RC- Reviewer comment; **AC – Authors comment**

RC- The authors carried out a comprehensive study on the use and integration of data from multiple sensors for flood mapping. They used some approaches already tested in literature and others more innovative and experimental. In particular, they designed an approach using free or low cost data/sensors that was tested on a real case study considering both urbanized and not urbanized areas.

The work is certainly of interest for the readers of NHESS. Nevertheless, I have a number of comments that may help the authors in improving the final quality of the manuscript.

**AC- The authors would like to thank Salvatore Manfreda for his useful revision and suggestions. We reply point-by-point in this document.**

RC- 1) In order to provide enough information to replicate the experiment, I would suggest to include more details about the methods used for the classification of the satellite images (COSMO-Skymed, Aqua satellite co-flood image).

**AC –1. thank you for your suggestion. As also suggested by another reviewer, we improve the description of type of data and processing used for COSMO-Skymed and MODIS-Aqua satellites. In particular:**

**a) For Cosmo-data in section 3.1.1 (about line 172-176 of revised manuscript):**

*"The Cosmo-Skymed data provided is a simple, not-geocoded, image in greyscale format (0-255). After the geocoding we re-classify, using GIS software, the SAR amplitude images using empirical thresholds in three main classes: water covered areas (0-60) soil/vegetation (60-160) and urban area (160-255). The investigated area is almost flat, so it is not affected by problems related to geometrical distortions. The validation of the classification accuracy was made by comparing the reclassified image with aerial photos, optical images, and land-use."*

**b) For MODIS-Aqua: for this the revisions we used the atmospheric calibrated data and we added a sentence to the manuscript (section 3.1.2 – about line 213 of revised manuscript):**

*"For the elaboration, we used the MYD09 - MODIS/Aqua Atmospherically Corrected Surface Reflectance 5-Min L2 Swath 500m, (Vermote, 2015) downloaded from http://ladsweb.nascom.nasa.gov/ )"*

**We also better explain how we made the supervised classification with this new paragraph (about Line 227 of revised manuscript):**

*"Supervised classification has already been used in literature to map flooded areas, using machine learning, as described in Ireland et al., (2015). In our work we made a simple supervised classification with SAGA GIS. We first manually defined the training areas with main land use typologies visible on the false colour image. We tried different methodologies for the classifications and we chose as most accurate the maximum likelihood with absolute probability reference and spectral angle methods. We validate the reliability of these classifications with a comparison with false colour image and land-use database. Then, using a GIS query, we extracted the category "area covered by water or wetland" that mostly correspond to the flooded area for accuracy statics reported in the result section."*

RC - 2) It is notable a relevant amount of manual operations, as stated in several sentences: - Section 3.1 Flood mapping at regional scale with satellite data "*For every considered dataset, we produced a map of the flooded area: We use a visual-operator approach to map flooded areas as resulted more precise than automatic classifications especially in the case of post-flood images*";

3.1.2 Multispectral satellite data, I) Medium-Low resolution satellite data: "F*or the identification of flooded areas, we make the following elaborations: a) False colour image made with combinations of 7-2-1 bands for a visual interpretation of flooded areas*";

3.1.2 Multispectral satellite data, I) Medium-Low resolution satellite data: "*Supervised maximum likelihood classification of co-flood image made with SAGA GIS. We manually defined the training areas with main land use typology visible on the image..*"

3.1.2 Multispectral satellite data, II) Medium-high resolution satellite data: "*To detect flooded area, we first made a visual interpretation using images (Sentinel-2 images) with different bands composition of post-*

*flood data.*"
3.2.3 Ground-based ultra-high resolution images: "*For the identification and mapping of water levels, the video is analysed and a frame sequence is extracted from it when the operator sees some marks lefts by water over facades.*"

4 Results, Flood mapping from low to medium-high resolutions with satellite data: "*The flooded area limits were manually extrapolated considering satellite data and geomorphological features obtained using the hillshade model derived from 5-m DTM..*"
4.1.2 Flood mapping with multispectral data, I) Multispectral low resolution, MODIS-Aqua: "*MNDWI variation (MNDWIVAR) at 20 m of spatial resolution: However, like for NDVI, the presence of many areas with positive variations outside the flooded sector makes more accurate a manual interpretation*"
4.1.2 Flood mapping with multispectral data, II) Multispectral medium-high resolution post-flood mapping Sentinel-2: "T*he images of Sentinel-2 were analysed by visual interpretation of RGB composite image and using two different indexes (NDVI - MNDVI) to identify flooded areas shown in figure 5.*

Therefore, I am wondering if such an approach might still be considered low-cost and fast, considering the amount of work that needs to be performed by human operators. Also, the reliability and accuracy of the results would significantly depend on the ability and experience of the operator.

