Mapping tsunami damaged area caused by the magnitude 9.0 Japan earthquake using China's HJ-1 satellite imagery

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Damages caused by earthquakes are hard to detect with medium spatial resolution satellite data. However, the magnitude 9.0 Japan earthquake occurred on March 11, 2011 has caused a devastating tsunami. The tsunami pushed widespread flooding over the coast of eastern Japan. If satellite data can be obtained at the time of tsunami flooding, it should be possible to map the submerged coastal area. Unfortunately, today′s technology is still far from perfect to allow acquisition of detailed enough satellite data at the right time of a disaster.

The Chinese HJ-1 satellite launched in September 2009 was designed for monitoring environmental change and disasters. We collected two HJ-1 CCD scenes (orbit number 428-68) over Sendai and its surroundings, one before (May 17, 2010) and the other 3 days after the Japan earthquake (Fig. 1). Corresponding to the HJ-1 scene, we also collected two scenes of Landsat TM images (path-row number 107-33 and 107-34) with an acquisition date of June 4, 2004. The TM images were used as reference for geometrically correcting the HJ-1 images.

The post-earthquake HJ-1 image was georeferenced to the two previously geo-coded Landsat TM images with ground control points primarily chosen along the coastal zone including street intersections, major constructions and stable and easily identifiable lake features (Fig. 2). A total of 15 ground control points produced a root-mean squared error of 0.49 pixels. The pre-earthquake HJ-1 image was geo-registered to the post-earthquake HJ-1 image with 10 ground control points to a 0.47 pixels of root-mean squared error.

On the March 14 HJ-1 image, water flooded areas along the east coast of Japan are quite observable. We used a normalized difference water index (NDWI) to enhance water covered areas on land along the coast. We choose one threshold value over which interpreted as water flooded area (Fig. 3). However, using NDWI alone is not sufficient as water submerged areas are likely to dry out three days after the tsunami except relatively low-lying areas. Therefore, it is important to look for additional traces of the tsunami. Through pre- and post-earthquake image comparison, vegetation and some of the non-vegetated and non-surface water areas have changed considerably along the coast. Poorer vegetation vigor following the earthquake is an indicator of high level of damage that could only be possible after tsunami flooding. We therefore used normalized difference vegetation index (NDVI) to detect damaged vegetation area along the coast. With a region growing algorithm, we extracted the damaged areas over the non-vegetated and non-surface water areas. The final result of tsunami submerged area was a combination of the water covered areas determined from NDWI, the vegetation damaged areas determined from NDVI, and other damaged areas over non-vegetated and non-surface water areas.

