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Near-Earth Objects (NEO) and other current space threats

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Abstract

The subject of the study are space threats – Near-Earth Objects (NEO) and Potentially Hazardous Asteroids (PHA). The research methods employed in this article included the classic theoretical methods used in security sciences and a practical method – a quantitative study of social media. At present, space threat studies aim to resolve the terminological confusion related to NEOs, to determine current and potentially hazardous space objects and estimate the potential threats from them. The research is also expected to come up with two methods for estimating NEO threats, the Palermo and Torino scales. The practical result is to evaluate the public mood regarding NEO threats. Studies have shown that certain active space objects are capable of reaching the Earth's surface and colliding with human-made in-space objects and devices, such as communication satellites. Should this happen, it could cause substantial social damage and destabilise state security, particularly if elements of critical infrastructure of the state were to be affected. Continuous monitoring of NEOs may play a central role in the provision of security. Furthermore, the public should be kept abreast of the threats.

Keywords:

outer space, security, Near Earth Object (NEO), Potentially Hazardous Asteroids (PHA)

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Introduction

Outer space is a clear and present source of hazard to the Earth; the scope of dangers includes natural objects such as: asteroids, planetoids or fireballs. How serious the space threats may be was best illustrated by one of the most important and dangerous astronomical events of the last century that occurred in Chelyabinsk in the morning of 15 February 2013. A 20-meter meteor, travelling at a speed of approx. 19 km/s, flew over the Russian town generating a shock wave of kinetic energy amounting to 500 kt (Kartashova *et al.*, 2018, p. 107), which caused damage to nearly 7,500 buildings and numerous injuries (mainly from shattered glass) and the need for hospitalisation for over 1,600 people (Oshtrakh *et al.*, 2019, p. 206). The incident evidenced that the threat from space objects is real and that it may be the source of substantial damage to infrastructure and population. In response, in 2016, the General Assembly of the United Nations proclaimed June 30th as the International Asteroid Day, intended to promote public awareness regarding collisions of space objects with the Earth.

This paper combines review and research methodologies. The purpose of this study was to organise terminology related to NEOs, to provide examples of Near-Earth Objects and to present literature methods for the estimation of impact threat levels. The final aim of the research works was to study public activity and moods based on social media monitoring in a one-year timeframe.

An attempt for clarification of NEO terminology and etymology

Given that outer space has only recently begun to be considered in the context of emergence and evolution of threats, the relevant nomenclature requires clarification. Therefore, for the purpose of this and future scientific studies, this section reviews the specialist literature in order to define key terms and organise the terminology.

Asteroids are rocky remnants dated back to approx. 4.6 billion years ago – to the early formation of the solar system. Sometimes referred to as minor planets, they are orbiting the Sun in the main asteroid belt between Mars and Jupiter. Asteroids vary in size: the smallest specimens are less than 1 km in diameter, while the largest body, Ceres, is about 950 km across and is categorised as a dwarf planet. The total mass of all the asteroids combined is less than that of the Earth's Moon (NASA, 2013). Depending on their composition three types of asteroids are distinguished:

C-type (carbonaceous) – the most common type, accounting for 75% of known asteroids. Very dark objects with an albedo of 0.03-0.09. Their composition is thought to resemble the Sun, i.e. the base material is depleted in hydrogen, helium and other volatiles. They are typically found in the outer regions of the main belt;

S-type (silicaceous) – 17% of known asteroids. Due to the metallic iron mixed with iron- and magnesium-silicates composition, they are relatively bright (albedo 0.10-0.22). Mainly in the inner asteroid belt;

M-type (metallic) – Relatively bright (albedo 0.10-0.18) on account of their main element – metallic iron. Dominate the middle region of the asteroid belt.

The differences in composition converge with the distance from the Sun. Exposure to elevated temperatures has resulted in their partial melting and caused iron to move to the centre and basaltic lava to the asteroids' surface (NASA, 2013). Vesta (Karimi, Azmoudeh Ardalan and Vasheghani Farahani, 2017) is the only reported asteroid of this type to have survived to this day.

Asteroids are classified into families according to the domains of proper elements. They are either a product of collision or rotational fission. Young collisional asteroid families are particularly closely investigated as they contain information on their original expulsion velocity field and also because they may host a significant population of clusters produced by rotational fission (Carruba and Ribeiro, 2019).

Some studies trace the origins of the Earth and other inner planets to aggregation of vapour condensates and powders – planetoids – following a supernova explosion. Up to 1000 such planetoids, resembling physical fractals, have been detected (Slobodrian and Rioux, 2002).

Small solar system bodies were initially described as planetoids, only later to become known as asteroids. The shift in terminology also entailed introducing the technological limits of the time. With an increasing amount of spectral data for minor bodies, they are presently classified as asteroidal (primordial, undifferentiated surfaces) or planetoidal (showing some surface differentiation). The paragraphs that follow attempt to differentiate between a planet, a planetoid and an asteroid.

One source of confusion is that American and English-speaking sources tend to generically refer to all small, rocky bodies orbiting the Sun as asteroids (Dai and Hu, 1980; Pezent, Sood and Heaton, 2019), whereas only the largest objects are designated as planetoids (Metzger *et al.*, 2019).