**AC -2. Thank you for your suggestions. In the following our reply:**

**a) About the cost: We considered this approach low-cost because we used only free satellite data for regional mapping. With actual revisit frequency of free sensors in most of the events, it should be possible to avoid or limit the on-demand commercial satellite or traditional aerial flight over a large area that have high costs and not always can be planned.**
**For instance, for Piemonte flood the cost of traditional aerial survey was about 80'000 € (about 130 €/km$^2$)**
**http://www.regione.piemonte.it/governo/bollettino/abbonati/2017/28/attach/dda1800000620_660.pdf**
**(Regione Piemonte, 2017 Italian)**
**Where is necessary to have a high-resolution mapping, we proposed low-cost (respect to traditional methods) sensors. Go-pro cameras or the RPASs now have affordable costs. Also the aerial photos that we used have a low cost compared to the traditional aerial platform.**

**b) About the rapidity in flood mapping: We agree that our manual approach cannot be fast as an automatic classification mapping like the EMSR service, but our aim is different from providing an early warning /emergency mapping that is not validated and represents the inundated area at a specific instant.**
**Our method has the aim to provide (low cost) maps of the flooded area and water depth with good accuracy and with a reliable validation. These maps, like the maps provided by official authority (e.g., ARPA Piemonte in our case) could be used for a post-flood damages assessment or to improve urban planning and to evaluate damages.**
**Free satellite images are available few hours or at least one day after their acquisition. Moreover, it is possible to know in advance the time of satellite pass. The processing both for SAR and multispectral satellite data could be made in few days like the water depth model based on DEM.**
**It is possible to estimate that within few weeks after the flood to have a good map of the flooded area.**
**At local scale, RPAS, aerial photo and Car Camera surveys can be made in few days, while post-processing and SfM elaboration and data validation require few weeks of work.**

**c) About human operator: the human factor (operator ability) is crucial, but our method is proposed for people who have expertise in flood mapping (e.g., geomorphologists or remote sensing operator who work in regional services, academia,). Moreover, our methods are mostly based on simple raster GIS calculations that can be easily replicated.**
**The automatic detection of flooded area works only if we have perfect co-flood image, otherwise an interpretation is necessary. This analysis takes into account also local conditions (geomorphology of**

**flooded are, anthropic structure).**

RC - 3) It is not possible to infer the performances of the methods/data investigated. Please, describe and provide results of any statistical analyses that you performed:

AC-3. we thank for your suggestion. In the answer to reviewer 1 we presented a new table (Table 6) in which we show the performances of data and methods that we used.

| Sector | Area | Sentinel-2 | | MODIS-Aqua | | | CSKM | Sentinel-1 |
|---|---|---|---|---|---|---|---|---|
| | $km^2$ | $MNDWI_{var}$ | $NDVI_{var}$ | $MNDWI_{var}$ | MLC | SA | Recl Ampl | $\Delta\sigma^o$ |
| Not Flooded | 259.5 | 87% | 87% | 91% | 94% | 95% | 96% | 99% |
| Flooded area | | | | | | | | |
| - Po | 47.8 | 48% | 37% | 49% | 70% | 64% | 23% | 4% |
| - Oitana | 11.6 | 49% | 42% | 60% | 11% | 36% | 37% | 1% |
| - Chisola | 7.3 | 21% | 51% | 30% | 24% | 23% | 12% | 1% |
| - Chisola urban | 1.1 | 4% | 24% | | | | | |

In the manuscript we explain how we evaluated the performance (introduction of chapter 4- about line 355 of revised manuscript):