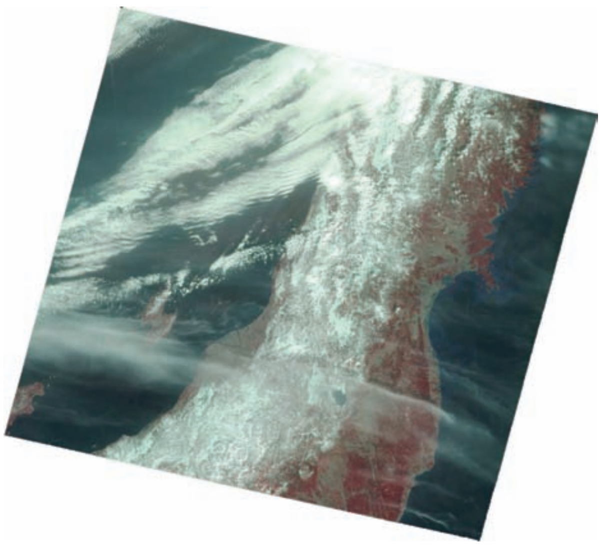

Fig. 1 HJ-1 image acquired over Sendai and its vincinity area on March 14, 2011

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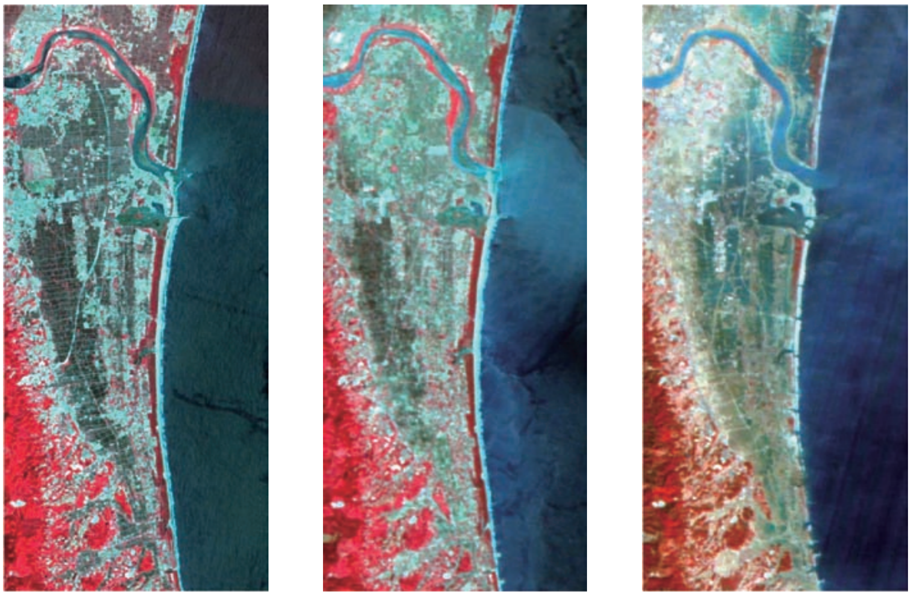
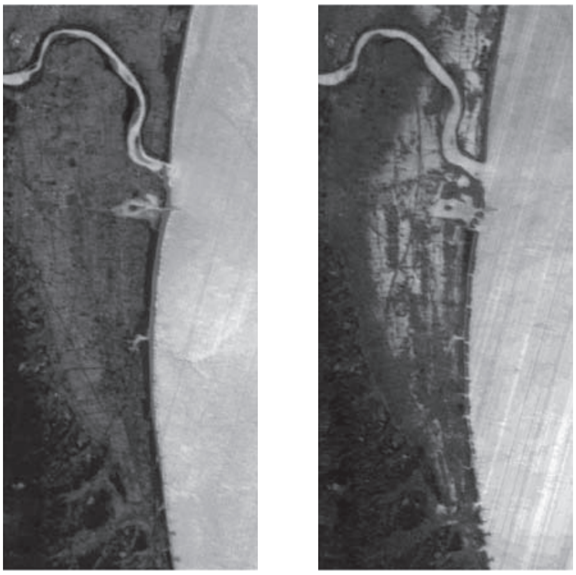


(a) (b) (c)

Fig. 2 A subsection of the Sendai image with the TM image
(a) before earthquake; (b) HJ-1 image before earthquake; (c) HJ-1 image after earthquake



(a) (b)

Fig. 3 NDWI images derived from HJ-1 images, the bright areas inland of the post-earthquake image shows tsunami water coverage three days after the submerging
(a) before the tsunami; (b) after the tsunami

We used the above method to detect tsunami flooded area with the HJ-1 imagery acquired on March 14, 2011. The results were presented in Fig. 4. Although we were not able to acquire satellite images right after the tsunami caused flooding and the quality of the HJ-1 image was not as desirable because there were thin clouds during the image acquisition, the areas flooded and vegetation damaged by tsunami can be determined from comparing the post-earthquake and pre-earthquake images. We estimated that area affected by this tsunami in the image to be approximately 308 km^2. This estimate is not far from the 351 km^2 tsunami affected areas of non-urban land as reported by the Geospatial Information Authority of Japan ([2011-04-24] http://www.gsi.go.jp/kikaku/kikaku60003.html). It is reasonable to have an underestimation of the tsunami affected areas due to the 3 day delay. Some of the non-vegetated urban areas damaged by tsunami are difficult to determine due to the limitation of image resolution. The partial cloud in the March 14 image blocked part of the tsunami damaged areas. Once the tsunami damaged areas are obtained, we overlaid them on the 30m resolution DEM data determined with ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data. Through zonal statistics we estimated the vertical dimension of the tsunami (Table 1). The average elevation is the weighted elevation of tsunami submerged areas and the highest elevation is the range of most inner elevation that the tsunami reaches along the coast.