Apart from asteroids and planetoids, the specialist literature uses other terms that require specifying such as meteoroids, fireballs and bolides. *Fireballs* and *bolides* are large and extremely bright meteors that are observed over an extensive area. A meteoroid is a small asteroid – between ten microns and a metre across – orbiting the Sun, whereas meteors are the "shooting stars," i.e. the visible paths of meteoroids moving at high speeds in the Earth's atmosphere. A *fireball* is an exceptionally bright meteor of an apparent magnitude of -3 or brighter that can typically exceed one metre in diameter. Technically speaking, bolides are fireballs exploding in the atmosphere, however, the terms fireballs and bolides are often used interchangeably (*The Center for Near-Earth Object Studies*, 2019).

When an asteroid or comet approaches the Earth's orbit, it is referred to as a Near-Earth Object – NEO. The threat from NEOs is an object of ongoing debates by the international scientific institutions and governments and has not yet been clearly defined (Peter *et al.*, 2004, pp. 1–2). According to NASA sources, NEOs are asteroids and comets with a perihelion distance q less than 1.3 au, while shorter-period comets (orbital period P of less than 200 years) are described as Near-Earth Comets (NECs). Most of NEOs are asteroids – i.e. Near-Earth Asteroids (NEAs), which are grouped according to the perihelion distance (q), aphelion distance (Q) and the semi-major axes (a) into four classes: Atira, Aten, Apollo and Amor (*The Center for Near-Earth Object Studies*, 2019).

Asteroids exhibiting the capability of making close approaches to the Earth have come to be called Potentially Hazardous Asteroids (PHAs). To be exact, PHAs are all asteroids at a distance equal to the Earth Minimum Orbit Intersection Distance (*MOID*) of 0.05 au[1] and an absolute magnitude (H) of 22.0 or less. On the other hand, an asteroid that cannot make a potentially closer approach to the Earth than 0.05 au (approx. 7,480,000 km or does not exceed roughly 140 m in diameter (i.e. H = 22.0 with an assumed albedo[2] of 14%) is not considered PHA.

1. au (Astronomical Unit) – is defined by the International Astronomical Union (IAU) as exactly 149,597,870,700 m.

2. albedo – the ratio of the light received by a body to the light reflected by that body. Albedo values range from 0 (pitch black) to 1 (perfect reflector). Examples – our Moon has a very low albedo (0.07), while Venus has a high albedo (0.60). The albedo combined with the absolute magnitude can help determine the size of an asteroid (The Center for Near-Earth Object Studies (CNEOS), 2019).

Particular names of NEO objects are a combination of digits and letters, which require proper clarification. A newly discovered asteroid receives a provisional name e.g. 1999 RQ36, which must conform to the guidelines of the Minor Planet Center at the Smithsonian Astrophysical Observatory. The first four digits designate the year of discovery, and further details are given by the last four characters: 1999 RQ36 was the 916th object observed in the first half of September 1999. An asteroid is issued an official sequential number when its orbit is established. Since 1999 RQ36 was the 101,955th asteroid to have been numbered, it is known as 101955. Statistics show that merely 5% of numbered asteroids are given formal names, e.g. following the proposal of their discoverers to the International Astronomical Union. In brief, proposed names must not exceed 16 characters (spaces and punctuation included), should be preferably one word that is pronounceable in some language and written using Latin characters (transliterations from non-Latin languages are acceptable); the name cannot be offensive nor similar to an existing name of a minor planet or natural planetary satellite. An additional requirement for NEOs is that their names are to be derived from any mythology, except for those associated with creation or underworld themes, which are reserved for other bodies in the Solar system. In certain cases, the definition may have to be stretched to include fictional mythological characters. These guidelines are to an extent flexible, and names that are not mythological are not automatically disqualified, yet a mythological name is more likely to receive an approval (*The International Astronomical Union*, 2020).

Examples of contemporary space threats

At present, NEOs are under constant surveillance. The Center for Near-Earth Object Studies (CNEOS) provides high-precision computations of their current orbits, projections of their future motions and assessment of their impact risk. (*The Center for Near-Earth Object Studies*, 2019). The results from CNEOS analyses are published online, including the list of active asteroids shown in Table 1 below (Table 1). Each asteroid is described in terms of number, name and other data: diameter, approx. mass, rotation period, orbital, spectra class, semi-major, axis, orbital eccentricity and orbital inclination.

Table 1. Currently active major asteroids (*The Center for Near-Earth Object Studies*, 2019)

Asteroid Number and Name		Diameter (km)	~Mass 10^{15} kg	Rotation Period	Orbital (yrs)	Spectral Class	Semi-major Axis (au)	Orbital Eccentricity	Orbital Inclination (deg)
1	Ceres	965 x 961 x 891	939,3	9.074	4.60	C	2.768	0.0758	10.59
2	Pallas	582 x 556 x 500	205	7.813	4.61	U	2.772	0.2310	34.84
3	Juno	234	20	7.210	4.36	S	2.670	0.2563	12.99
4	Vesta	569 x 555 x 453	259	5.342	3.63	U	2.362	0.0889	7.14
21	Lutetia	124 x 101 x 80	1,7	8.168	3.80	C	2.435	0.1646	3.06
45	Eugenia	215	6,1	5.699	4.49	FC	2.721	0.0835	6.60
140	Siwa	103	1,5	18.5	4.51	C	2.732	0.2161	3.19
216	Kleopatra	217 x 94		5.385	4.67	M	2.794	0.2504	13.11

