied by chemical agent and geographic location. Dar'a Governorate recorded the highest CFR at 16.7%, while sarin-related incidents exhibited a CFR of 11.5% (Table 2).

Table 2: Reported chemical-weapon incidents attributed to Syrian government forces by chemical agent type, Syria, 2012–2019 (24)

Agent	Count	% of total attacks	Killed	Injured	Total casualties	CFR (%)
Chlorine	225	67.4	238	5209	5447	4.4
Unknown	92	27.5	87	985	1072	8.1
Sarin	16	4.8	1603	12378	13981	11.5
BZ	1	0.3	7	60	67	10.4
Total attacks	334	100	1935	18632	20567	-

Temporal and Geographic Patterns of Chemical-Weapon Use

Documented chemical-weapon incidents exhibited distinct temporal and geographic clustering across the Syrian conflict period.

The highest monthly frequency of reported chemical-weapon incidents occurred in May 2015 (*Figure 1*). Spatially, the Rif Dimashq and Idlib

governorates together accounted for nearly half of all regime-attributed incidents (*Figure 2*). Additional concentrations of documented incidents were observed in Hamah, Aleppo, and Dar'a governorates, corresponding to areas of sustained military activity and contested territorial control during the conflict period (24).

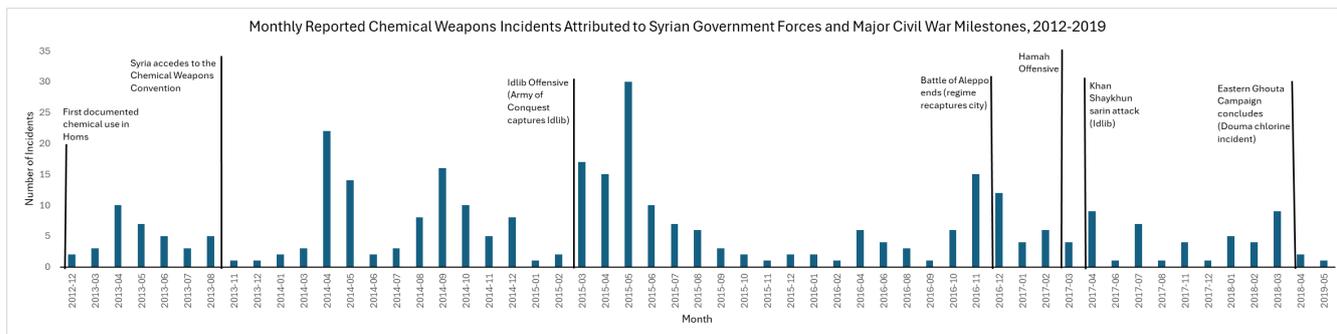


Figure 1: Time series of monthly reported chemical-weapon incidents attributed to Syrian government forces, 2012–2019 (24).

Note: Vertical lines indicate major military, regulatory, and investigative milestones and are provided for contextual reference only.