*"For the evaluation of automatic flooded area maps based on satellite data, we applied a GIS query for each map to create boolean rasters of flooded / not flooded area. Then we overlapped the obtained raster with manual polygons for a geo-statistical analysis, for each polygon is reported the percentage pixel classified as flooded/not-flooded. The main results are reported in table 6."*

We also added more quantitative results in the section 5 (discussion / Conclusions):

About SAR (about line 570 of revised manuscript):

*"Concerning SAR data, we reclassified a simple preview low-resolution Cosmo-Skymed amplitude image acquired some hours before the co-flood time. The results show that the time of satellite pass is fundamental: if the area is covered by water (like upstream part of Po river) up to 60% of pixels was correctly classified as flooded and it was possible to observe a clear pattern. We compared pre- and post-flood SAR images of Sentinel-1 making SAR backscattering difference of radiometrically calibrated images. The result shows that SAR is weaker for post-event mapping: in our case 3 days after the flood (Sentinel-1) less than 4% of the flooded area is still detectable"*

About multispectral data (about line 580 of revised manuscript):

*"The low-resolution MODIS image acquired near the co-flood stage allowed a good identification of flooded areas using different methods: MNDWI variation and supervised classifications. The detection accuracy is good especially for the area flood by Po river where about the 70% of the flooded area was correctly identified.*
*Medium-High resolution multi-spectral data have more capability with post-event images. In this work, we tested NDVI and MNDWI variations for the detection of flooded areas based on the comparison of pre- and post- event images. Both methodologies show quite good -performance in cultivated land, (40 % - 45% of accuracy). Here it is possible to detect a clear pattern: inside the inundated area the percentage of pixel classified as flooded is four times greater than in not flooded area. The inundated areas are more difficult to detect in the dense urban area of Moncalieri (only 4% area was correctly mapped).*

*RC* - 4) Probably, after 8 pages of Materials and Methods and 7 pages of Results, the article would benefit from an expanded discussion, where those data are interpreted. I would try to address the following questions: What is the overall advice (if exists) authors can give to readers for an efficient approach for flood inundation mapping? Since appears that some analyses provided results not accurate or too uncertain or under/overestimation too significant, is any of the tested methods and data less relevant than others? Can any of these methods/data be completely replaced by the information provided (with a higher accuracy) by other analysed methods/data?

**AC -4. Thank you for your suggestions. We added a flowchart (figure 13), and a paragraph (4.3) in the manuscript to clarify all these points:**

**1) The most important thing that we would give to readers is that it is not possible to select a priori which type of data/processing is the better for flood mapping. This depends on different factors:**

**1. Time of satellite acquisition respect to the time of flood peak.**

**2. Type of satellite data (SAR / multispectral, spatial resolution)**

**3. Study area features and risk (dimension, cloud cover, land-use and element at risk)**

**4. Affordable cost (e.g., we use commercial satellite data or traditional aerial photo only if they give significant advantages to flood mapping)**
**Another aspect is the data policy. The applied use of free data could encourage the authorities (e.g., The European Union) to make further investment in open data.**

**2) To compare the performance of data and methods would be necessary that all satellites acquired at the same time and this is a rare combination.**
**For instance, in some cases, a 500 m spatial resolution multispectral image acquired at flood peak could be more accurate than a SAR image with 1 m resolution acquired 2 days after the flood. On the other hand on particular area image from a commercial satellite could be the only one that covers the flood peak. In our case Sentinel-1 show low performance the Cosmo not for the data quality (Sentinel-1 at full resolution is far better than a quicklook image) but only for the time of satellite pass.**
**The results of band indexes variation of Sentinel-2 show little better performance of MNDWI respect to NDVI. In urban areas both NDVI and MNDWI performance are very weak (we add this consideration to manuscript)**