243	Ida	58 x 23	100	4.633	4.84	S	2.861	0.0412	1.13
253	Mathilde	66 x 48 x 46	103.3	417.7	4.31	C	2.647	0.2655	6.74
433	Eros	33 x 13 x 13	cze.69	5.270	1.76	S	1.458	0.2227	10.83
1566	Icarus	1.4	0.001	2.273	1.12	U	1.078	0.8269	22.83
1620	Geographos	2.0	0.004	5.222	1.39	S	1.245	0.3354	13.34
1862	Apollo	1.6	0.002	3.063	1.81	S	1.470	0.5599	6.35
2060	Chiron	180	4	5.9	50.7	B	13.637	0.3827	6.94
2530	Shipka				5.25		3.017	0.1280	10.11
2703	Rodari			5.5	3.25		2.194	0.0566	6.03
2867	Steins	6.8 x 5.7 x 4.4		6.049	3.64	E	2.363	0.1455	9.93
3352	McAuliffe	2–5			2.57		1.879	0.3690	4.77
3840	Mimistrobell				3.38		2.250	0.0827	3.92
4179	Toutatis	4.6 x 2.4 x 1.9	0.05	130	3.98	S	2.534	0.6294	0.45
4769	Castalia	1.8 x 0.8	0.0005	4.095	1.10		1.063	0.4831	8.89
4979	Otawara	5.5	0.2	2.707	3.19		2.168	0.1441	0.91
5535	AnneFrank	4.8		15.12	3.29	S	2.213	0.0635	4.25
9969	Braille	2.2 x 1.0		226.4	3.58	B	2.341	0.4333	29.00
25143	Itokawa	0.5 x 0.3 x 0.2	0.000035	12.13	1.52	S	1.324	0.2801	1.62
101955	Bennu	0.49	0.000073	4.276	1.20		1.126	0.2037	6.03

One of the most recently observed NEOs is (367943 Duende) 2012 DA14. At about 19:26 UTC (Fig. 1) on 15 February 2013, as it travelled from the southern evening sky into the northern morning sky, the asteroid (approx. 45 metres in diameter) approached the Earth at the distance of 27,700 km or 4.2 Earth radii (de Leon *et al.*, 2013, p. 1; Moskovitz *et al.*, 2019) 2013, when it passed at a distance of 27,700 km from the Earth's surface. It was the first time an asteroid of moderate size was predicted to approach that close to the Earth, becoming bright enough to permit a detailed study from ground-based telescopes. Asteroid 2012 DA14 was poorly characterized before its closest approach. We acquired data using several telescopes on four Spanish observatories: the 10.4m Gran Telescopio Canarias (GTC. The apparent magnitude of the object was <7, and was thus invisible to the naked eye. 2012 DA14 entered the Earth's shadow for about 18 minutes and subsequently quickly faded.

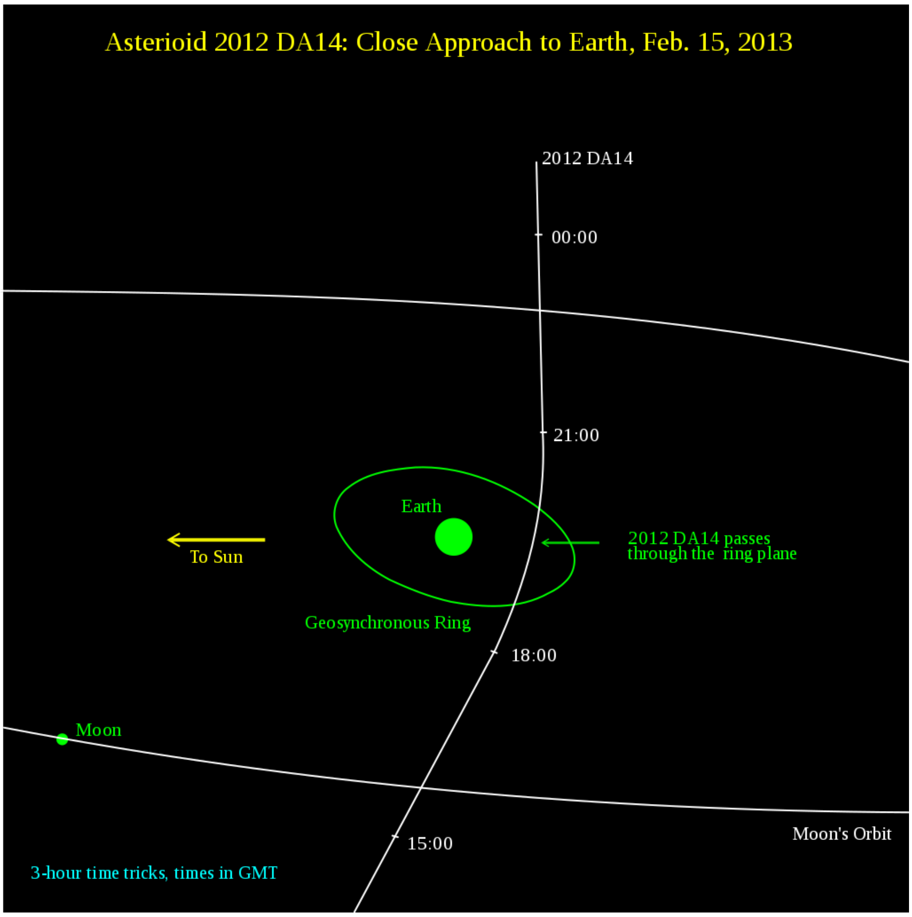

Fig. 1. The orbit of 367943 Duende as it approached the Earth (NASA, 2013)

Another potentially hazardous (PHA) near-Earth asteroid (NEO) is 25143 Itokawa (1998 SF36). This S-type object is roughly 0.5×0.3×0.2 km and weighs in approximation 0.000035×10^{15} kg. It is a particularly interesting subject of investigations due to its shape and internal structure evidencing a history of violent collisions, which may bring new discoveries regarding the structure and formation processes of rubble pile asteroids. The asteroid's exceptionally rough surface is composed of boulders and in 20% of centimetre-sized gravel, constituting the flat surface. The "smooth terrain" areas are believed to indicate low areas of the gravitational potential where pebbles accumulated. According to computational models, Itokawa is composed of two dissimilar lobes – "head" and "body" – that should have different respective densities 2,450 kg/m^3 and 1,930 kg/m^3. (Kanamaru, Sasaki and Wieczorek, 2019).