Table 1 Tsunami affected elevation

	Average elevation/m	Highest elevation/m	Area/km^2
Tsunami damaged area	5.701	19–20	308.7
Surface water 3 days after	5.328	19–20	177.3

The simple analysis indicates that data obtained from the Chinese environment and hazard satellite HJ-1 can be used in tsunami damage assessment. Remote sensing data not only can provide the horizontal extent of tsunami damage triggered by the Sendai earthquake but also can provide the tsunami affected height. Additional work might help with subpixel image analysis techniques. Nonetheless, in front of the disasters of this tremendously large earthquake, it is clear to us that there is a long way to go for satellite based remote sensing to achieve what has been said–anywhere and anytime when the technology is needed.

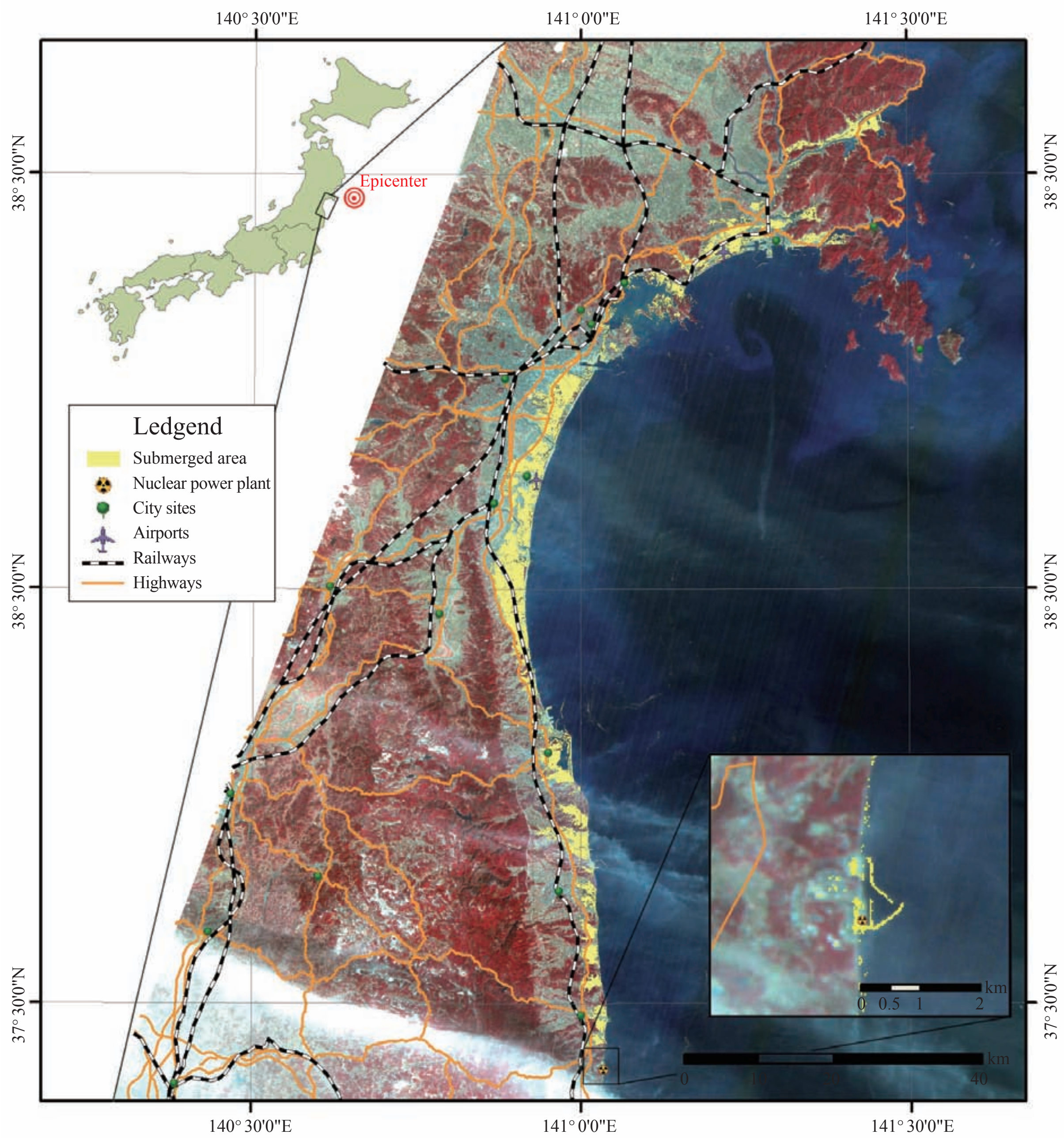


Fig. 4 Tsunami flooded and damaged area determined with HJ-1 satellite

