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Global Impact Distribution of Asteroids and Affected Population

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Motivation

Asteroids will collide with the Earth in the future and this natural disaster poses a serious threat to populations on Earth. National space agencies search for potentially hazardous asteroids and determine their impact probabilities. Those asteroids that could collide with the Earth in the next decade are published online but it is not reported where these asteroids would impact. Based on the observational record, the previously unknown future asteroid impact distribution has been calculated here. This information is important to characterize the nature of the impact hazard and to shape the international response to this threat. The results show that smaller developing nations face a special dilemma because they cannot actively address the threat yet have a disproportionally high risk and are most vulnerable.

Figure 1: Impact probability distribution of 261 VIs until 2100.

Impact Probability Distribution

The impact locations of 261 potential impactors, that can collide with the Earth before the year 2100, were calculated and visualized. Using the information on asteroids provided in NASA's and ESA's NEO risk lists, the freely available software OrbFit was utilized to identify orbit solutions that lie inside the uncertainty region of the asteroid's nominal orbit solution and result in an Earth impact in the future. The impacting orbit solutions are called virtual impactors (VI). The Asteroid Risk Mitigation Optimization and Research (ARMOR) tool was used subsequently to project the impact probability of these VIs onto the surface of the Earth. ARMOR used the VI orbit solution from OrbFit as initial condition for the trajectory propagation until impact. A solar system model that provided gravitational forces from the Sun, the planets and the Moon (based on the JPL DE430 planetary ephemerides) was employed for the propagation. For each VI all possible impact locations were calculated yielding the impact corridor. Taking into account the width of the asteroid's uncertainty region and the global impact probability, the impact corridor was scaled to represent the impact probability distribution for that VI. This method was applied to all VIs and the result is a set of impact corridors, each in the form of a Gaussian distribution. All impact solutions were combined within a global map and the result is shown in Figure 1. The impact corridors are distributed globally and every region on Earth can be hit by an asteroid.

Impact Risk Distribution

Previous, historical impact data only allowed the assumption of a uniform impact probability distribution. Here, the actual impact distribution of the known asteroids until 2100 was calculated. The asteroid impact probability distribution in Figure 1 was combined with the Earth population map to produce the global asteroid impact risk distribution presented in Figure 2. While every region on Earth is at risk of being hit by an asteroid, the risk concentration varies considerably across the Earth and Figure 2 reveals individual regions that show high risk. Risk is not uniformly distributed. High risk regions exist for two reasons: First, high risk regions correlate strongly with population density. The correlation coefficient between population size of a country and its risk is 0.953. In other words, in highly populated regions, an asteroid impact would cause more damage than in less populated ones, thus, the risk is high. The close link between risk and population size produces a global risk distribution that resembles the Earth population density map. Second, impact corridors belonging to a high impact probability VI raise the risk of the regions that they cover. These high risk corridors are clearly visible in Figure 2 and provide information beyond the basic assumption of a uniform asteroid impact distribution. Because of high impact probability corridors, some regions are at high risk regardless of their population size.

Figure 2: Asteroid impact risk distribution.

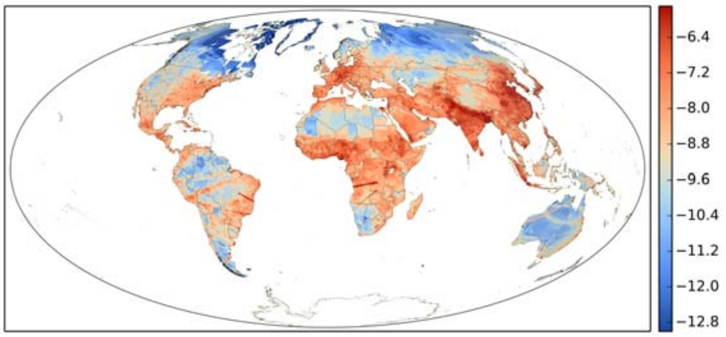
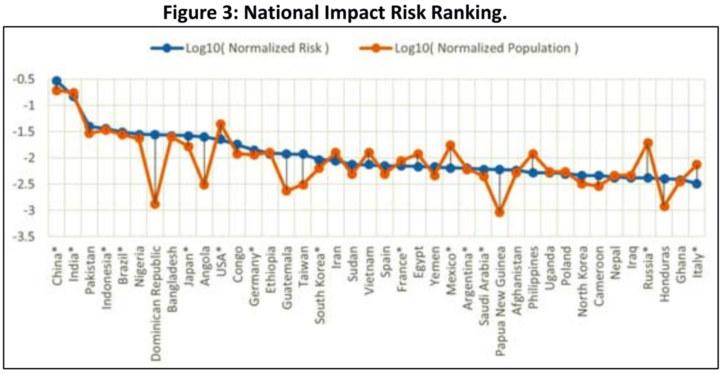


Figure 3: National Impact Risk Ranking.



National Impact Risk Ranking

Based on the risk distribution shown in Figure 2, the 40 nations that exhibit highest risk were identified. The normalized risk and population size for each country is shown in Figure 3. The blue (risk) and orange (population) curve are strongly correlated and follow a similar pattern. However, the population curve features some outliers. Here, nations show a disproportionally high risk relative to population size (orange curve falls below blue curve). The cause for this behaviour are high impact probability corridors that cover large portions of a smaller nation and thus raise its risk significantly. Since there are more developing nations than developed nations, this phenomenon is more likely to occur for developing nations. In fact, almost all nations that show a disproportionally high risk in Figure 3 are developing countries. These nations face a dilemma because they experience a disproportionally high impact risk, are most vulnerable to an impact (because of weak infrastructure), yet do not have the resources to sufficiently respond to an imminent impact threat. This dilemma suggests a moral obligation of larger nations to lead the asteroid response effort. The international community is currently in the process of establishing organizations (SMPAG and IAWN) that coordinate the international response to an impact threat supplementing national efforts. The work presented here provides insights into the asteroid threat nature that substantiate and support this approach. Not all high risk countries are part of SMPAG and IAWN yet. Membership should be extended to countries such as China and India.

Conclusions

The work describes the future global asteroid impact and risk distributions of observed asteroids until 2100. The previously unreported dilemma of developing nations is identified. They experience a disproportionally high risk but do not have the resources to adequately respond to the asteroid threat. The results substantiate and support current international asteroid threat response efforts. SMPAG and IAWN represent these efforts and they need to include more relevant nations such as China and India in their activities.

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