Another notable NEO/PHA object is (99942) Apophis (2004 MN4), named after an Egyptian demon of destruction and the symbol of darkness. It was discovered on 19 June 2004 by researchers affiliated with the NASA-funded University of Hawaii's asteroid detection and tracking programme. The asteroid's average diameter is 0.325±0.015 km and mass 6.1×1010 kg, and it moves at a velocity of 30.73 km/s, which allows it to circulate the Sun in 323 days and 14 hours. According to estimates carried out using the full six-dimensional Monte Carlo method, on 13 April 2029, Apophis is expected to be at the closest distance from the Earth, 38,000 ± 580 km. (Giorgini *et al.*, 2008, p. 1). For the purposes of comparison, it will be at a lower altitude from the Earth's surface than geosynchronous communication satellites (Królikowska, Sitarski and Sołtan, 2009, p. 1965). In addition, the asteroid is forecasted to be visible in Europe, Africa and West Asia. Regarding NEOs as sources of potential hazard, it must be noted that asteroids <50-100 m across rarely impact the Earth as a single body; they rather explode in the atmosphere. Nevertheless, their detonation can still cause substantial damage, comparable to the infa-

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mous incident in Tunguska, Siberia in 1908. Small bodies rarely fall in the scope of focus of observatories, which pursue larger objects. A Tunguska-class event, which involved the release of the energy equivalent of 10 Mt of TNT, believed to take place approx. every 200-300 years, and the largest annual airburst was estimated to have reached up to 20 kt TNT equivalent. The flux of objects in the 1-10-m size range has been calculated to unleash the same power-law distribution as bodies up to 5 times as large. Therefore, it is estimated that the Earth is hit on an average annual basis with approximately 5 kt equivalent energy, and, in addition, that incidents resembling the Tunguska explosion are expected to repeat every 1,000 years (Brown *et al.*, 2002, p. 294).

During the atmospheric entry phase, the atmospheric friction causes such an object to decelerate and pick up temperature. It is preceded by a bow shock where atmospheric gases are concentrated and grow to extreme temperatures. The energy involved in the process tends to be exuded to the object resulting in melting and fragmentation. The breaking up increases the amount of atmosphere intercepted, further contributing to ablation and atmospheric breaking. In physical terms, the object breaks up when the forces from the unequal pressure distribution on the front and back faces exceed in aggregate its tensile strength.

Owing to their insufficient size, objects entering the atmosphere as fireballs are highly unlikely to pass intact; however, their fragments/meteorites are occasionally found on the ground. The atmospheric total radiated energy is given in Joules, a unit of energy expressed by kilograms times velocity squared, or kg x $(m/s)^2$. An event with an energy equivalent of one thousand tons of TNT explosives is termed a kiloton (kt) event, where 1 kt = 4.185×10^{12} Joules. For fireballs, the total radiated energy is always less than the total impact energy. The latter is approximately provided by an empirical expression developed by Brown et al., giving the total impact energy in kt (E) and the optical radiant energy in kt (E_o) (Brown *et al.*, 2002, pp. 294–296).

Given the current data, it is estimated that a space object (asteroid) sized between 1.5 and 2 km represents a threshold for a global catastrophe, which could result in the death of even a quarter of the world's population. Various possible effects of such a collision are considered: the propagation of shock waves or tsunamis lasting several hours, fires continuing for several weeks, several months of darkness; in the longer time horizon and a wider scope, the impact would affect the entire planet, as it could inevitably lead to the greenhouse effect or the destruction of the ozone layer. The frequency of such objects' impacting the Earth is, however, once in a million years. The probability increases with the decrease in the size of an object, e.g. an asteroid approx. 200 m in diameter is likely to impact once every 10,000 years, causing considerable damage should it hit densely populated areas. However, an asteroid that could trigger mass extinction is expected to come into contact with the Earth no more frequently than once every 100-200 million years.

One of the most spectacular impacts recorded in the relatively recent history happened in Tunguska. The composition of the object has been debated ever since, however, the hypothesis of the stony (asteroidal) nature of the object appears to prevail. In general, a low-density icy comet unleashing the energy in this range would not be expected to penetrate beyond the lower atmosphere; on the other hand, a tougher rocky object is more likely to reach the surface and produce a crater. Unless there are very few rocky objects in the small NEA population, numerous fresh kilometre-sized craters would be found. Instead, most of the relatively recent craters (such as Barringer Crater) are connected with rare metal objects. This confirms the mathematical models that provided the indication of the Tunguska explosion having been caused by a rocky asteroid rather than a comet. Considering a lower impact energy, 3 Mt, this the results from computations appear even more convincing. Numerical modelling has allowed researchers to assess the impact of such collisions, which is even more important given that the impact of this scale, by an asteroid of hundreds of metres or larger capable of causing a regional or global catastrophe, has not been observed by modern science. Mathematical models employ data from orbiting monitoring systems for small objects, which account for the low-energy end of the population distribution. Despite the inefficiency of the data, it is estimated, from 136 reported atmospheric entries between 1975 and 1992, that the annual maximum impactor has an energy of roughly 10 kt, corresponding to the Hiroshima atomic bomb and yet 1000 weaker than the Tunguska event. The strongest collision observed in the past 25 years (several tens of kilotons) (McCord *et al.*, 1995) further confirms the numerical estimations. It is, therefore, anticipated that small impactor collisions will continue to occur, although the modern history has offered little experience of large events, which dominate the overall impact risk (Morrison *et al.*, 2002, p. 741).