用中国环境减灾卫星1号数据评估日本仙台9.0级大地震引发海啸淹没区

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地震对平坦地区引起的损失用中等分辨率的卫星数据比较难于辨认。但是，2011-03-11在日本仙台发生的9.0级大地震引发了巨大的海啸。海啸造成日本东北部近海岸带的低洼陆地巨大的淹没损失。如果能及时获取当时海啸淹没的遥感影像，应该能够获得比较准确的淹没区制图。但是，我们能够获得的资料仅仅是地震发生以后3天的中国环境减灾卫星1号的多光谱成像数据，我们报告利用这份资料获得的淹没区的制图结果。

中国环境与减灾卫星1号于2009年9月发射，其目的就是监测环境与灾害损失。其携带的CCD相机空间分辨率为30 m。我们获得了两景日本仙台及周边地区震前(2010-05-17)和震后(2011-3-14)的CCD数据 (编号428-68)，震后影像见图1。 对应于环境星数据，我们采集了2004-06-04过境的两景陆地卫星TM图像(轨道编号107-33和107-34)。TM图像已经进行了几何校正和地理编码，所以可以对环境星数据进行几配准正。

选择震后环境星和陆地卫星数据中可识别的道路交叉口，显著建筑物以及稳湖泊水库不变特征点15个做几何纠正建模，2次多项式变换得到0.49个像元的均方根误差，利用双线性内插获得对环境星数据进行重采样，得到具有地理编码的环境星数据(图2)。震前环境星的数据根据10个控制点做几何纠正，均方根误差控制在0.47个像元。

尽管已经是震后3天，从3月14日的环境星图像上可以看出日本仙台东岸被海水淹没的范围依然很明显。未做辐射纠正，我们使用了简单的归一化水指数增强东岸内陆淹没积水区。根据水指数进行取阈值处理得到淹没积水在3月14日影像上的明水范围(图3)。阈值选取根据多次试验主观确定。由于距离海啸发生已经是3天之后了，所以这样确定的淹没范围势必要比实际发生的范围小很多，所以我们通过其他特征找寻海啸淹没的痕迹。植被的破坏以及非植被区和非水

