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Developing a Prototype of Geospatial Data Sharing and Analysis System for Disaster Management in the Philippines: A Case Study on Typhoon Haiyan (Yolanda)

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Abstract

Following the severe disaster by typhoon Yolanda (Haiyan) in November 2013, we constructed a web-based geospatial database system for disaster management in the Philippines. Focusing on meteorological data, particularly those for heavy rainfalls, obtained from sensor network deployed in the Philippines, we developed a prototype of a geospatial database based on a web-based, open source GIS (geographical information systems), to facilitate sharing and visualization of various geospatial data concerning both natural and social environments. In this system, desktop GIS is effectively used for performing geospatial analyses, while our assessment on data transfer through the internet revealed the necessity of solving the network- and hardware-related problems. The prototype system developed in this study will be further enhanced for practical applications to the mitigation of natural disasters in the Philippines.

Keywords: data sharing, spatial data visualization, natural disasters, Philippines

1. Introduction

The islands of the Philippines suffer from frequent natural disasters including heavy rainfall, floods, landslides and severe winds related to typhoons (e.g., Boquet, 2015; Brassard et al., 2015), along with volcanic and seismological disasters. For disaster mitigation in such developing countries, construction of a nationwide climate monitoring system and a real-time emergency alert system is an urgent issue. This study aims to complement existing projects regarding a meteorological monitoring system for the Philippines operated by DOST-ASTI (Advanced Science and Technology Institute), and develop related applications by providing technology that will enhance the observation, collection, and transmission of environmental data by CSIS (Center for Spatial Information, The University of Tokyo). Focusing on meteorological data from numerous sensors with special attention to heavy rainfall, we constructed a geospatial database including various spatial data concerning both natural and social environments. We also developed a prototype of data sharing and visualization systems using a WebGIS platform, which effectively connects the web-based geospatial database and desktop GIS. Preliminary spatio-temporal analyses for disaster mitigation were also performed using the geospatial datasets.

2. Materials and Methods

2.1. Meteorological Monitoring System in the Philippines

Here we explain the existing system for climate monitoring in the Philippines. The objectives of the construction of this system by ASTI are:

1) to produce locally developed instruments for weather monitoring and forecasting, and
2) to develop cost-effective platforms and applications for real-time data gathering of environmental parameters.

ASTI utilizes low-cost instruments for the nationwide monitoring system. Advantages of this system over commercially available instruments are: much lower finantial cost for the same or even higher performance; locally available technical support; and utilization of local suppliers of components and parts. The sensor deployment status is summarized in Table 1.

The first related project is under the Hazards Information Media, a project for disaster management using WebGIS. This project consolidates geospatial data with the end output. This will be a complete online hazard and disaster decision support system accessible to the public through web browsers and mobile applications. This web portal shall provide visualization of geospatial data with real-time high resolution hazards and disaster-related information. Data from the other component projects under the NOAH program, includig flood maps, 3-D mapping of major river basins and point data from hydromet sensors, other weather stations from other projects, and the probability of rain, will be displayed in this portal.

The data collection started in 2011. For data sharing, the downloadable data are provided as CSV format. The CSV data are available through a website (http://repo.pscigrid.gov.ph). Some directories are restricted for specific users requiring a username and password. APIs are also available if one requests for formal approval of accessing. The available data include the list of installed meteorological stations, all data of the meteorological stations and historical data, which are provided in the JSON format.

Through the operation of the system, several issues have been found to be further improved. The security of the stations in the field is most crucial: If left unsecured, the stations will be vandalized, or at worst stolen and sold for scrap metal. Also stations are being used as homes for insects and bats. The necessity of backups is another important issue. Keeping backups for everything is necessary not to lose the real-time monitoring data. For this, twofold network communications are applied: SMS and satellite networks (Fig. 1). Furthermore, servers in highly redundant configuration is necessary. These should include RAID disk configuration and multiple server setup for implementation of best practices for system architecture. Communications in the community is also important for sustainable management and operation of the system.

2.2. Construction of a Web-GIS Server and Applications to Spatial Analysis

Following the current state of the meterological sensor network for the Philippines described above, CSIS has provided help with geospatial analysis on sensor data especially on Typhoon Yolanda (Haiyan), network performance analysis and recommendations for improvement, and recommendations on the current GIS architecture to implement a prototype of geospatial data sharing systems. For this purpose, we carried out 1) network performance assessment, 2) offline experiment using sensor data, 3) development of a WebGIS system, and 4) spatial data visualization and analyses using the sensor data and other geospatial data layers incorporated in the WebGIS.

As a performance assessment, experiments were carried out regarding the direct connection from the CSIS network system to the ASTI data server using API (Fig. 2). The meteorological sensor data provided as CSV files were then processed to be incorporated in GIS software.

We utilized GeoServer for the basic system of the WebGIS. Geosptial datasets were integrated into the WebGIS, including the meterological data by ASTI and other open data: OpenStreetMap (road, building, boundaries), population data, Yolanda typhoon data, and topographic data (SRTM digital elevation model). People Flow 1996 Manila Metropolitan Area provided by CSIS People Flow Project Office (Sekimoto et al., 2011), comprising a population of ca. 189,000, were also incorporated. Geospatial analyses were also performed using the spatial datasets listed above and desktop GIS (QGIS and ESRI ArcGIS).

3. Results and Discussion

3.1.Experiment on the server connection

The result of the performance assessment of direct connection between CSIS and ASTI is shown in Fig. 3. The response time of ASTI server from/to the ASTI network seemed to be short and stable, while that from/to CSIS showed large delay (3 to 4 times than that within ASTI network) of the data transfer. Large jitter was also observed, causing the delayed packets of data transfer. We conclude here that real-time data transfer between CSIS and ASTI and concurrent analyses are currently impracticable due to the delay of data transfer. Further improvements in the network infrastructure and the strengthening of related hardware including servers would be necessary to fulfill real-time data utilization.

3.2. CSV data formatting for offline experiments

The meteorological sensor network provides more than 700 CSV files of the sensor data everyday. Although the data format is in CSV, the original component of the files are complicated and hard to be used in GIS. The data therefore need selection and reformatting for geospatial analyses. We selected and reformatted CSV files for sensor data having rainfall and air pressure data, giving 201 records per day.

Even after the reformatting, some error removal was necessary. The main causes of the errors are the lack of location data of several sensors, duplication of sensor data obtained, and erroneous outlier values of the sensor data. Such errors are supposed to be derived from unexpected inaccurate values from the original sensors, as well as the loss of data packets during data transfer from the sensor to the storage server.

3.3. WebGIS development

Fig. 4 shows a snapshot of the administration page of the web-based GIS database using GeoServer. This system is capable of distributing map layer data to local (desktop) GIS software via the Internet, as well as map visualization of the data layers on the web browsers. Once the spatial data are retrieved to the desktop GIS (Quantum GIS, QGIS) of approved users, spatial analyses that are available in the desktop GIS modules can be performed in the local machine (Fig. 5). The results of such analyses can also be uploaded to the server. The data layers in the WebGIS can therefore be enriched by various kinds of analyses performed on user desktop machines.

An advantage of this system using both the WebGIS and the desktop GIS is flexible spatial data analyses and visualization. Because the ability of spatial analyses on server-based GIS strongly depends on the performance of the server and network connection, the time for data processing can be reduced when the analyses are performed on the desktop GIS.

3.4. Visualization and spatial analyses of the data

Using the sensor data and the other spatial datasets, we carried out spatial data visualization and analyses. Fig. 6 shows a basemap of the sensor network located in the Philippines.