The Center for Near-Earth Object Studies collects information about fireballs. The list published by the centre (first submission 15 April 1988, 3:03:10 am) contains information regarding the date and time of each fireball-related event reported, including its approximate Total Radiated Energy (J) and calculated Total Impact Energy (kt) – CTIE. The records also describe the geographical location, altitude and speed at peak brightness. The available data, which is filtered to exclude minor events, have been presented in the form of a graph (Fig. 2). The vertical axis shows the velocity of the fireballs (black) and their Calculated Total Impact Energy (kt) (red).

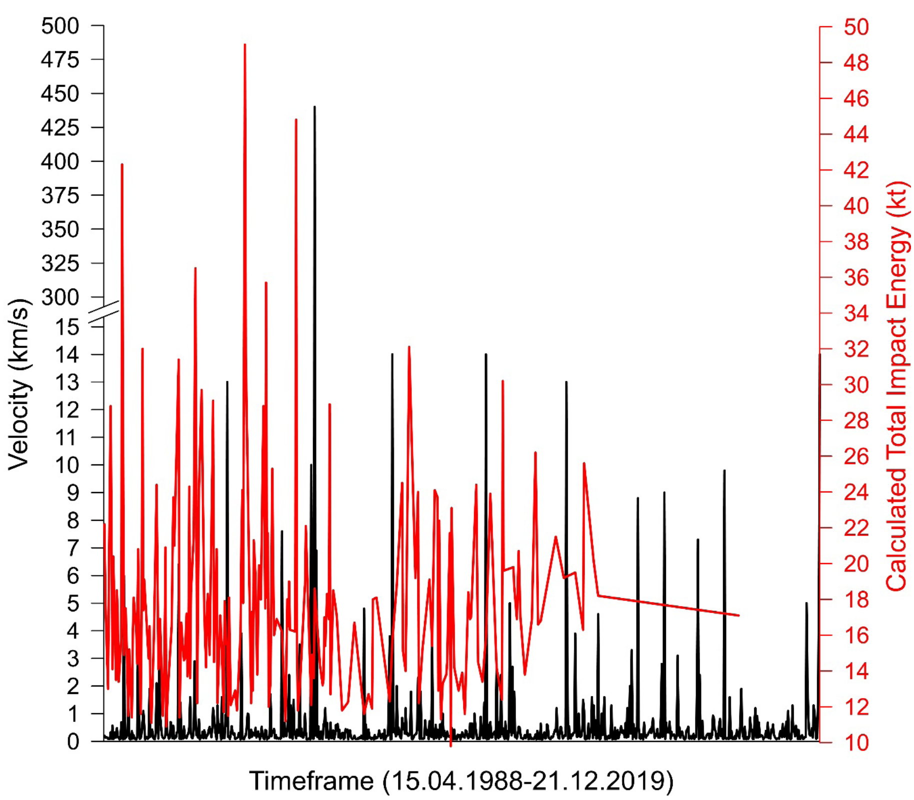

Fig. 2. Fireball velocities and Calculated Total Impact Energy

The records show that fireballs develop average speeds of several km/s as no significant changes in these values have been observed since the beginning of the records. However, CTIE (kt) is observed to have been decreasing to reach an average level of approx. 17 kt. A decrease in CTIE may indicate lower hazard levels from NEOs at present and in the near future.

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Methods for NEO risk estimation and countering NEO threats

The specialist literature tends to employ two formalised possibilities of estimating NEO threats – Palermo and Torino scales. The Palermo Technical Impact Hazard Scale[3] was developed to categorise and prioritise potential impact hazard specifying the following NEO data: dates, energy and probabilities of impact. Palermo Scale values less than -2 describe events of no likely consequences, whereas between -2 and 0 – situations that substantiate cautious monitoring. Situations designated by positive Palermo Scale values warrant concern (Chesley *et al.*, 2002). The scale juxtaposes observed potential impact events with the background risk, i.e. the risk created by same-sized or larger objects over the period of time until the date of the potential impact. The Palermo method employs a logarithmic scale, which means that a value of -2 indicates the detected potential impact being only 1% as likely as a random background event, a Palermo Scale value of zero indicates an event to be as threatening as the background hazard, and a value of +2 – an event that is 100 times more likely to occur than a background impact by an object at least as large before the date of the potential impact in question.

3. The Palermo Technical Impact Hazard Scale – the full name of Palermo scale.

The Torino scale is shown in the table below (Table 2). It distinguishes four colour zones (white, green, yellow and red) and 11 number levels of hazard.