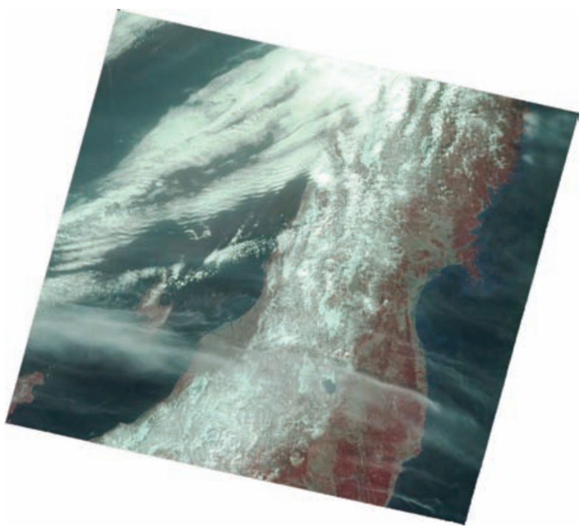

图1　2011-03-14中国环境与减灾卫星1号在日本东北部获取的CCD影像

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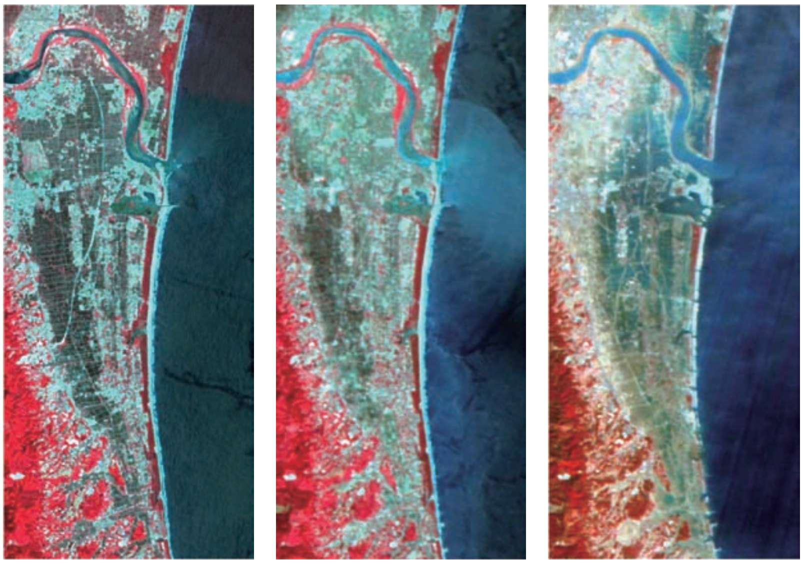
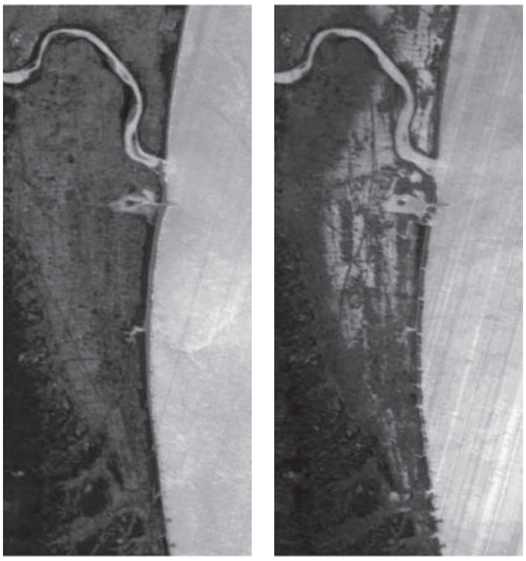


(a) (b) (c)

图2 日本仙台地震灾区局部影像示意图，用近红外、红和绿波段配以红、绿、蓝显示的标准假彩色数据

(a) 陆地卫星；(b) 震前环境星；(c) 震后环境星



(a) (b)

图3 中国环境与减灾卫星CCD相机数据计算的归一化水指数

(a) 海啸前；(b) 海啸后

淹区有被水淹没痕迹，可以通过比较震前震后的图像得以辨别。我们对震前和震后环境星影像计算了归一化植被指数，通过比较震前和震后影像的差值获得震后海啸破坏的植被区。对于非水淹亦非植被遭到破坏区域，但明显是受海啸冲击过的地区，在震后影像上采用区域增长提取出来。得到的植被淹没区的范围、非植被和水淹被破坏区域、和从同一图像上得到的明水范围求并集，构成能从环境卫星获得的海啸淹没范围(图4)。

尽管海啸已经发生3天，用环境星还是初步确定了受海啸淹没影响的植被和明水覆盖范围。我们的结果算得海啸淹没区面积为308 km^2。而日本国家地理院调查得到海啸造成351 km^2的淹没([2011-4-24] http://www.gsi.go.jp/kikaku/kikaku60003.html)。由于我们统计的范围和数据有少许云盖的原因，加上在中等分辨率图像上城市区域遭到的破坏痕迹多不明显，容易遗漏，得到略低的淹没范围面积是合理的。海啸对建成区的淹没和损失是人们最为关注的区域，但环境星受到分辨率等原因的限制，难于分辨损失。把用搭载在美国Terra卫星上的高级星载热红外辐射仪数据提取的30 m分辨率的DEM高程数据和淹没损失数据结合进

行淹没区高程统计，得到表1。表中平均高程是根据淹没范围高程加权平均的结果，而淹没最高海拔是海啸淹没的在最内边界的高程范围。

表1 海啸淹没区的高程和面积统计

	平均高程/m	淹没最高海拔/m	面积/km^2
海啸淹没区	5.701	19—20	308.7
震后三天的积水区	5.328	19—20	177.3

这个简单的尝试报告展示了中国自主研发的卫星在应对全球突发事件时的数据获取能力和信息提取潜力。利用遥感数据，我们不仅可以监测海啸引起的平面范围，还能得到淹没高程信息。中国全球监测的能力无疑较以前大有提高，中国环境星的发射使中国学者可以根据兴趣和需要较快获取除接近两极少许高纬度地区以外全球任一区域的中等分辨率图像的能力。这类数据的潜力或许通过进一步挖掘子像元分解技术等能够提取更加详细的由于灾害引起的变化。尽管如此，在大的灾害和突发事件面前，遥感技术至今尚未做根据需要获取任何时间、任何地点的数据，发展地球观测技术还需长期不懈努力。