As an example, maps of hourly rainfall on the day of typhoon Yolanda (Haiyan) on November 8, 2013 were created (Fig. 7). The point data of hourly rainfall obtained by each sensor were interpolated using the kriging interpolation method (ordinary kriging, circular function, 12 neighborhoods). The rainfall variability is relatively moderate due to the interpolation. The central part of the Philippine islands shows larger rainfall values, which is consistent with the path of the typhoon (Fig. 5).

The rainfall data were further summarized and categorized into two classes of daily rainfall for the day of typhoon Yolanda, and put over the topographic data showing areas with slope gradients larger than 30 degrees (Fig. 8). Such slopes steeper than 30 degrees (approximation of the angle of repose) are supposed to be prone to landslides. The areas with steep slopes and high amounts of rainfall are shown as potential landslide hazard areas. The relationship between topographic slope and rainfall was also examined (Fig. 9). The result indicates that the moderately sloping areas (4–12 degrees) have more rainfall, and the spatial distribution of such areas shows a higher potential of flood disasters where lots of people may live.

Spatial relationships between local population derived from the people flow data and the typhoon rainfall were compared in the Manila area (Figs. 10, 11). Although the rainfall amount due to the typhoon Yolanda was not so critical in the Manila area, the concentration of population in the central Manila, where a large river is located, indicates potentially higher risk of flooding under heavy rainfall (Fig. 11). In fact, a heavy rainfall event occurred around Manila area around August 20, 2013, caused by both a typhoon and a monsoon rain front (Lagmay et al., 2015). Characteristics of the rainfall event (mid-late August, 2013) and that by typhoon Yolanda (early-mid November,

2013) were compared (Fig. 12). The hourly rainfall and the soil water index (SWI; Okada et al., 2001) of the station at Sangley Point, located 14 km southwest of the center of Manila, show different characteristics of the rainfall events. As noted, the rainfall by typhoon Yolanda was not critical, while that in August resulted in high SWI values indicating a high risk of flooding in the lowland area around Manila.

4. Concluding remarks

Combination of the meteorological sensor network system operated by DOST-ASTI and the WebGIS system developed by CSIS looks promising for future hazard mitigation in the Philippines, because it enables various GIS applications and geospatial analyses. It also became clear that network-related problems have to be solved for further developing more practical real-time hazard assessment and alert systems.

Acknowledgments

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Table. 1. Sensor deployments in the Philippines (as of March 2015).

Type of Station	Parameters Measured	Quantity
ARG	Rainfall, air pressure	686
WLMS	Water level	332
Tandem	Water level, rainfall, air pressure	134
AWS	Rainfall, rain intensity, rain duration, air pressure, temperature, humidity, wind speed/ direction	111
Agromet	Same as AWS + soil moisture, soil temperature, sunshine duration, sunshine count, solar radiation	80

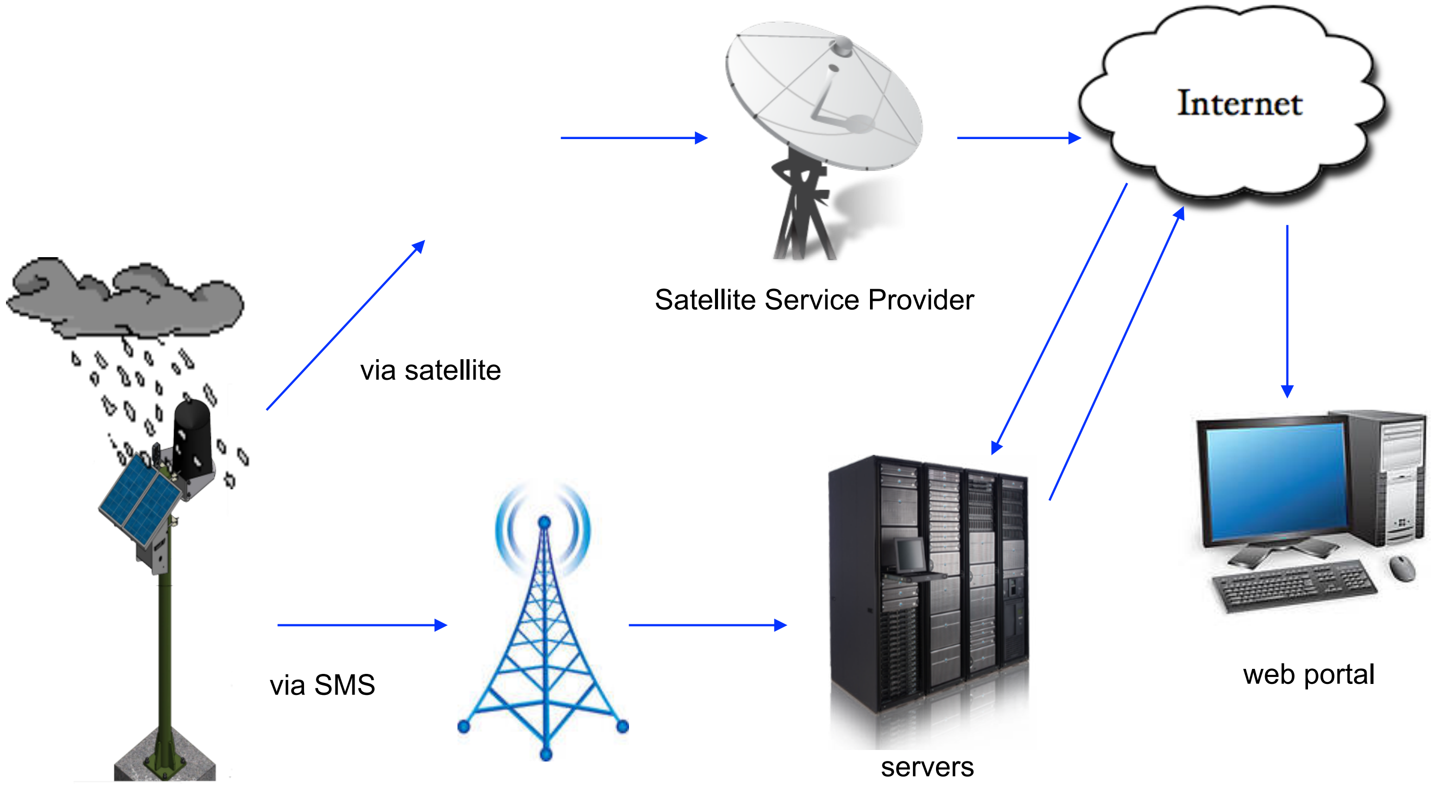

Fig. 1. Network transfer of meteorological sensor data.