Table 2. Torino Impact Hazard Scale (Morrison et al., 2004)

Level of hazard (colour of zone)	Value	Description
No Hazard (White Zone)	0	The probability of a collision is very low or zero. Includes events involving small objects that are destroyed by heat in the atmosphere and rare meteorite falls unlikely to cause damage.
Normal (Green Zone)	1	A standard observation indicating a NEO's pass with no serious threat level. A collision is highly unlikely, and the incident doe not need to be communicated to the public to worry. Following telescopic observations, events are typically downgraded to Level 0.
Meriting Attention by Astronomers (Yellow Zone)	2	An object makes a relatively close but not an excessively unusual near-Earth pass. The incident merits attention by astronomers, however, due to little chance of impact, informing the public would be excessive. On further observation, events are typically downgraded to Level 0.
	3	A close encounter that deserves attention by astronomers or even the public or officials should the encounter to occur within a decade of detection. Current mathematical models ascribe these events a 1% or greater chance of collision capable of localised destruction. Following telescopic observations, events are typically downgraded to Level 0.
	4	A near pass requiring scientific analysis. As in Level 3, a potential impact event is given a 1% or greater chance of collision but is understood to be capable of regional rather than localised devastation. Following telescopic observations, events are typically downgraded to Level 0. Unless the event is expected to occur within 10 years, the public and authorities do not require informing.

Threatening (Orange Zone)	5	A near encounter that poses a serious, yet indeterminate threat of devastation on a regional level. Critical attention from astronomers necessary, in order to provide a conclusive determination of whether or not a collision will occur. Should the encounter be projected to occur within 10 year of observation, governmental planning may be warranted.
	6	The catastrophe that would be likely to follow from the impact would have a global reach. Demand the attention from astronomers to provide conclusive indication of whether an impact should be expected. Governmental planning may be warranted should the event occur within 30 years of discovery.
	7	An unprecedentedly close encounter by an object of big size and a potential to cause a global catastrophe. If expected within a 100-year period, the risk should trigger international emergency planning, particularly to obtain a clear communication of whether or not a collision is due.
Certain Collision (Red Zone)	8	An impact is unavoidable and likely to cause localised devastation if hitting the land or a tsunami if in the near-shore region. The events are estimated to occur at a frequency in the region between once per 50 to several 1000 years.
	9	Extremely rare events (between once per 10,000 years and once per 100,000 years) capable of triggering extensive regional devastation/a major tsunami.
	10	A collision is not to be avoided and may likely cause a global climate catastrophe, posing a serious threat to the entire civilisation, regardless of the impact site. These collisions are highly infrequent and are estimated to occur once per 100,000 years, or less often.

A 0-10 point Torino Impact Hazard Scale serves as a communication medium between scientists and the public to provide information on threats from near-Earth objects. To an extent, a space threat carries an inherent uncertainty regarding the determination of orbits of newly discovered asteroids and comets, which results from the natural limitations of measurement precision. In the case of objects making near-Earth passes that uncertainty causes that the collision cannot be ruled out. In brief, the scale is to contextualise the level of public concern and urgency that is merited for any near pass in a 100-year timespan. The Torino Scale values describe both the chance of collision and its kinetic energy; however, the scale value may be modified in view of the new, refined data describing the probability and energy estimates. Category 1 describes a collision probability equal to the current annual chance for any given size impactor. The top categories denote an inevitable collision (probability >99%) whose consequences are increasingly serious. While Category 0 events may not require public attention, their occurrence should spur researchers to improve orbital data for such objects for improved accuracy of impact prediction. Nevertheless, due to the multi-dimensionality of these problems, it is unattainable to express them by means of a one-dimensional system such as the Torino Scale (Binzel, 2000).

While Torino Scale is predominantly a communication tool with the public, accounting for the predicted impact energy of the event and the chance of occurrence, the Palermo Scale is rather dedicated for specialists to aid the assessment of an event with respect to the level of concern warranted for a potential future impact. The Palermo Scale enables a careful hazard assessment of minor Torino Scale 0 events, which in fact account for virtually all potential impacts determined so far. The priority rules for space objects considered in Palermo Scale determine the amount of due scientific observations and analysis. As noted earlier, the scale is continuous (positive and negative values) and specifies the time of the predicted potential impact, the object's projected impact energy and probability of occurrence.

From data collected and published by NASA (*The Center for Near-Earth Object Studies*, 2019), Palermo and Torino scores can be computed for most NEO objects (Table 3); however, the characteristically rapid changes determine the need for constant updates.

Table 3. Palermo and Torino scale scores for selected NEOs (The Center for Near-Earth Object Studies, 2019)

Object Designation	Palermo Scale (cum.)	Palermo Scale (max.)	Torino Scale (max.)
29075 (1950 DA)	-1,42	-1,42	*
101955 Bennu (1999 RQ36)	-1,71	-2,32	
99942 Apophis (2004 MN4)	-2,83	-2,93	0
(2000 SG344)	-2,86	-3,23	0
(2007 FT3)	-3,07	-3,73	0
(2008 JL3)	-3,27	-3,27	0
(2009 JF1)	-3,28	-3,28	0
(2019 DS1)	-3,29	-3,3	0
(2010 RF12)	-3,3	-3,31	0
(2005 QK76)	-3,55	-3,7	0
(1994 GK)	-3,65	-3,66	0
(2019 ND7)	-3,67	-4,38	0
(2008 UB7)	-3,69	-4,3	0
(2017 US)	-3,75	-4,03	0
(2012 HG2)	-3,76	-4,26	0
(2000 SB45)	-3,77	-4,24	0
(2012 QD8)	-3,81	-3,95	0
(2007 DX40)	-3,84	-4,26	0
(2018 VP1)	-3,86	-3,86	0
(2008 EX5)	-3,88	-4,16	0
(2005 ED224)	-3,9	-3,93	0
(2019 WG2)	-3,91	-4,22	0
(2013 VW13)	-3,92	-4,09	0

