Finding Osama Bin Laden: An Application of Biogeographic Theories and Satellite Imagery

Thomas W. Gillespie
John A. Agnew
Erika Mariano
Scott Mossler
Nolan Jones
Matt Braughton
Jose Gonzalez

CCPR-002-09

January 2009
Latest Revised: January 2009

California Center for Population Research
On-Line Working Paper Series

Finding Osama Bin Laden:
An Application of Biogeographic Theories and Satellite Imagery

Thomas W. Gillespie and John A. Agnew are professors of geography at UCLA. They may be contacted at, respectively, tg@geog.ucla.edu and jagnew@geog.ucla.edu. Erika Mariano, Scott Mossler, Nolan Jones, Matt Braughton, and Jorge Gonzalez are undergraduates in UCLA's geography department. They may be contacted at, respectively, erikmari@ucla.edu, smossler@ucla.edu, nolanjones@ucla.edu, mbraught@ucla.edu, and jorgon@ucla.edu.

Abstract

One of the most important political questions of our time is: Where is Osama bin Laden? He is alleged to be responsible for inspiring and financing, if not exactly organizing, the September 11, 2001 attacks on the New York Trade Center and the Pentagon that resulted in the deaths of over 3,000 people. We use biogeographic theories associated with the distribution of life and extinction (distance-decay theory, island biogeography theory, and life history characteristics) and remote sensing data (Landsat ETM+, Shuttle Radar Topography Mission, Defense Meteorological Satellite Program-Operational Linescan System, QuickBird) over three spatial scales (global, regional, local) to identify where bin Laden is most probably currently located. There is a 98% probability that he is in Kurram within the Federally Administered Tribal Areas of Northwest Pakistan based on distance-decay theory. Island biogeography theory based on "city islands" further predicts that he is in the largest and least isolated city of that area, Parachinar. A systematic search across 1-kilometer grids within Parachinar identified three buildings (N 33.901944° E 70.093746°, N 33.911694° E 70.0959°, N 33.888207° E 70.113308°) that match all six of bin Laden's life history characteristics (for example, security, privacy, resources, and quality of life needs). We believe that our work involves the first scientific approach to establishing his current location. The methods are repeatable and could easily be updated with new information obtained from the US intelligence community.

Acknowledgements

The authors would like to thank Chase Langford for his assistance with graphics. The California Center for Population Research, UCLA provided funding through the Spatial Demography Program. We would also like to thank Patrick Healy, Kathy Deuel, Rebecca Goodine, Duccio Rocchini, Stephanie Pincetl, and Bill Clark for reviewing this manuscript.

Introduction

One of the most important political questions of our time is: Where is Osama bin Laden? He is believed to be responsible for inspiring and financing the September 11, 2001 attacks on sites in the United States that resulted in the deaths of over 3,000 people(1). Over the last seven years, little progress has been made towards identifying his whereabouts, even with a $25,000,000 reward for information leading to his capture. There has also been little published scientific research testing hypotheses about his current location. However, there have been significant advances in biogeographic theory and remote sensing imagery that can be applied to provide testable propositions about his current location (2-3).

Distance-decay theory and island biogeography theory are two biogeographic theories associated with the distribution of life and extinction that can be used to identify the location of bin Laden at, respectively, global and regional spatial scales. Distance-decay theory states that as one goes further away from a precise location, there is an exponential decline in the turnover of species and a lower probability of finding the same composition of species (4-6). The theory of island biogeography states that large and close islands will have high immigration rates and support more species with lower extinction rates than small isolated islands (7). The identification of bin Laden's current location can thus be assessed over different spatial scales by identifying his last reputed geographic location. Distance-decay theory would predict that he is closest to the point where he was last reported and, *ceteris paribus*, within a region that has a similar cultural composition (that is, similar religious and political beliefs) and physical environment. For instance, the further he moves from his last reported location into the more secular parts of Pakistan or into India, the greater the probability that he will be in an area with a different cultural composition, thereby increasing the probability of his being captured or

eliminated. Island biogeographic theory predicts that bin Laden is in a larger town rather than a smaller and more isolated town. This conclusion significantly reduces the probability that he will be captured or eliminated by being surrounded by a very large number of individuals with similar beliefs instead of residing in a small isolated city or house that could be easily monitored or searched by his adversaries. Finally, high-resolution analyses of a city can be undertaken to identify individual buildings that match bin Laden's life history characteristics (for example, he is 6'4", uses a dialysis machine given his putative kidney disease, has a small number of body guards).