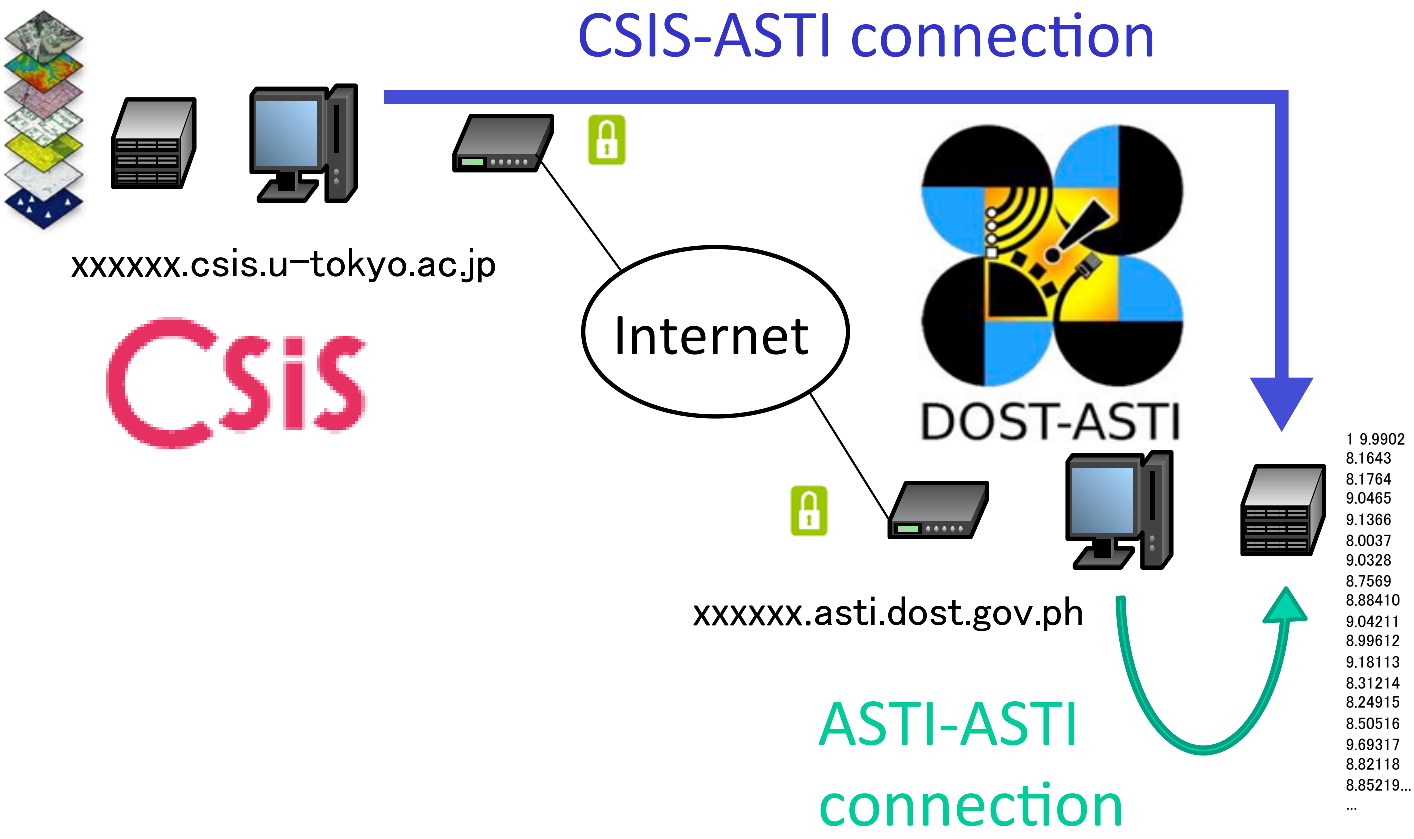

Fig. 2. Schematic illustration of the network connection between CSIS and ASTI.

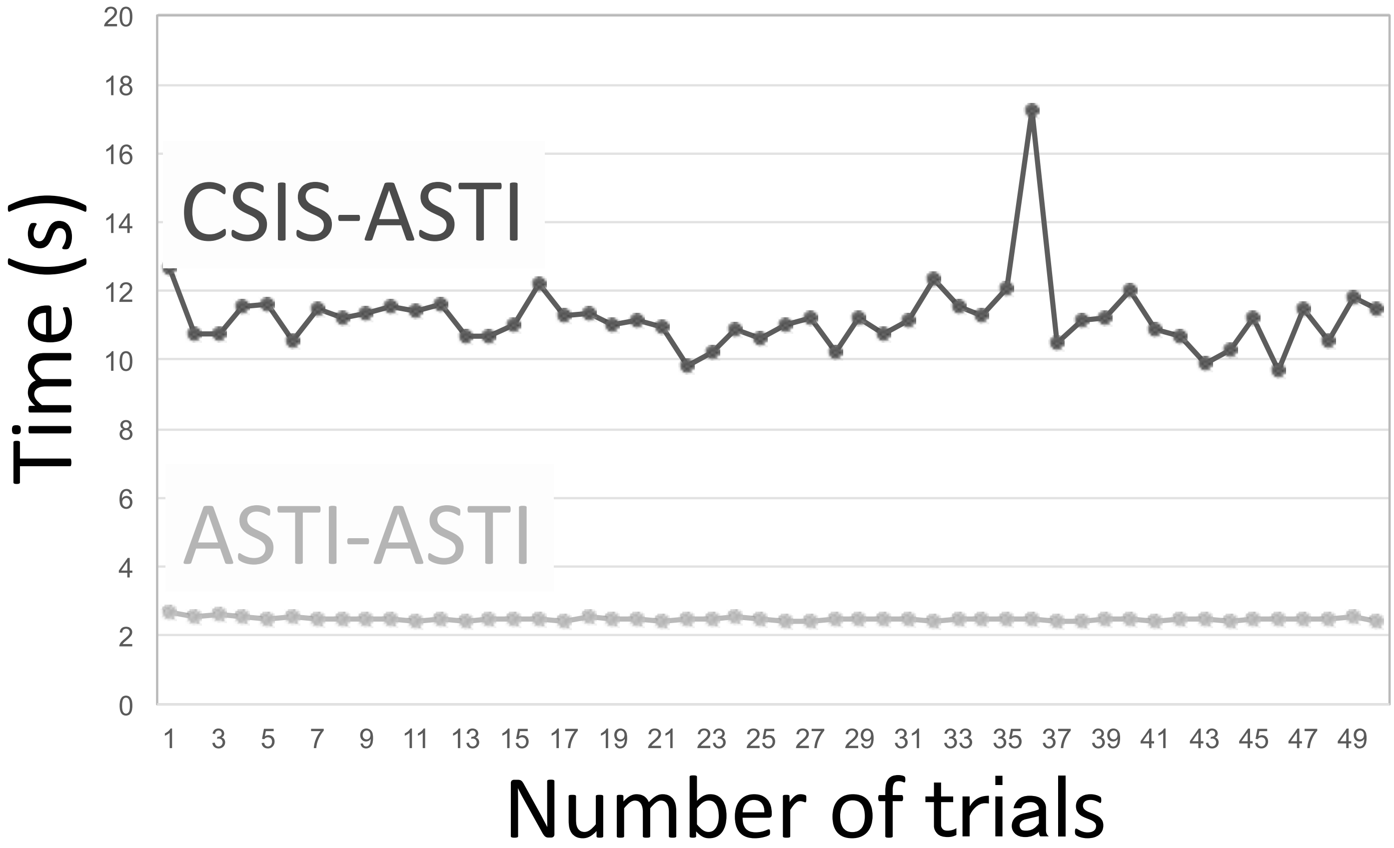

Fig. 3. Performance assessment of direct connection between CSIS and ASTI and that within ASTI.