In the manuscript we added a new paragraph 4.3 (after line 534 of revised manuscript):
*"4.3 Flood mapping strategy flowchart*
*The flowchart in figure 13 shows the approach that we purpose for the choice of instruments and methods to map the flooded areas, based on the results of this study. If free satellite data are available, it is possible to sort them taking into account the parameters of time elapsed from flood and the spatial resolution:*
*I) The priority is to search for co-flood images that allow an easy mapping. In case of night and cloudy conditions it is necessary to use SAR image (Sentinel-1) while for multispectral data acquired during the day the choice is related to spatial resolution: for instance, Sentinel-2 or Landsat-8 data are more resolute than MODIS data.*
*II) In the case we have post-flood satellite pass only multispectral data can be used. Also for post-flood data, the spatial resolution and time elapsed from the flood are the parameters that should drive the choice. The use of post-flood data implies more complicated post-processing (e.g., bands index variation) and with the support of ancillary data and DTM to extract the flooded area map. In general, the rapid access to data portal of free satellite data allows to download the data and to make an evaluation of the best solution for the case under study, that not necessarily is the data with high spatial resolution.*
*After this step, it is possible to make a first delimitation of flooded areas, that in case good data may be an already corrected and ready to use map. Then it is possible to focus the acquisition of on-demand of high-resolution sensors only in the most critical or unclear areas (case 2A). If we use only on-demand data, without rapid satellite mapping, we could map large area at high spatial resolution (case 2B). This solution, however, implies a higher cost. In case of direct mapping at very-high resolution, it is better to use low-cost aerial platforms that are more flexible respect to on-demand commercial satellites. The integration with DEM data allows creating the water depth model at basin scale and a further refinement of flooded area maps (2C).*
*Urban area flood mapping (3) can be considered a hotspot priority inside the general flood map. It needs a more accurate and high-resolution mapping with use of ground-based measures (like SfM model based on car photo), RPAS survey, and the creation of a water depth model that is essential for a precise flood magnitude assessment.*
*It is important to remind that is not possible to select a priori which type of data/processing is the better for flood mapping. The best method to use depends on different factors: 1. Satellite acquisition and time elapsed from flood peak; 2. Type of satellite data (SAR / multispectral, spatial resolution); 3. Study area features and risk (dimension, cloud cover, land-use and element at risk); 4. Affordable cost (e.g., we use commercial satellite data or traditional aerial photo only if they give significant advantages to flood mapping)"*