There have been over 73 successful launches of earth-observation satellites between 2000 and 2007. Most of these satellites contain passive or active sensors that scientists can utilize to sense the earth remotely. Currently, spaceborne satellites such as IKONOS 2, EROS, QuickBird 2, and OrbView 3 can provide imagery with 0.6-meter to 2.5-meter pixel size and have repeat times of three to 14 days. The NASA satellite series can provide regional scale data on land cover and elevation, and the Defense Meteorological Satellite Program-Operational Linescan System can provide nightlight imagery to measure city size and energy use based on nightlight brightness at a global spatial scale. Although these satellites and sensors are not as high resolution as US intelligence satellites, they may be accurate enough to create working hypotheses on bin Laden's current whereabouts.

We proceed as follows. First, we describe our data sources and methods. Then we identify his last known location and apply a distance-decay model to identify the regions where he should have the highest probability of residing. To scale down, we then apply island biogeography theory using remote sensing imagery to identify "city islands" within the region to identify the largest and least isolated city islands. In the next phase, we systematically survey the

most probable city island to identify buildings that match bin Laden's life history characteristics. Finally, we identify methods that can be used to provide a practical outcome of the research.

Sources and Methods

Satellite Imagery: Landsat ETM+, Shuttle Radar Topography Mission, QuickBird, and Defense Meteorological Satellite Program-Operational Linescan System imagery were used to provide hypotheses on the current location of bin Laden. All imagery was georectified into the same geographic coordinate system (WGS84). Two Landsat 7 ETM+ images of Afghanistan and Pakistan with a pixel size of 30 m × 30 m were acquired from March 28, 2001 and September 22, 2002. Shuttle Radar Topography Mission data on elevation with a pixel size of 90 m × 90 m were acquired and combined with Landsat ETM+ imagery of the region. QuickBird imagery with a pixel size of 0.6 m × 0.6 m in the visible wavelengths was acquired via Google Earth for March 19, 2004 and November 12, 2007. Defense Meteorological Satellite Program-Operational Linescan System imagery under cloud-free and low moon conditions was collected for 2007.

Analysis: Three spatial scale analyses (global, regional, local) were undertaken to determine the current location of bin Laden (8). At a global scale, his last known location (Tora Bora) was used to create distance-decay probability maps over satellite imagery. A three-dimensional model of the Tora Bora landscape, using Landsat ETM+ and Shuttle Radar Topography Mission imagery, identified the point that bin Laden would have passed in Tora Bora based on spectral imagery and topography. A distance-decay model using an exponential curve was used with his last known location in Tora Bora (N 34.0641° E 70.1375°) set at 99% probability of bin Laden's occurrence, and with the White House in Washington D.C., located

11, 246 kilometers away, set at 1% probability of bin Laden's occurrence (N 38.8976° W 77.0366°) (Figure 1). We use a simple exponential model ($P(d) = k^d$) where k is the constant derived from our assumed values of there being a 1% chance of Osama bin Laden being located in Washington, D.C. and a 99% chance that he is located in the area he was last seen, d is the distance from his last known location and $P(d)$ is the resulting probability of his being located at that distance. Thus, we predict according to distance-decay theory that the further Osama bin Laden is from Tora Bora and the nearer he is to Washington, D.C. the lower the probability that he is located there. The resulting equation ($P(d) = 0.99959058977238^d$) was then used to calculate individual values of probability given a certain distances.

At a regional scale, the distance-decay map was overlaid on the city islands to identify cities with the highest probability of bin Laden's occurrence. City islands larger than 100 m x 100 m were digitized over geo-referenced QuickBird imagery in ArcGIS 9.0 to quantify area and isolation metrics. City-islands were quantified as area of continuous man-made structures and the distance in kilometers to all other city-islands was used as an isolation metric (9). Boundaries of the Federally Administered Tribal Areas (FATAs) were overlaid on nightlight imagery to identify city islands in the region.