* – is not assigned a Torino scale rating, because the 2880 date is over 100 years in the future

From the survey of existing literature, it can be concluded that space objects are indeed a source of serious threat of destruction on the Earth's surface. Consequently, opportunities to counteract them must be continually explored. One of the joint concepts developed by NASA and the US National Nuclear Security Administration is a programme Hypervelocity Asteroid Mitigation Mission for Emergency Response – HAMMER. The solution considers a nuclear charge explosion as a method to impart kinetic energy to a hazardous asteroid in order to change its trajectory and distance from the Earth. The deflector is nine metres tall and weighs more than 8,000 kg. HAMMER can be used as a kinetic impactor (a high-speed spacecraft applying the push), or as a nuclear payload carrier. The explosion planning phase will be preceded by space probe testing of a designated object using an unmanned space probe. A similar NASA mission, OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) is currently underway, since 8 September 2016. It is aimed at asteroid 101955 Bennua and its objectives are the possibility of a high-precision determination of the asteroid trajectory, and secondly, the analysis of its chemical composition in terms of new raw materials and organic compounds. Another mission objective is to evaluate the detonation of a nuclear charge in order to mitigate the risk of a collision with the Earth. However, given the current legislative state, there are no provisions regarding the possibility of placing nuclear charges in space, which is an issue for future studies.

Methodology

The Internet and social media monitoring was performed using Unamo SEO software (Domalewska, 2019, pp. 36–37). The keyword selected for metrics purposes was "asteroid," whose occurrence in social media and the Internet was monitored in a 1 year timeframe (from 23 December 2018 to 23 December 2019). In addition, the phrase was subjected to sentiment analysis: the sentiment was added after each update of a mention. The purpose of the observation was to study current and project future public awareness of natural space hazards. Understanding public awareness is highly relevant for the development of emergency procedures.

For the purpose of further numerical analyses, the following metrics were considered:

potential reach (number of views of a given entry) – the number of followers of a profile determined its size, subsequently, the algorithm ascribed the specific weight multiplier expressed in percentages, from 3% to 18%, which was used for further analysis of interactions inspired by particular entry. The terms potential reach and potential impact will be henceforth used interchangeably in subsequent studies;

popularity score (of entries) – interactions inspired by individual entries. Their specific weight depends on the effort of the user exhibited in interaction: the higher the effort the user puts into the interaction, the more weight the action is given (low, medium or high effort). The differentiation between the weight of interactions stems from the fact that commenting, sharing or reposting demands higher involvement in the entry than liking the post;

estimated ad equivalent – is the corresponding amount of money that would have to be invested in promotion so as to produce the same result. This metrics is based on the impact value of a given post according to FB, Twitter, Instagram and YouTube rates. The algorithm accounts for the size of fan pages (number of followers), sets reach as a multiplier, and considers the interactions separately. The valuation is based on the rates of the websites in question, which further adds to its relevance.

Results and Discussion

The results obtained for particular channels are presented in Table 4. 26,180 interactions were recorded in the most popular social media, of which 73.1% were on Facebook, 17% on Instagram and 9.9% on Twitter. The highest reach, popularity and ad equivalent were observed for Twitter, Facebook and Instagram respectively. The results from the sentiment analysis (Table 5) indicate that neutral emotion was exhibited by 63.94% of interactions, negative 4.94% and positive statements constituted 31.12%.

The graph in Fig. 3 shows the number of interactions (black) and their reach in time (red). The graph in Fig. 4 presents media equivalent and popularity score in the concurrent timeframe. From the comparative analysis of these metrics emerges a distinct correlation between range, media equivalent and popularity, which is particularly strong in February 2019 and August 2019. There is a high probability that the data from the tables reflect the media coverage on near-Earth flights of asteroids i.e. 99942 Apophis, which occurred on 10 August 2019, when the distance between the object and the Earth was 0.04977 au. The results prove that NEO and PHA threats generate significant response in social media and tend to increase when these activities intensify. Nevertheless, the high positive sentiment indicates that the public seemed rather unconcerned by the emergence of the threats.

Category	Interactions	Reach	Likes	Comments	Re-posts	Popularity	Ad equivalent (USD)	Links	Images	Status change	Videos
Twitter	2,614	2.13E+08	586,975	7,929	161,338	3,200,099	3,305,572	533	177	1,872	32
Facebook	19,138	6409,062	40,800	15,170	7,334	218,824	307,453	3,109	1,862	14,003	164
Instagram	4,428	882,890	49,267	3,952	0	65,075	36,069	0	293	4,112	23
Blogs	89	0	0	2	0	8	0	0	18	69	0
Portals	115	0	0	0	0	0	0	0	0	0	0
Communities	112	0	0	18	0	72	0	0	0	0	0
Fora	48	0	0	0	0	0	0	0	0	0	0
YouTube	13,993	4,143,671	103,317	12,058	0	151,549	10,359	0	0	13,822	171

Table 4. Responses to NEO posts on the Internet and in social media

Sentiment	Interactions	%
Neutral	25,923	63.94%
Negative	2,003	4.94%
Positive	12,617	31.12%