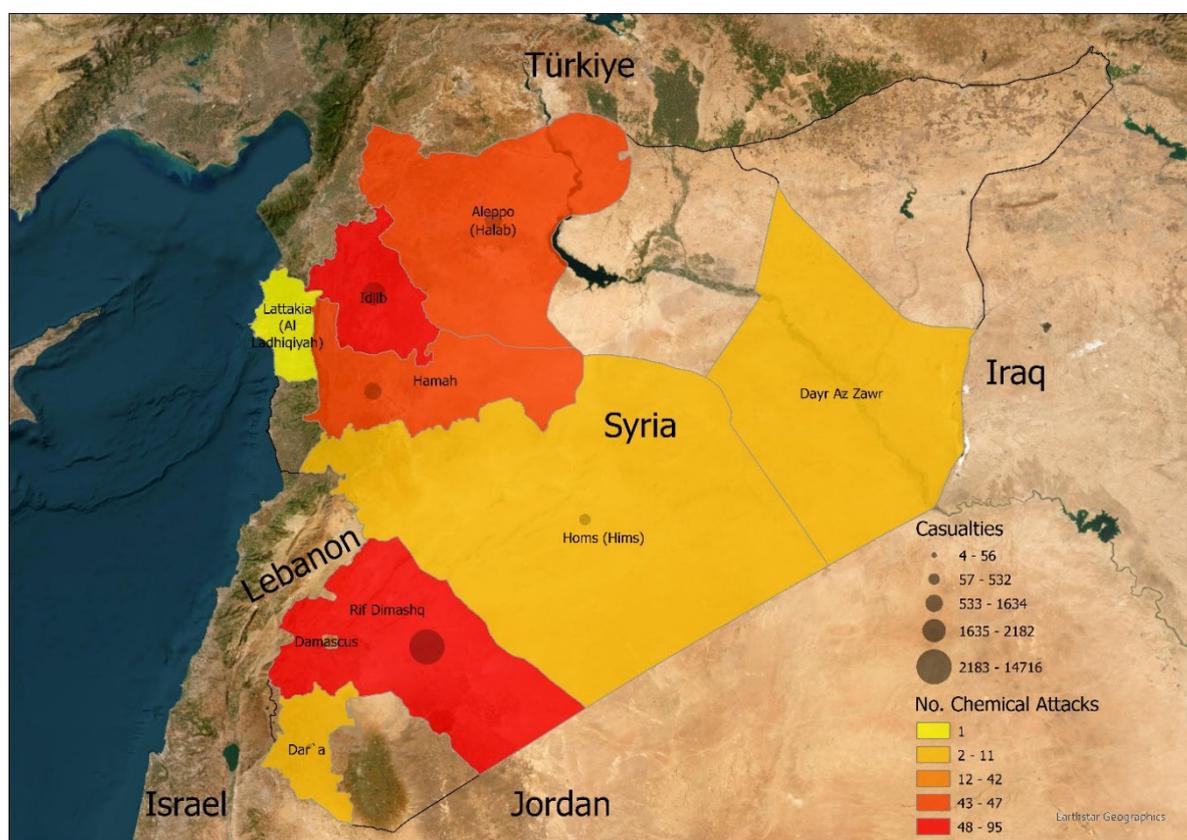


Figure 2: Geographic distribution of chemical-weapon incidents attributed to Syrian government forces by province, with reported casualty data, 2012–2019 (24)

Operational Context of Documented Chemical-Weapon Use

Chemical-weapon incidents recorded in the GPPI dataset temporally coincided with major military offensives and siege operations; these associations are descriptive and do not imply causality or strategic intent.

The Damascus Offensive (2013) marked an early phase of intensified government operations in the capital's eastern periphery. Rebel advances near Jobar and Eastern Ghouta prompted the government's counter-operation, *Capital Shield* (31). During this campaign, the 21 August 2013 Ghouta sarin incident, comprehensively confirmed by multiple investigations, including the United Nations mission to investigate allegations of the use of chemical weapons in the Syrian Arab Republic, was estimated to have killed more than 1,700 civilians and injured approximately 3,600 (24).

During the Idlib Offensive (March 2015), the newly formed Army of Conquest (Jaish al-Fath) captured Idlib city, establishing one of the largest opposition-held strongholds in Syria (32). The consolidation of opposition control in the northwest coincided with a series of chlorine-related incidents between 2016 and 2018, many of which were classified by GPPI as credibly substantiated or established. These incidents were documented during periods of intensified contestation and reported alongside efforts to reassert territorial control (33).

The Battle of Aleppo (2012–2016) was one of the longest and most destructive urban conflicts of the war (34), culminating in the recapture of the city by Syrian and Russian forces in December 2016. Although Aleppo was not a major centre of confirmed chemical-weapon use, the campaign's final phase featured indiscriminate airstrikes and barrel-bombing patterns similar to those documented in regions with verified chemical-weapon activity, such as Hamah and Rif Dimashq (23, 24).