At a local spatial scale, QuickBird imagery of the city with the highest probability of occurrence – that is, the highest probability of having bin Laden – was systematically searched across 1 km × 1 km grids to identify structures that match his six life history characteristics (Table 1). Each structure was quantified as 1 or 0 for accommodating each one of these six characteristics. Structure values were summed and the highest values (for example 5 or 6) were selected as his probable location.

Results

Osama bin Laden was last seen by non-local observers in Jalalabad, Afghanistan on November 13, 2001 and, according to radio traffic, he was last heard from in a transmission from Tora Bora on November 28, 2001 (Figure 2) (10). When a distance-decay model was applied to his last known location, the FATAs of Kurram had the highest probability of housing bin Laden (98%) (Figure 3). There were 26 city islands within a 20-km radius of his last known location in northwestern Kurram. Parachinar was the largest and the fourth-least isolated city (Figure 4). Nightlight imagery shows that Parachinar is the closest city to his last known location and by far the brightest city by nightlight intensity in Kurram (Figure 5). A systematic search across seven 1 km × 1 km grids was undertaken in the city of Parachinar to identify structures that accommodate bin Laden's life history characteristics (Table 2). This approach resulted in three structures that meet all six of them (Figure 6) and 16 structures that meet five of them. Results were submitted to the Federal Bureau of Investigation via instructions on the "Wanted by the FBI" website (www.fbi.gov/wanted.htm).

Discussion

From one viewpoint, bin Laden himself is not of great strategic significance. He and his immediate cohort do not seem to have had much direct impact on any terrorist activity, even that associated by the media with al-Qaida, such as the London, Madrid and Mumbai terror attacks, since 2001. Perhaps this is why official US interest in capturing or killing him has declined. Be that as it may, bin Laden remains an important symbol of the very "clash of civilizations" conception of what happened on 9/11 that the Bush Administration has nurtured. More recently, if without evident reference to bin Laden's network, President Bush has touted as his major

accomplishment in office the absence of any terrorist attack since 2001 within the home territory of the United States. Obviously this signifies a sense of continuing danger from wherever the attacks of 9/11 are presumed to have come. At the same time, in the Arab World, and more widely, bin Laden certainly seems to have acquired a Che-like image as a heroic figure in the struggle against American hegemony. Symbolically, if not necessarily materially, he is far from a spent political force.

Distance-decay theory suggests that Osama bin Laden's current location is not likely to be random, and his probability of occurrence exponentially decreases the further he moves from his last known location (4-6). Our results indicate that there is a 98% probability that he is in Kurram, Pakistan, and an 86.6% probability that he is within one of the seven FATAs. The FATAs have long been outside of central government control and served as reservoirs of militant Islamists working to change the governments in both Kabul and Islamabad since the 1970s. Based on his last known location in Tora Bora, we estimate that he must have traveled 3.1 km over a 4000 meter-or-so pass in winter to enter Kurram, Pakistan. Doing so would have been extremely difficult for a 44-year old man with diabetes. Kurram is surrounded on three sides by the Afghan border (known as the Durand Line), which essentially cuts right though the ethnically Pushtun belt that straddles it. It is unlikely that he would have headed back into Afghanistan after leaving Tora Bora, if only because doing so would have required him to abandon the mountains for more open countryside.

There are few published hypotheses concerning bin Laden's current global or regional location. One comes from a letter from Atiyah Abd al-Rahman to Abu Musab al-Zarqawi, bin Laden's presumed second-in-command, dated December 11, 2005 (11). It suggests that he and the al-Qaeda leadership were based in the Waziristan region of Pakistan at the time. However, it

is difficult to believe that a letter would be written by such a high-ranking official giving away bin Laden's location. Another alternative hypothesis is that he resides in the southern or northern FATAs where there is significantly greater Taliban (Afghan and Pakistani) military activity. However, we have good reason to believe that he would be safest in Kurram.