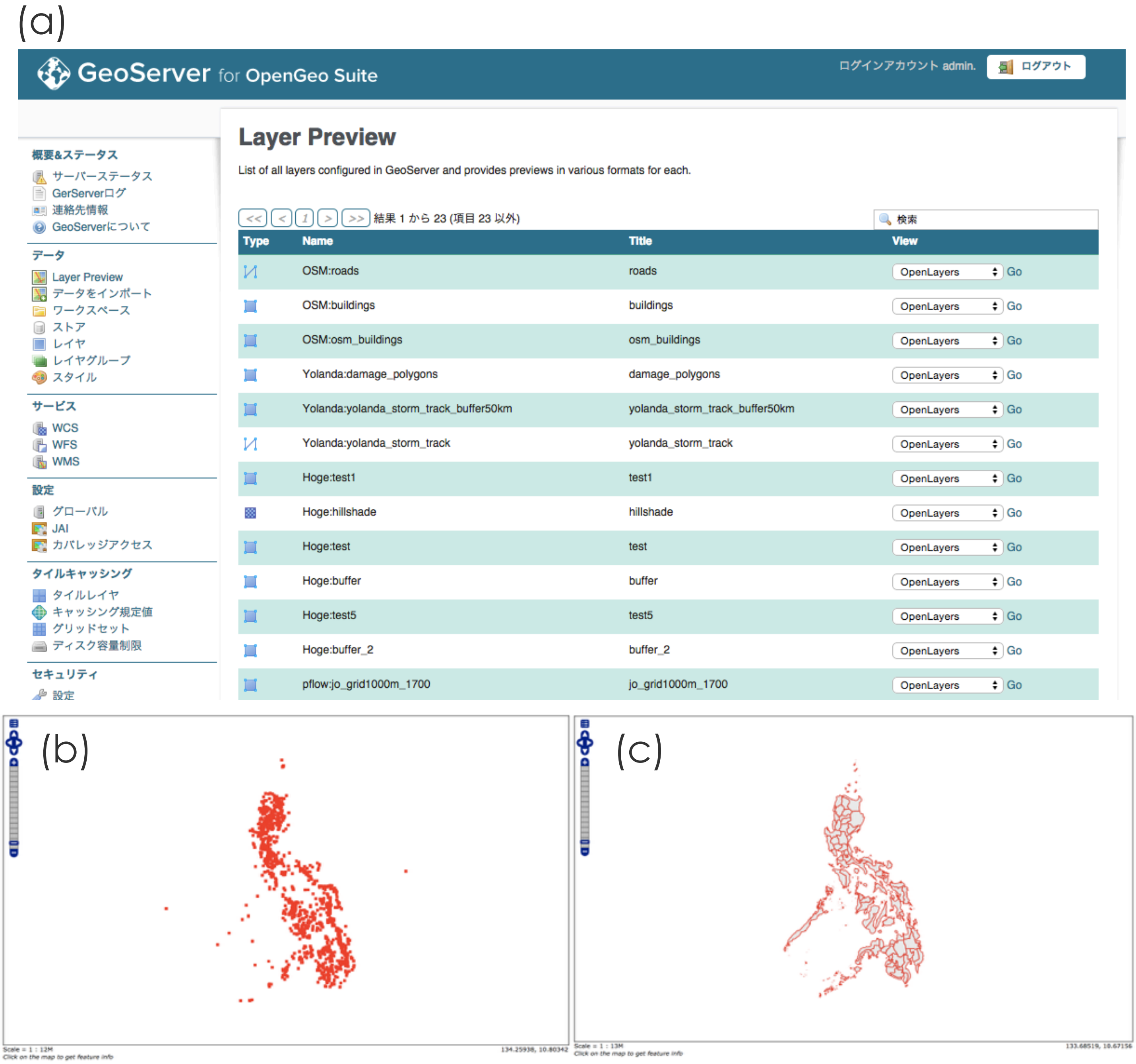

Fig. 4. Snapshot view of an administration page of the web-based GIS using GeoServer. (a) Table view of the layers stored in the GeoServer system. (b) Map view of point locations of the sensors using OpenLayers. (c) Map view of country boundary of the Philippines.

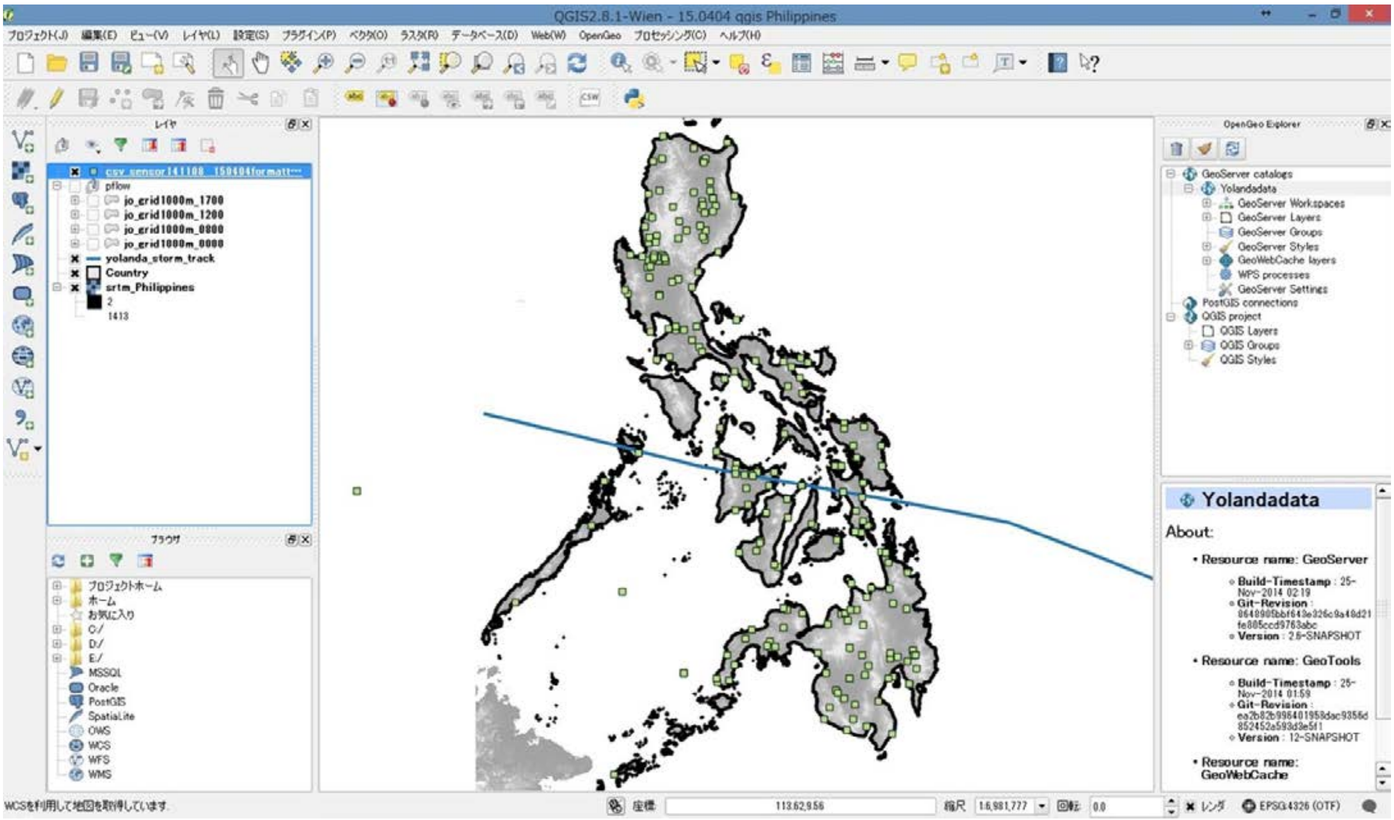

Fig. 5. Snapshot view of desktop GIS in a local machine showing the data retrieved from the WebGIS server. Green points indicate locations of the meteorological sensors. Black lines indicate the boundary of the Philippines. Blue line shows the track of typhoon Haiyan (Yolanda). Background grayscale image is the elevation derived from 90-m resolution SRTM DEM.