The Eastern Ghouta Campaign (2013–2018) epitomised prolonged siege warfare. Encircled for nearly five years, the enclave endured extensive bombardment and humanitarian deprivation. The Douma chlorine incident of April 2018, established by the OPCW as involving chlorine

exposure, occurred shortly before the area's surrender (35). Eastern Ghouta contained the highest concentration of verified chemical events, including both the 2013 sarin attack and multiple chlorine releases recorded throughout the siege (24, 36).

During the Hamah Offensive (March–April 2017), led by Hay'at Tahrir al-Sham and affiliated groups, insurgents advanced into northern Hamah before being repelled by government forces (37). The ensuing counteroffensive was accompanied by a documented increase in reported chlorine and sarin incidents across the region, including the 4 April 2017 Khan Shaykhun attack in neighbouring Idlib, which was comprehensively confirmed by the OPCW as involving sarin exposure (24).

The preceding results quantify documented chemical-weapon incidents in Syria between 2012 and 2020, describing patterns by attribution, agent type, delivery mechanism, casualty profile, and spatiotemporal clustering. The Discussion that follows interprets these descriptive findings in relation to plausible explanatory factors (including differences in agent lethality, medical access, and reporting completeness), assesses implications for chemical weapons governance and verification, and considers post-regime-collapse risks, while acknowledging uncertainty inherent to open-source investigative data.

Discussion

This analysis demonstrates that chemical-weapon use in Syria was characterised by marked heterogeneity in agent type, delivery mechanism, and health impact. Although chlorine accounted for the majority of documented incidents, sarin-related events were responsible for a disproportionate share of fatalities. This disparity is consistent with differences in agent toxicity and exposure dynamics, but also reflects contextual factors such as attack location, population density, and access to timely medical care. Variation in CFRs across governorates may further reflect differences in health system capacity, emergency response, and reporting completeness during periods of intense conflict.

Importantly, these findings should be interpreted as descriptive patterns rather than definitive estimates of burden. Casualty figures

derived from open-source investigations are subject to under-ascertainment, survival bias, and inconsistent documentation, particularly in besieged or inaccessible areas. Nevertheless, the concentration of high-fatality events associated with nerve agents underscores the continued public health relevance of chemical-weapon exposure, even when such agents are used relatively infrequently.

Beyond immediate mortality, the health consequences of chemical-weapon use were compounded by prolonged conflict, mass displacement, and health system degradation. By 2024, more than half of Syria's pre-war population of 22 million had been displaced, with millions seeking refuge in neighbouring countries (20). In this context, chemical exposures occurred in settings with limited medical infrastructure, likely amplifying both acute and longer-term health impacts. Of the 157,634 individuals reportedly detained between 2011 and 2024, at least 6,786 were documented to have died in government custody (13).

The temporal concurrence between documented chemical-weapon incidents and major military offensives suggests that chemical weapons were used within broader patterns of siege warfare and territorial contestation. However, these associations cannot be interpreted as evidence of uniform strategic intent. Fluctuations in external military support, including the evolving roles of the Russian Federation, Iran, Türkiye, and the United States, contributed to a fragmented conflict landscape characterised by shifting control and variable operational pressures (20).

By 2019-2020, Kurdish forces had consolidated autonomy in the north, Turkish military operations intensified following United States troop withdrawals, and the Islamic State sought to reassert influence over strategic resources, including oilfields (20). These dynamics complicate attribution and interpretation, particularly where access for independent verification was constrained. As such, the observed patterns likely reflect a combination of military, logistical, and political factors rather than a singular or consistent deployment strategy.

The persistence of documented chemical-weapon incidents following Syria's accession to the CWC and the declared destruction of its

stockpiles highlights enduring limitations in chemical weapons verification and enforcement mechanisms. While the OPCW certified the destruction of stockpiles in 2014, subsequent investigations indicated the probable existence of undeclared agents, precursors, or production capacity.