Parachinar had a long history of housing mujahideen during the Soviet invasion of Afghanistan in the 1980s, so it most likely contains a large number of Taliban soldiers who cross over from here into Afghanistan. Residing near or in a large city should reduce bin Laden's chances of exposure and elimination due to a military raid on a small city or an isolated structure. Smaller cities would greatly reduce his security and privacy, and there are only a small number of structures that appear well-protected in smaller towns (Figure 7). Nightlight imagery also reveals that Parachinar is one of the brightest cities in the FATAs after the city of Miram Shah in North Waziristan, which is 102.3 km away. Most cities there have little or no nightlight signature. The city of Peshawar has the brightest nightlight signature in the region and may soon fall to the Taliban. If Peshawar falls under Taliban control, the search for bin Laden will become significantly more difficult due to the large number of structures in that city compared to the relatively small number of structures overall in the FATAs.

Based on Osama bin Laden's life history characteristics, three buildings should be closely monitored to test the hypothesis that he is located at one of them. Structures A, B, and C are the best fortified and some of the largest residential homes or structures in the city of Parachinar. Structures A and C are residential homes, while structure B appears to be a prison. However, if it is a prison, it has one of the best-maintained gardens in all of Parachinar. There are also 16 structures that match five of bin Laden's life history characteristics (Table 2). If one follows our approach, one would predict that he is located in one of these three buildings. Of course, this

conclusion results from applying a model that, like all other models, makes critical assumptions. What we have attempted to demonstrate is that it is possible to narrow down where Osama bin Laden is by ruling out where he is unlikely to be.

High-resolution imagery of all structures in the FATAs is currently possible from a number of international commercial satellites such as Geoeye; however, open-access satellite images can be high enough to be a national security risk in the region (12-13). For instance, in an attempt to aid disaster relief efforts after the October 8, 2005 earthquake in Kashmir, numerous international aid agencies posted high-resolution satellite images on the web. The Pakistani government forced these images to be removed because they feared that the security of the Kashmir region might be compromised. Perhaps it is past time to embrace this technology and create a public database concerning models or hypotheses about bin Laden's current location.

The US intelligence community has at least three agencies that have been involved in searching for him. The National Security Agency does code breaking and communications monitoring, the National Geospatial Intelligence Agency makes maps and analyzes surveillance photographs, and the National Reconnaissance Office provides satellite imagery. Altogether, the US intelligence community spent over $50,000,000,000 on intelligence activities last year alone. Ideally, some of this money should have been spent looking for bin Laden and the US intelligence community could make public a report based on all data collected from 2001 to 2006. The three agencies mentioned above should also disprove the hypotheses that Osama bin Laden is: (1) located in the Kurram region of Pakistan, (2) located in the city of Parachinar, and (3) at one of the three hypothesized buildings. These methods are repeatable and could easily be updated with new information obtained from the US intelligence community.

References

1. Kean TH, Hamilton L (2004) *The 9/11 Commission Report: Final Report of the National Commission on Terrorist Attacks Upon the United States* (W.W. Norton and Company, New York).

2. Nekola JC, Brown JH (2007) The wealth of species: ecological communities, complex systems and the legacy of Frank Preston. *Ecology Letters* 10:188-196.

3. Gillespie TW, Chu J, Frankenberg, E Thomas D (2007) Assessment and prediction of natural hazards from satellite imagery. *Progress in Physical Geography* 31:459-470.

4. Nekola JC, White PS (1999) The distance decay of similarity in biogeography and ecology. *Journal of Biogeography* 26:867-878.

5. Koleff P, Gaston KJ, Lennon JJ (2003) Measuring beta diversity for presence-absence data. *Journal of Animal Ecology* 72:367-382.

6. Rocchini D (2007) Distance decay in spectral space in analyzing ecosystem β-diversity. *International Journal of Remote Sensing* 28:2635-2644.