Table 5. Sentiment towards statements

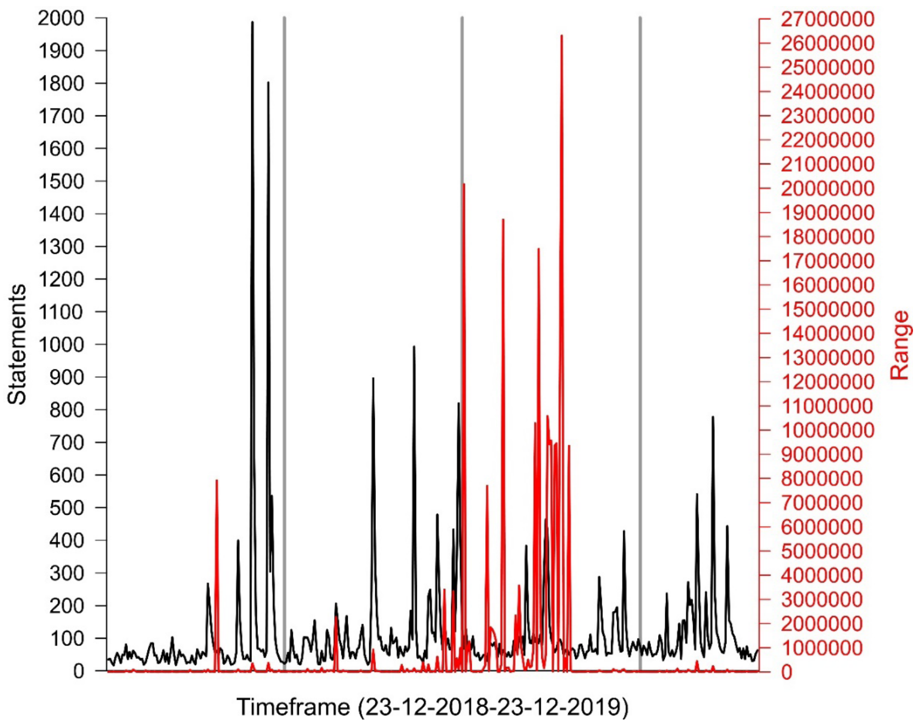

Fig. 3. Statements and reach in the analysed timeframe

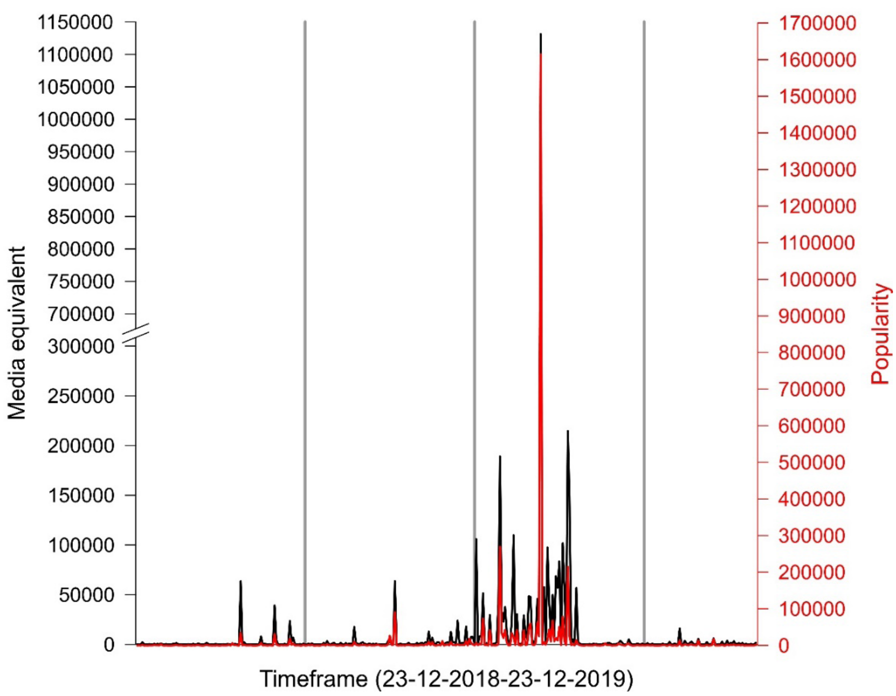

Fig. 4. Media equivalent and popularity in the analysed timeframe

From the presented social media/Internet study, it can be seen that threat news disseminated through social media demonstrate decent popularity and thus can serve to raise public awareness. If implemented with skill and careful thought, the social media messages are capable of warning the public about threats and support potential evacuation and protection of the population in crisis. Furthermore, the results provide data for the estimation of public concern (e.g. sentiment) in the face of this type of threat.

Conclusions

The main conclusions that emerge from the review of international specialist literature and the results from own research reported in this study are as follows:

1. The definitions of NEO and related objects vary in the literature, thus contributing to the terminological confusion. One of the objectives of this work was to introduce order and precision in the relevant nomenclature, for the sake of this and future works on space security.

2. Near-Earth Objects are capable of impacting the Earth or colliding with satellites and other equipment on the orbit of our planet, including systems critical for state security or e.g. air traffic safety (GNSS navigation systems).

3. The safety of citizens in view of space threats can be provided by continuous monitoring of variable parameters of NEOs, e.g. by means of Palermo and Torino scale indicators.

4. Fundamentally, the concept of protecting the Earth against NEOs comes down to discharging a nuclear missile at a hazardous object. The use of nuclear deflector should be, however, preceded by a thorough analysis of the object using a space probe. The inherent problem is the time factor. A further obstacle consists in the inadequacy of international space law provisions that in the current legislative state prohibit the placement of nuclear charges in space. Prior to resolving the outstanding legal and technological issues, the solution should be regarded merely as a potential future concept.

5. The study of the social media has confirmed an extensive interest in Near-Earth Objects among Internet users. Furthermore, the sentiment analysis has indicated that NEO-related news and stories do not create a sense of impending danger in the general public.

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