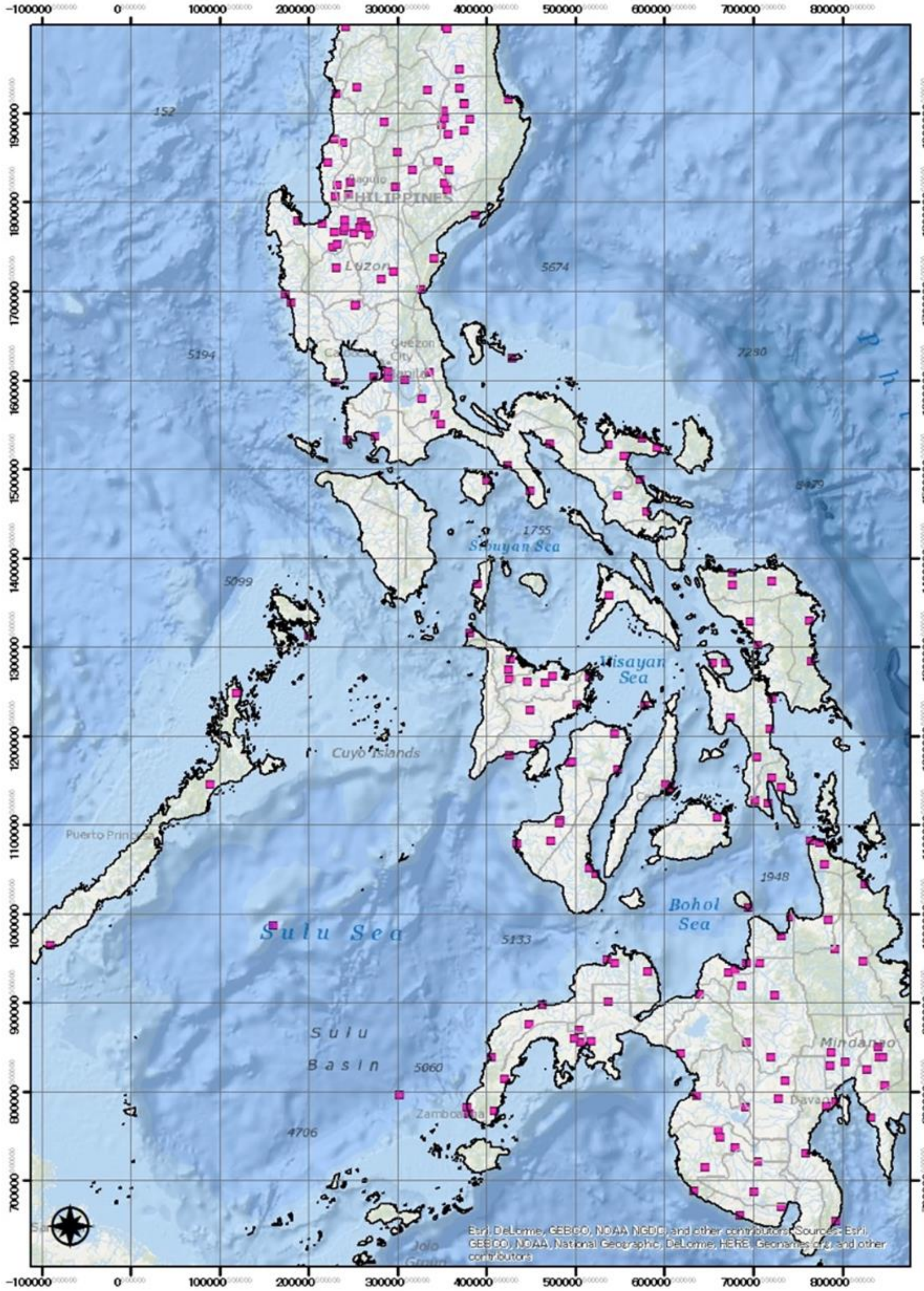

Fig. 6. Basemap showing the sensor network in the Philippines.

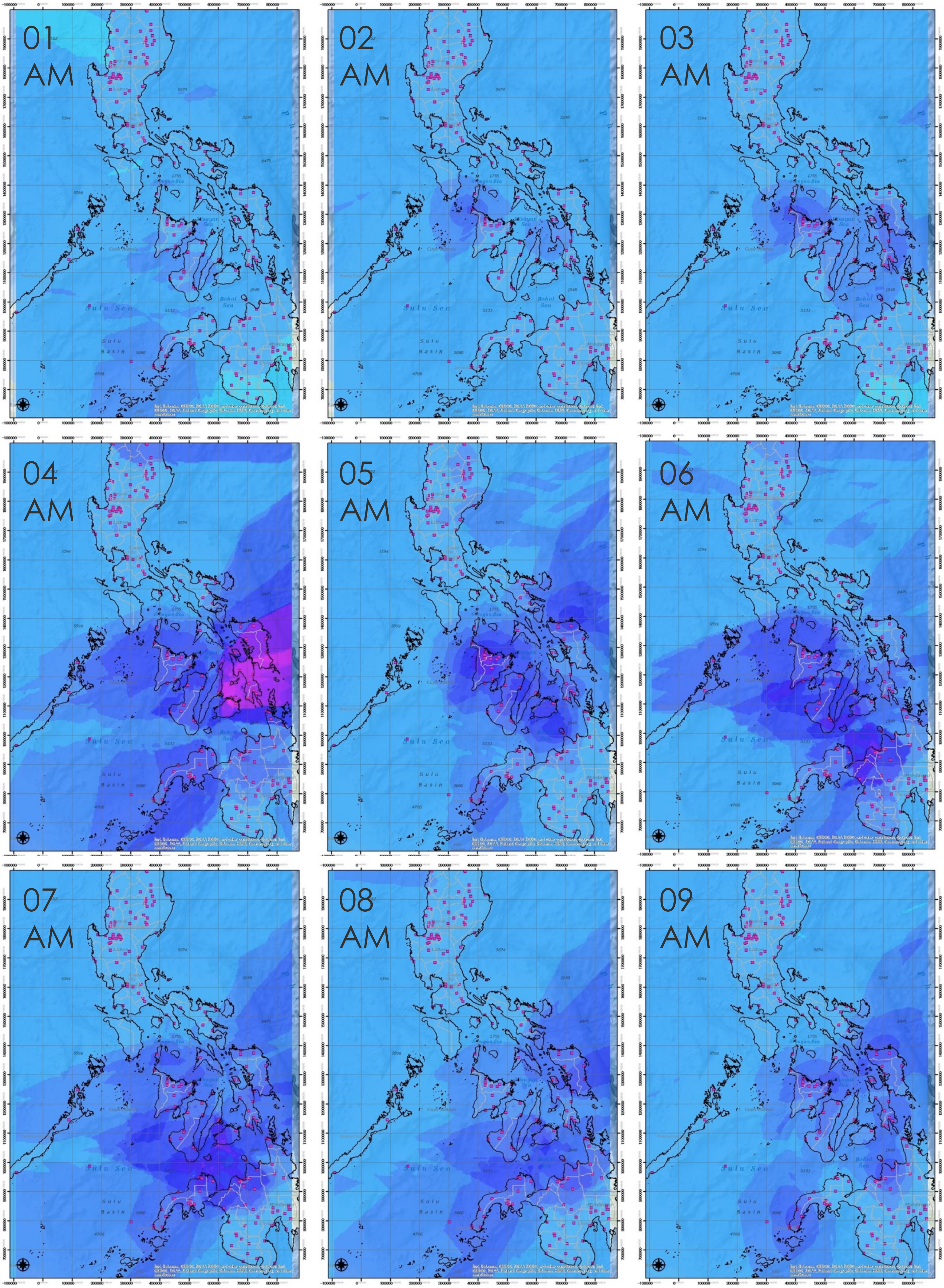

Fig. 7. Spatial distribution of hourly rainfall on November 8, 2013.