7. MacArthur RH, Wilson EO (1967) *The Theory of Island Biogeography* (Princeton University Press, Princeton)

8. Willis KJ, Whittaker RJ (2002) Species diversity-scale matters. *Science*, 295:1245-1248.

9. Hargis CD, Bissonette JA, David JL (1998) The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* 13:167-186.

10. Stewart J (2007) *The Savage Border: The History of the North-West Frontier* (Sutton Publishing Limited, Gloucestershire)

11. DeYoung K (2006) Letter gives glimpse of Al-Qaeda's leadership. *Washington Post*, 2 October 2006.

12. Butler D (2005) Quake aid hampered by ban on web shots. *Nature* 437:1072-1073.

13. Nourbakhsh I, Sargent R (2006) Mapping disaster zones. *Nature* 439:787-788.

APPENDIX

Figure 1: Distance-decay model with percent probability and distance

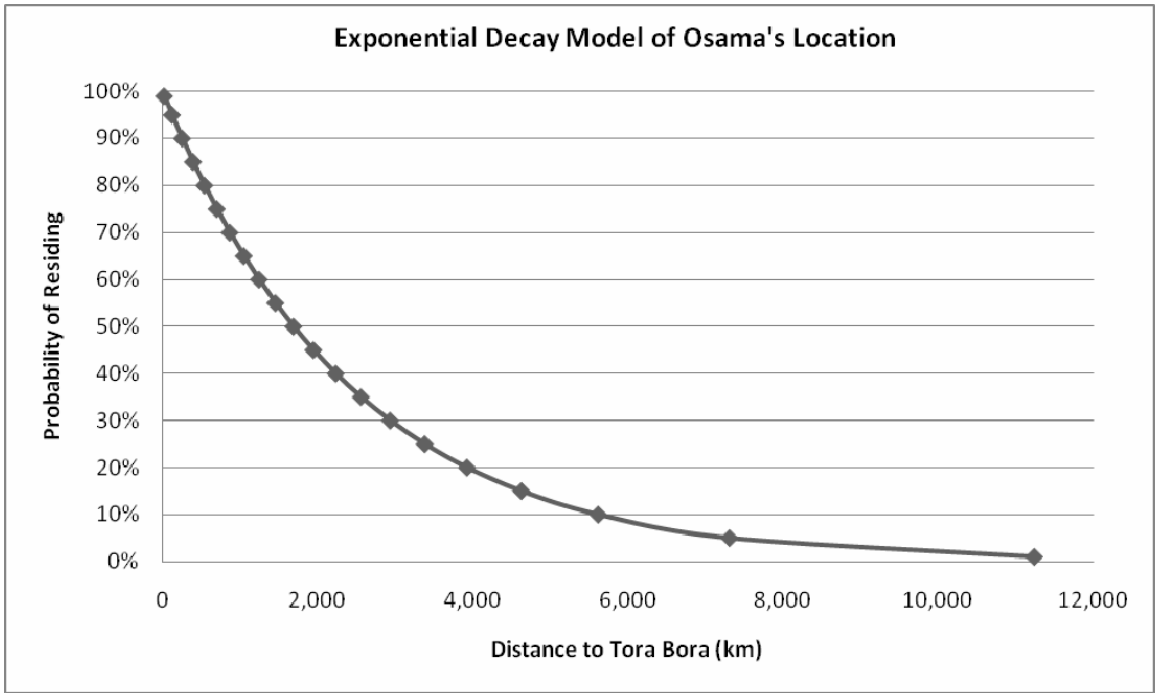

Figure 2: The last known location of Osama bin Laden in Tora Bora using two-dimensional spectral and three-dimensional spectral and elevation imagery