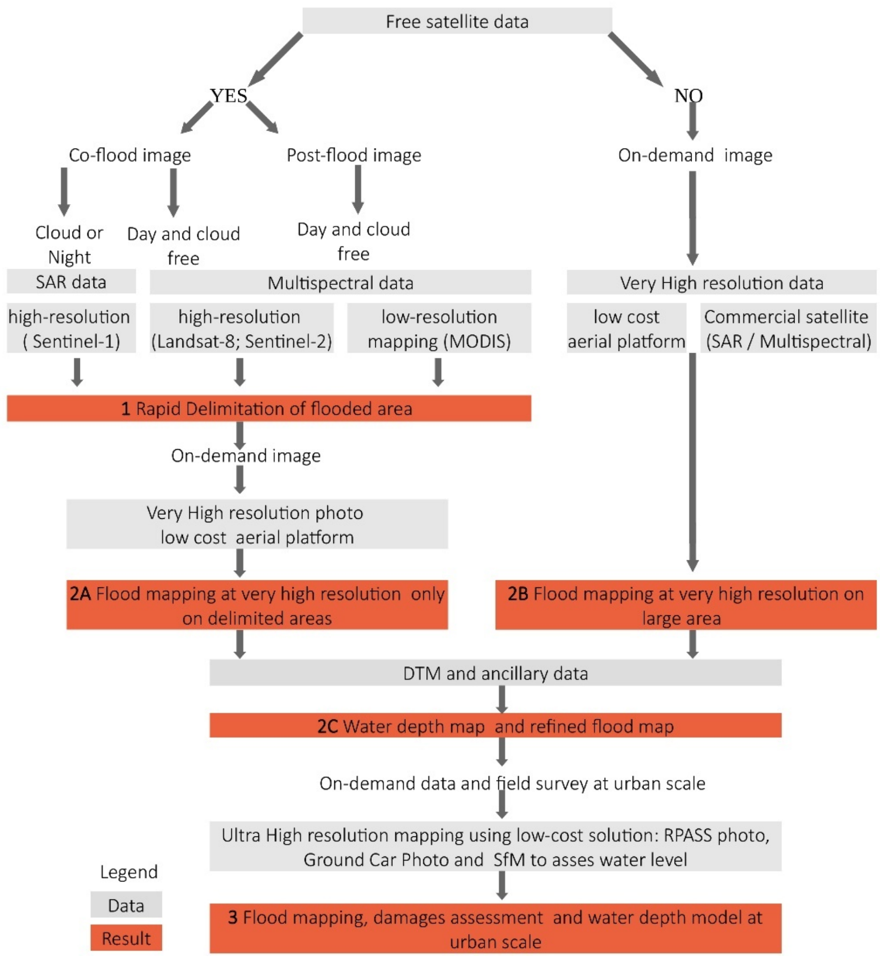


**Figure 13: Flowchart of the proposed flood mapping strategy**

RC - 5. Minor comments The paper contains a number of typing errors that requires a careful review of the English. Below some examples that I found while reading the manuscript.

**AC – 5. Meanwhile the paper was under revision we provided to improve formation and to revise English.**

RC - Check the way citations are written in the manuscript. Sometimes "et al" is followed by no full stop and just the comma (Luino et al, 2009) sometimes a semicolon (Wang et al; 2012), sometimes nothing (Boni et al 2016). Other examples in lines 37-38 "Boni et al 2016; Mason et al 2014; Guy et al 2015; Refice et al 2014; Pulvirenti et al; 2011; Clement et al, 2017; Brivio et al; 2002".

**AC - We corrected all the reference using the NHESS format "et al.," Also in the reference section, we have checked for a correct alphabetical index and NHESS format.**

RC - Line 42: correct "authorirhyes"

**AC – corrected**

RC - Line 44: it should be "details" (plural) instead of "detail"

**AC - corrected**

RC - Lines 47-48: check subject-verb agreement "A partial solution could be the use of a Remotely Piloted Aerial System (RPAS), that are usually able". A RPAS system is singular.

**AC - corrected in "***Remotely Piloted Aerial Systems***"**

RC - Line 81: check subject-verb agreement "The basin of Po and Tanaro rivers were"

**AC - corrected in basins**

RC - Line 90: check subject-verb agreement "the actual plain (Fig. 1 B and Fig 1 C) correspond to"
**AC – we changed in "corresponds"**

RC - Line 92: check english "The plain is marked by the terraces that delimit of actual Po valley…"
**AC - we changed in "***The fluvial terraces delimit of actual Po valley...***"**

RC - Lines 122: "pre-flood', 'co-flood' and 'pre/post-flood' data". I suggest you to remove pre-flood and just leave "co-flood' and 'pre/post-flood' data", since in the following lines you distinguish and explain these two categories.
**AC - Done**

RC - Lines 125-127: "Using a multi-scale approach, we developed a methodology that considers the progressive use satellites and then high and ultra-high resolution systems for the acquisition of a dataset that can be used to support the identification of water level reached by the flood and occurred damages". I think an "of" is missing before "satellites".
I also suggest authors to think about rephrasing or splitting this sentence in two.
AC - now is re-write as follows "*Using a multi-scale approach, we developed a methodology (Fig. 2) that progressively considers the use satellites and then high and ultra-high resolution systems. The aim is the acquisition of a dataset that can be used to support the identification of water depth and extension reached by the flood. The dataset also allowed making a first evaluation of damages both in urbanized and not urbanized areas.*"

RC - Line 130: "quikly indication". Proper spelling is quickly. By the way, I think the adjec-tive form "quick" is the appropriate one.
**AC - we change quick in general**

RC - Line 134 and 137: "Orthophoto" instead of "ortophoto".
**AC - done**

RC - Line 264: "the system can flight on demand during the flood of immediately after". "Or" instead of "of"
**AC - done**

RC - Line 332: "to assess" instead of "to assesses"
**AC - done**

RC - Line 363: "The MODIS-Aqua satellite takes an image,, during the late morning of November 26, 2016. "
"Took", instead of "takes".
**AC - done**

RC - Line 426: "mapped" instead of "mapp7ed"
**AC - done**