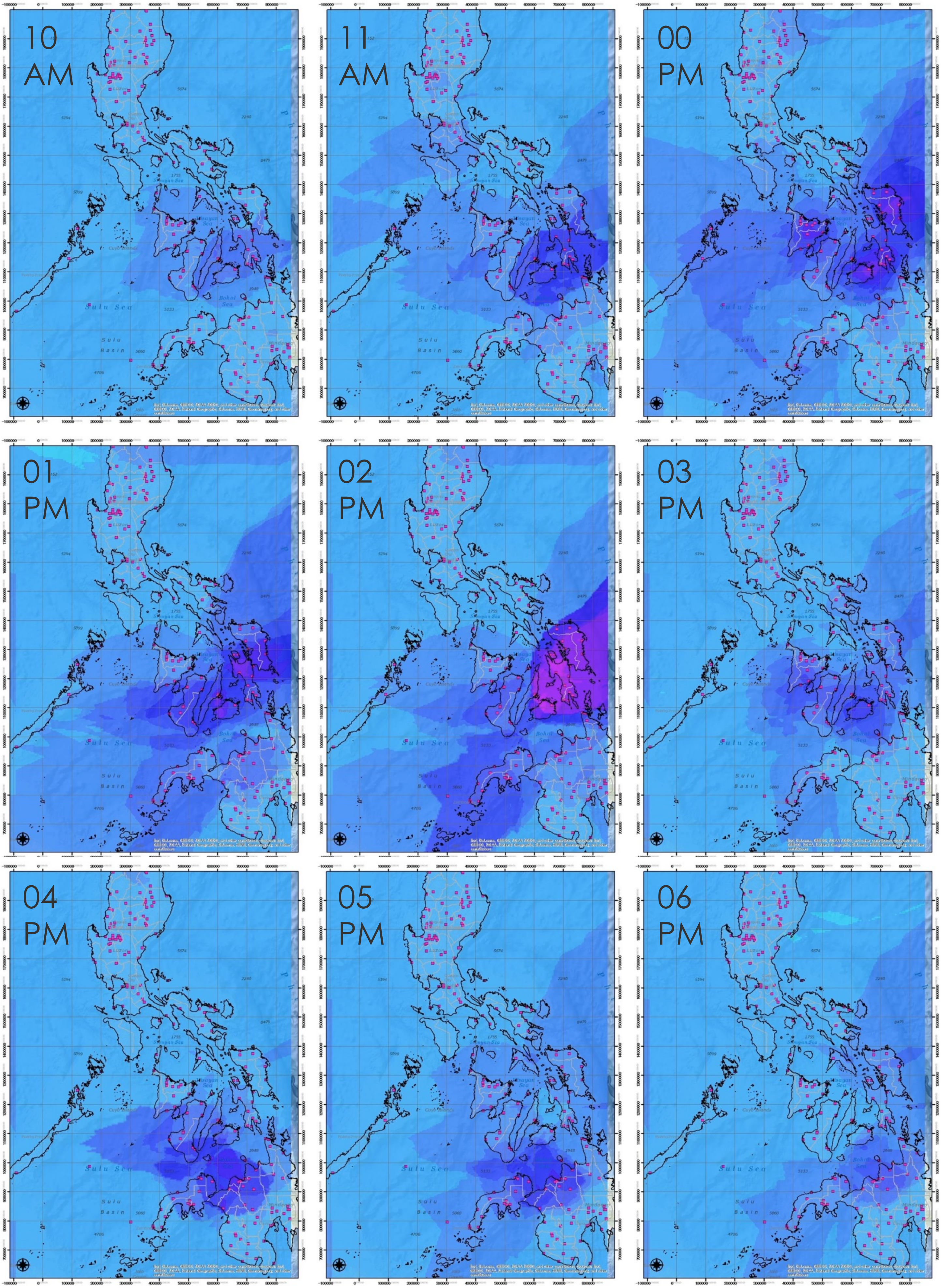

Fig. 7. (cont.)

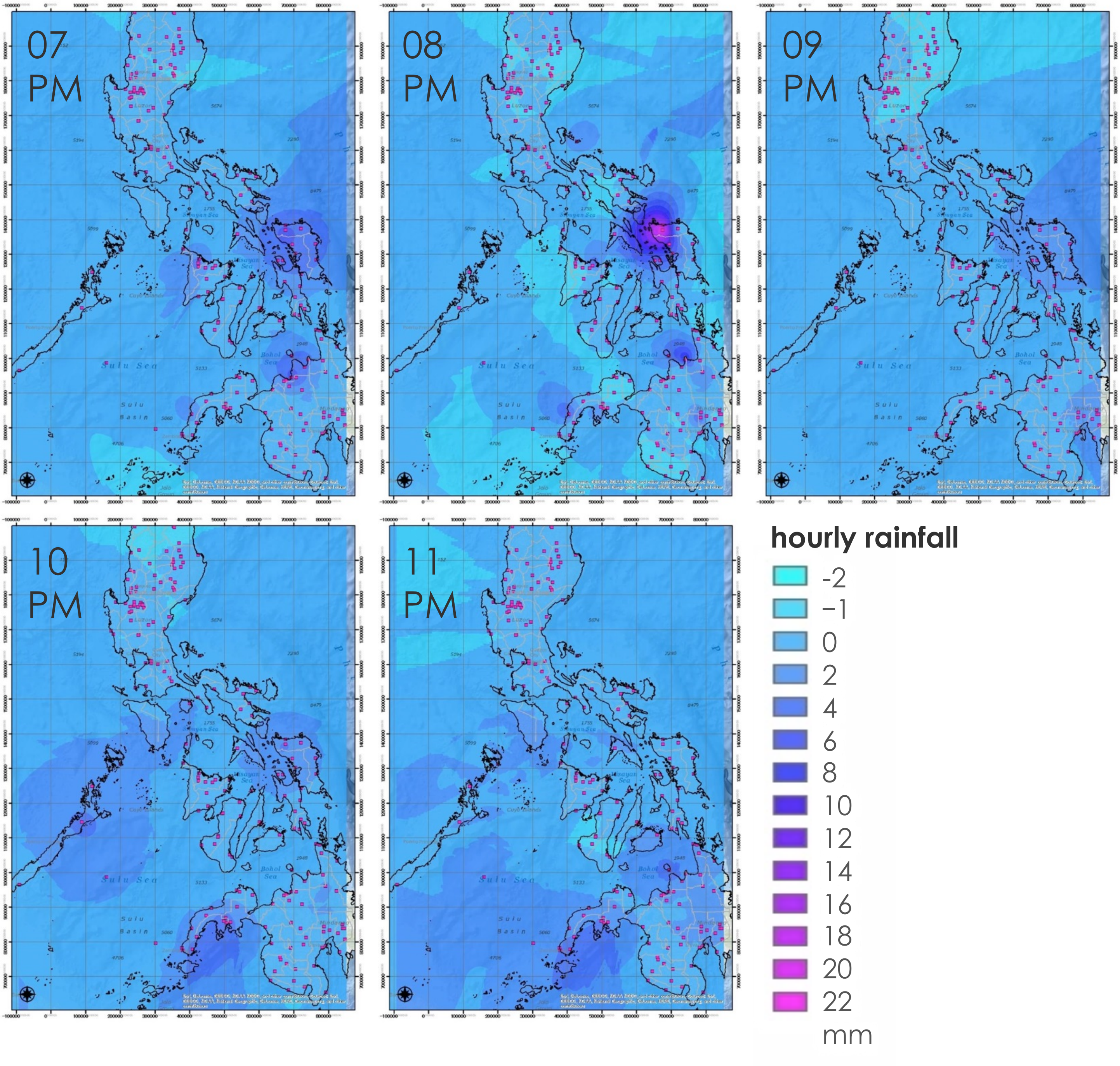
07
PM
08
PM
09
PM
10
PM
11
PM
hourly rainfall
-2
−1
0
2
4
6
8
10
12
14
16
18
20
22
mm

Fig. 7. (cont.)