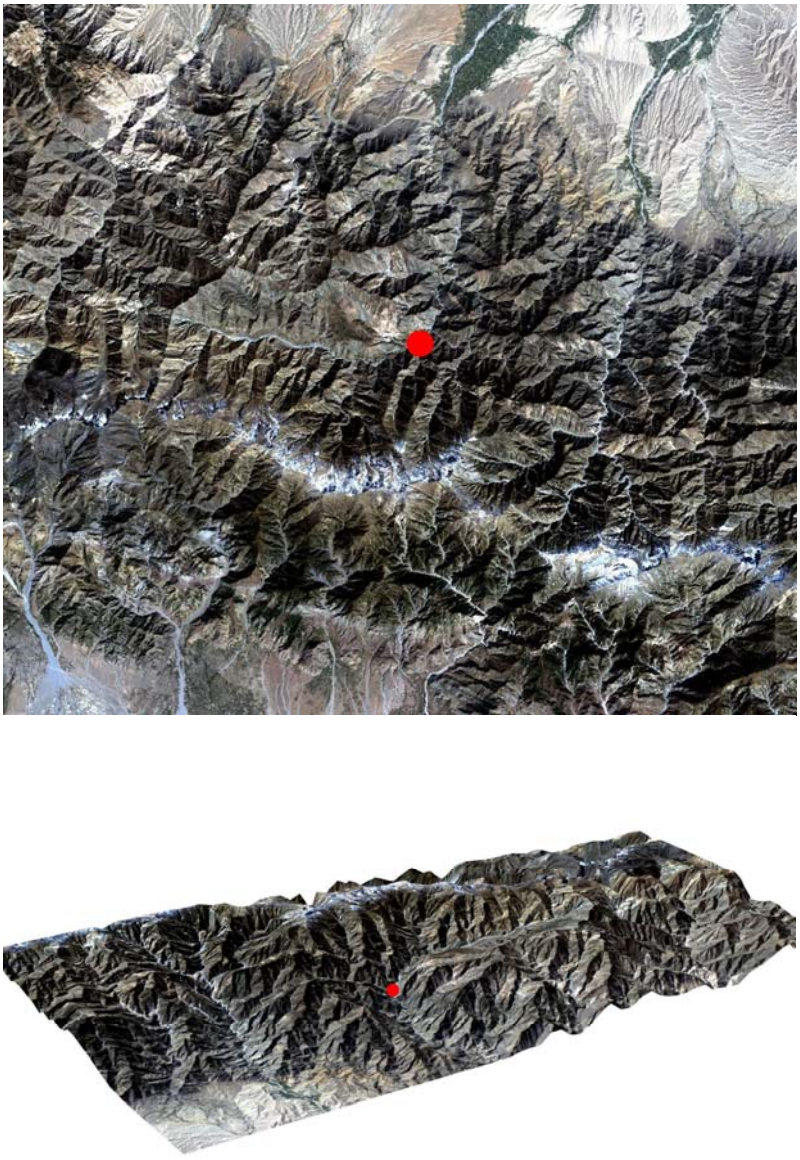

Figure 3: Probability model of bin Laden's current location based on distance-decay theory at a global spatial scale