These findings do not necessarily imply systematic non-compliance across all phases of disarmament but instead illustrate the inherent challenges in verifying chemical weapons destruction in active conflict settings. Restricted access, contested territory, and reliance on state declarations constrain the verification and reporting regimes. Syria, therefore, represents a critical case study for understanding how chemical weapons governance frameworks operate under conditions of protracted war and limited international leverage.

The collapse of the Assad regime in December 2024 marked a significant political rupture but did not eliminate chemical-weapons-related risks. A 7.8-magnitude earthquake in February 2023 devastated parts of Turkey and Syria, killing at least 6,000 people in Syria and over 50,000 in Turkey (20). The disaster deepened Syria's humanitarian crisis but also exposed the regime's fragility. Rebel groups such as Hay'at Tahrir al-Sham (HTS) began preparing a coordinated campaign to oust Assad, with preparations commencing in 2023 (38). The regime's dependence on the Iranian Revolutionary Guard Corps (IRGC), Hezbollah, and other Shia militias weakened as these groups shifted focus to conflicts elsewhere, including Hezbollah's prolonged confrontation with Israel (38). Meanwhile, Russia had already redirected resources toward its invasion of Ukraine in 2022 (38).

In late November 2024, HTS led a coalition offensive capturing Aleppo, Syria's second-largest city and economic hub (39). Assad, caught off guard, abandoned the city while awaiting reinforcements (36). Hamah and Homs fell soon after, with limited Russian air support failing to stem rebel advances (33). Iran, preoccupied with the Lebanon-Israel conflict, provided no aid (40, 41). Facing total collapse, Assad fled Damascus on 8 December 2024. His prime minister

surrendered to HTS forces, marking the end of 54 years of Assad family rule (30).

Following Assad's departure, fears grew that residual chemical stockpiles could fall into rebel or extremist hands. On 9 December 2024, Israel conducted airstrikes on suspected chemical-weapons and missile facilities, including the Syrian Scientific Studies and Research Center (SSRC) (26). The OPCW later confirmed that unaccounted quantities of sarin precursors and chlorine likely remained in the country (27). International inspectors estimated that roughly 360 tonnes of mustard gas and five tonnes of sarin precursors were still missing (28). In response, HTS issued a statement pledging cooperation with the OPCW and renouncing the use of chemical weapons (42). Nevertheless, concerns persist that hidden caches may resurface amid Syria's continuing political instability and the presence of designated terrorist organisations controlling parts of the country.

Limitations

This analysis relies on open-source investigative data and is subject to several limitations. Reporting bias, under-ascertainment, and differential access to affected areas may have influenced the number and characteristics of documented incidents. Attribution of responsibility and identification of chemical agents remain uncertain in some cases, particularly where independent verification was restricted. Casualty figures may be incomplete or inconsistent across sources. As such, findings should be interpreted as conservative estimates and descriptive patterns rather than definitive counts or causal inferences.

Conclusion

The Syrian case demonstrates both the catastrophic public health consequences of chemical-weapon use and the structural vulnerabilities of existing chemical weapons governance in protracted conflict settings. Despite formal accession to the CWC and the declared destruction of stockpiles, chemical-weapon incidents persisted, underscoring the limitations of verification mechanisms reliant on state declarations and access during constrained active hostilities. The post-collapse environment

further highlights the enduring biosecurity risks posed by residual agents, precursors, and fragmented governance, particularly where non-state actors control territory. Together, these findings emphasise the need for strengthened international oversight, adaptive verification strategies, and sustained post-conflict monitoring to prevent diversion and re-emergence of chemical weapons. Lessons from Syria should inform future non-proliferation efforts by reinforcing the integration of public health surveillance, open-source intelligence, and international inspection regimes to enhance early detection, accountability, and long-term chemical weapons risk reduction.

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