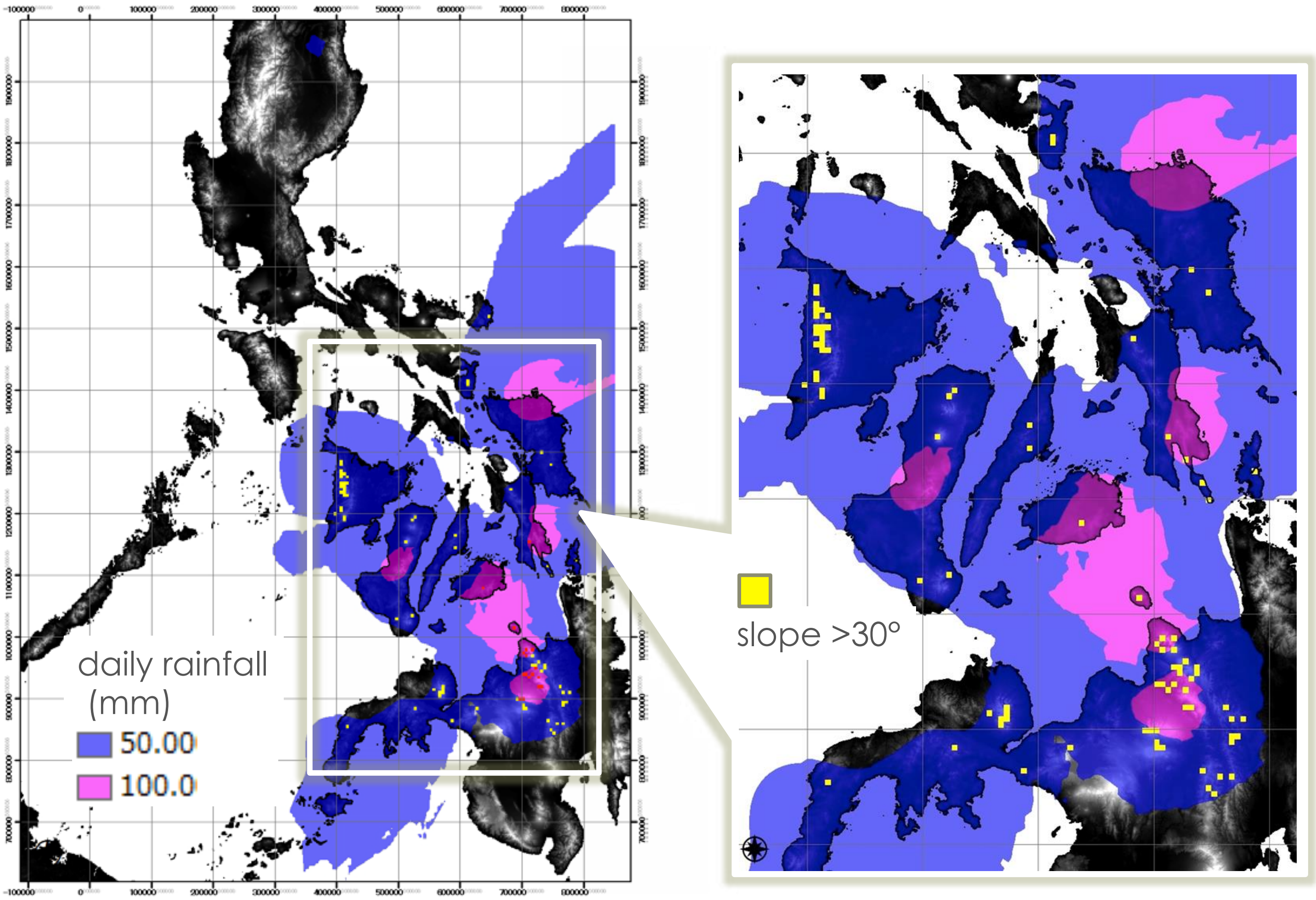

Fig. 8. Overlay of daily rainfall distribution and steep slope areas, showing potential landslide hazard areas.

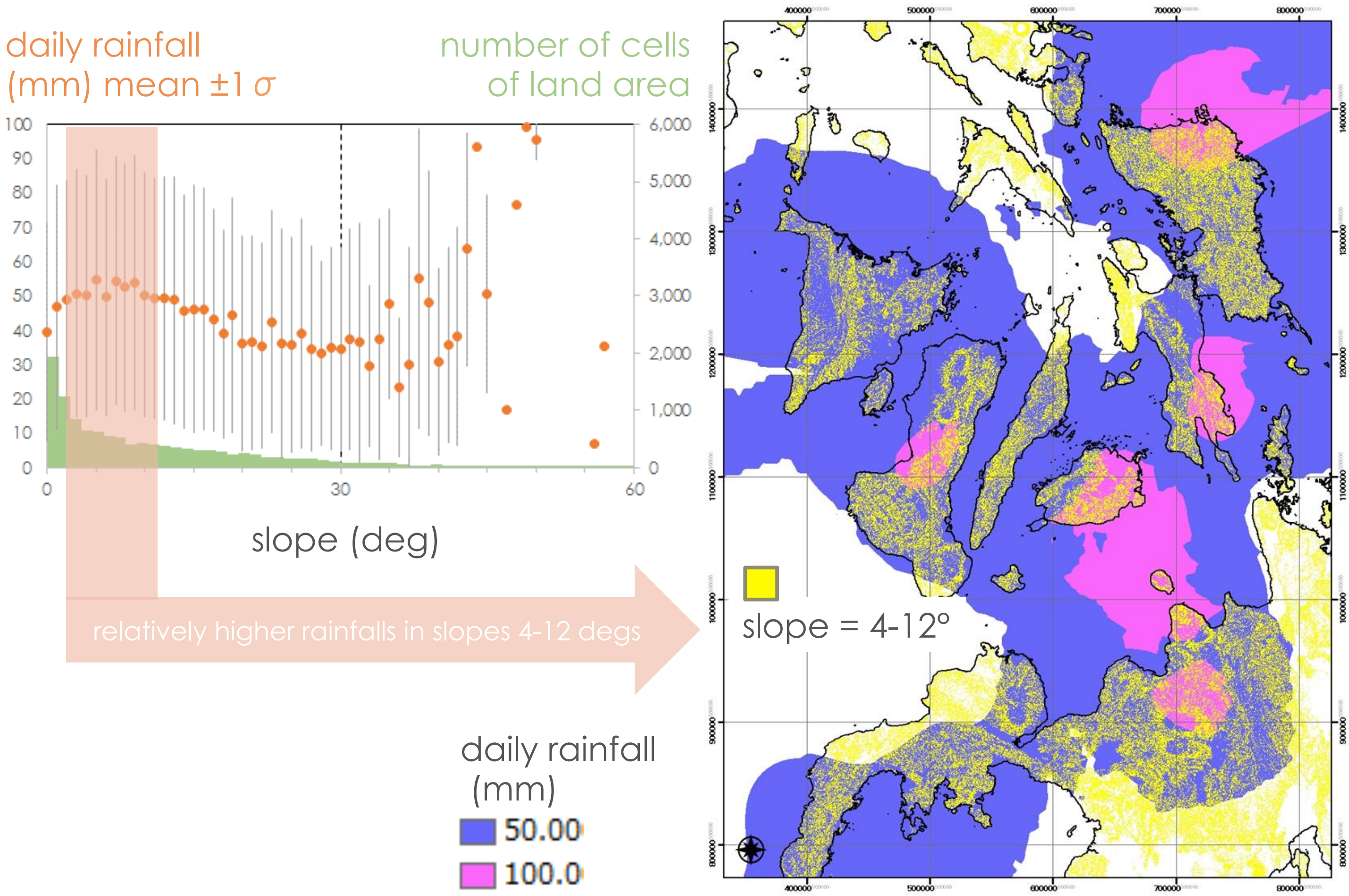

Fig. 9. Relationship between topographic slope and daily rainfall.