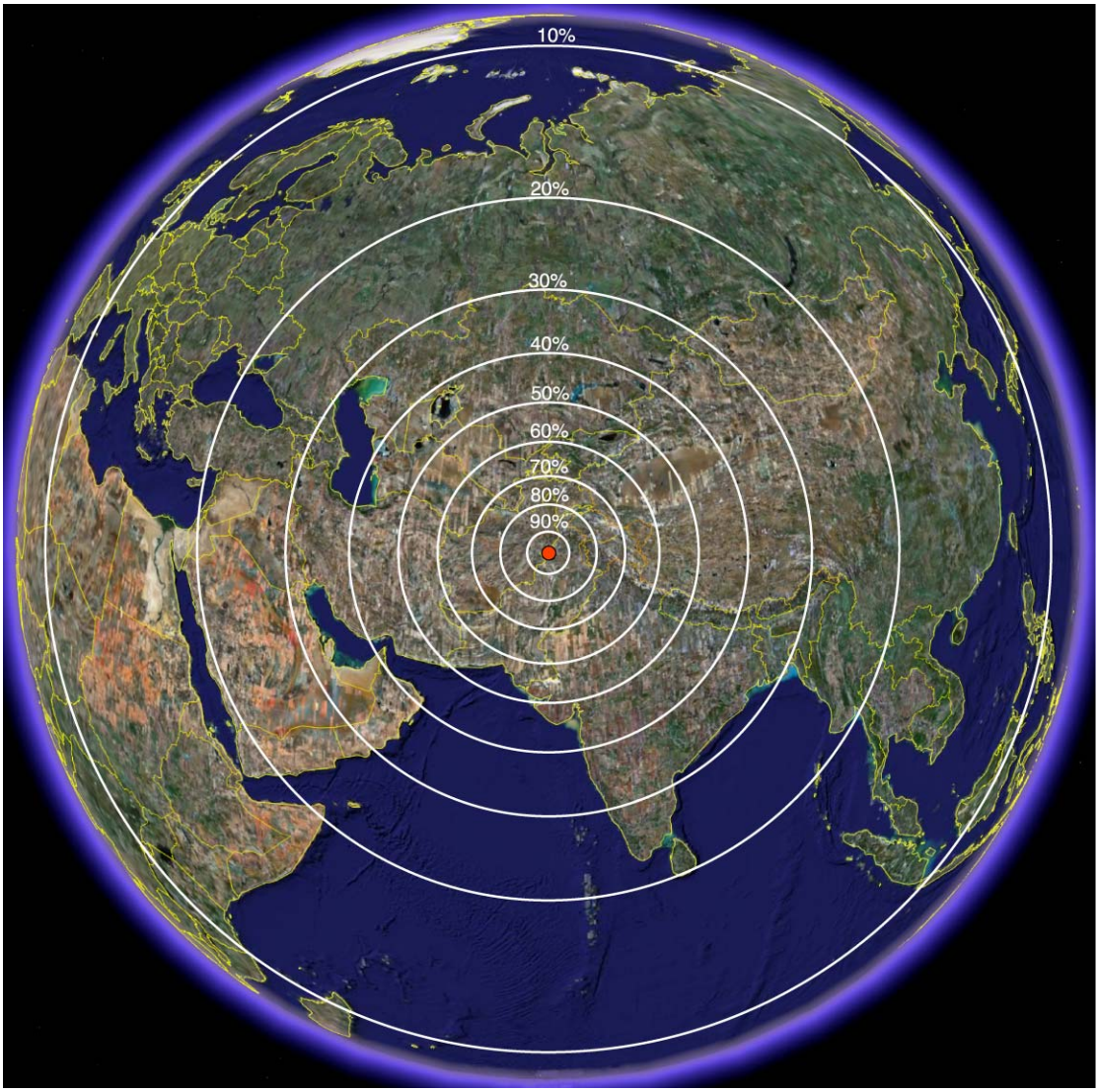

Figure 4: Regional analysis of city islands within a 20-km radius of bin Laden's last known location (red dot)