志 谢 感谢民政部减灾中心提供环境卫星数据。

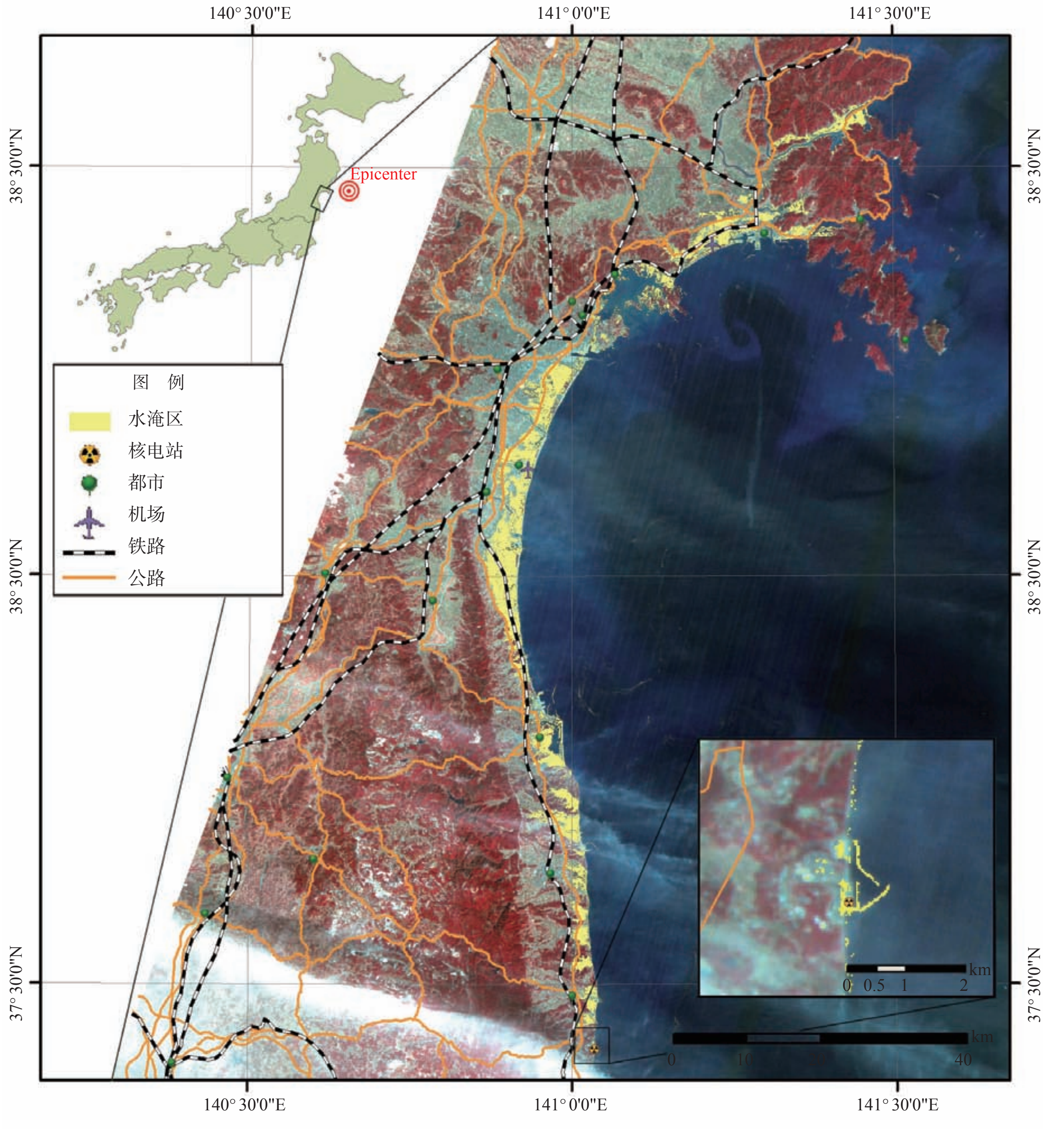


图4 日本东北仙台地区地震引发海啸淹没范围图