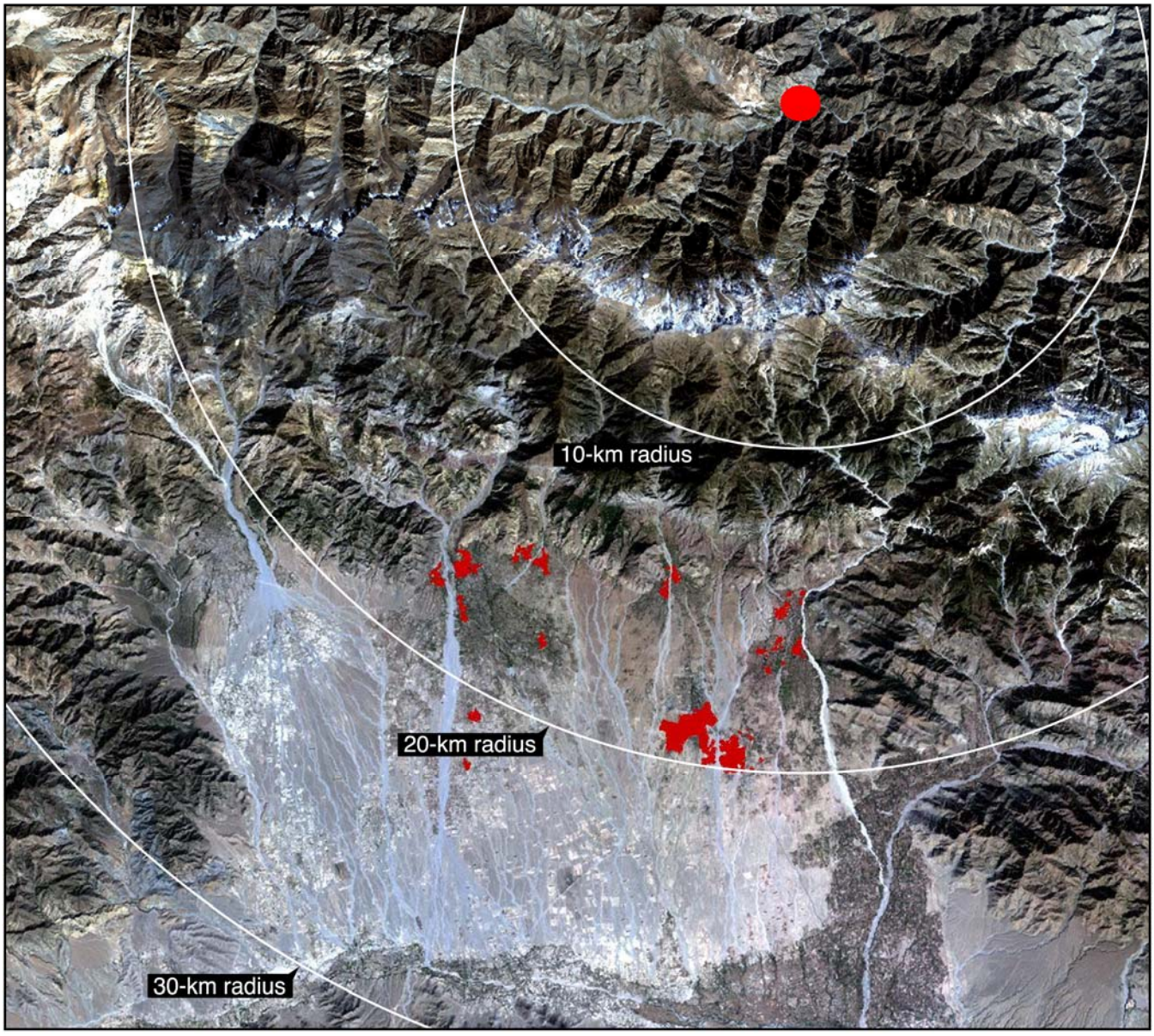

Figure 5: Regional analysis of city islands in Pakistan's FATAs using nightlight imagery

Figure 6: Three predicted locations of bin Laden based on his life history characteristics

Structure A

N 33.901944° E 70.093746°

Structure B

N 33.911694° E 70.0959°

Structure C

N 33.888207° E 70.113308°

Figure 7: Small city islands and structures in Kurram, Pakistan

Table 1: Life history characteristics of Osama bin Laden and associated physical structure attributes

Life History Characteristics	Physical Structure Attribute
6’4” inches	Tall building
Dialysis machine that uses electricity	Electricity
Protected structure	Walls over three meters
Privacy	Space between structures
Small number of body guards	More than three rooms
Trees cover	Trees for cover when outside

Table 2: Seven 1 km × 1 km grids in Parachinar, structure number within grid, and location of structures with a score of five and six based on the sum of bin Laden's life history characteristics and physical structure attributes

Grid #	Structure	Score	Latitude	Longitude
1	1	5	33.903432°	70.091091°
	2	6	33.901944°	70.093746°
	3	5	33.902662°	70.095839°
2	1	5	33.899715°	70.104956°
	2	5	33.900707°	70.103338°
	3	5	33.906885°	70.105129°
	4	5	33.896283°	70.111935°
3	1	5	33.898657°	70.116777°
	2	5	33.899745°	70.118473°
	3	5	33.894525°	70.121523°
4	1	5	33.897951°	70.089383°
	2	5	33.898255°	70.087519°
5	1	5	33.892353°	70.106461°
	2	5	33.887763°	70.111442°
6	1	5	33.885623°	70.115935°
	2	5	33.891417°	70.114477°
	3	6	33.888207°	70.113308°
7	1	6	33.911694°	70.095900°
	2	5	33.913399°	70.097189°