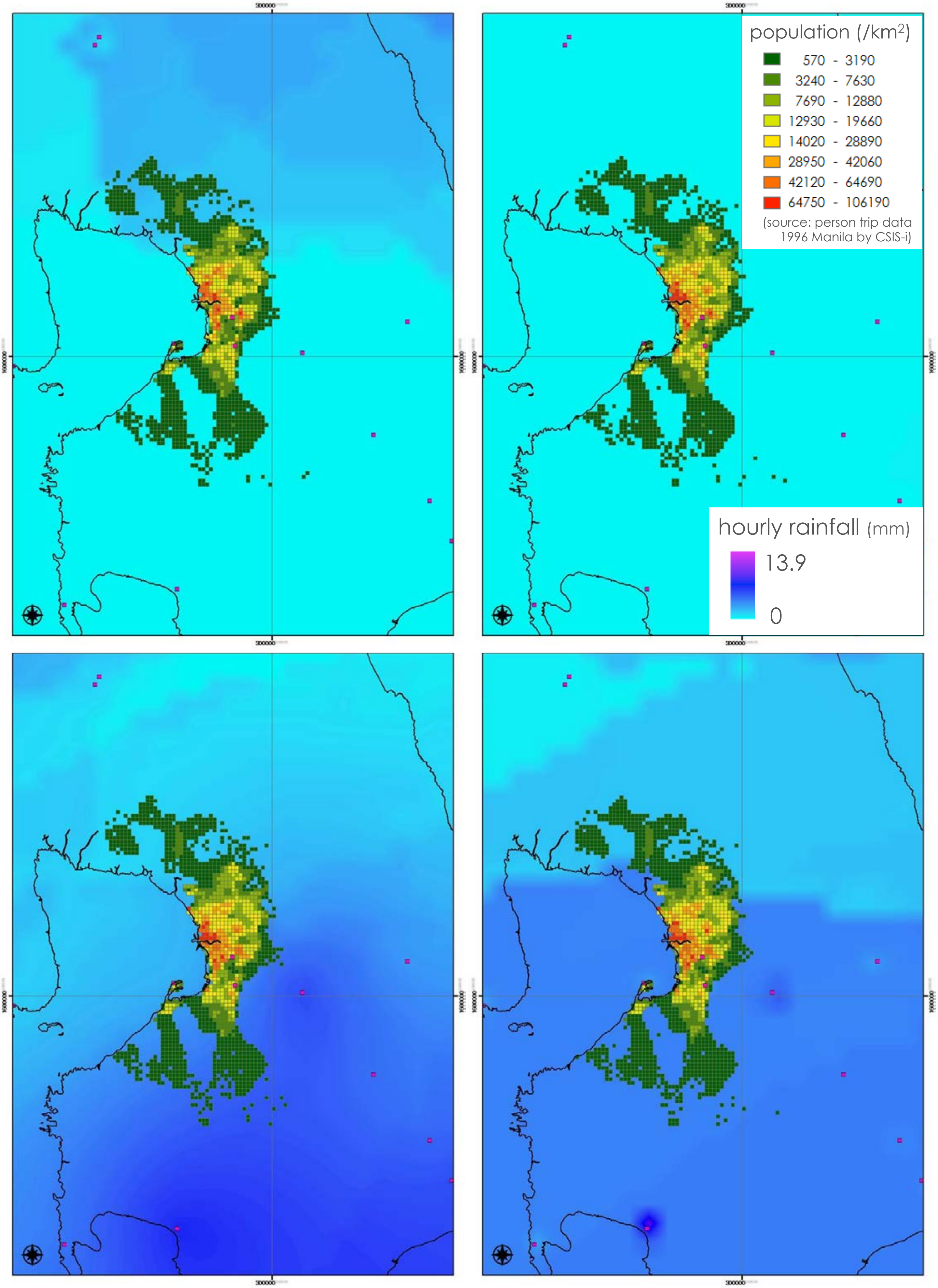

Fig. 10. Time series of typhoon rainfall and local population derived from people flow data.

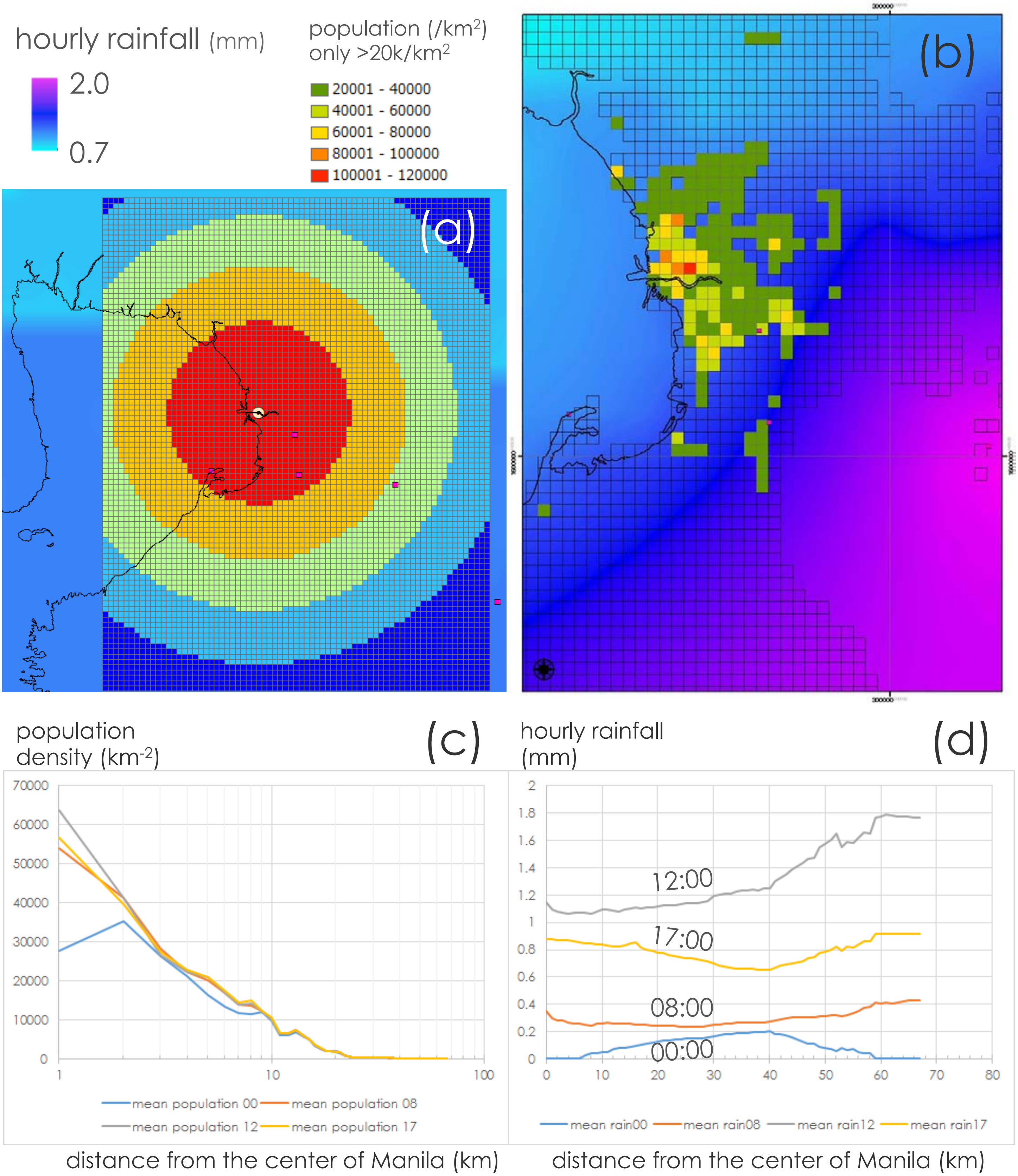

Fig. 11. Local population and rainfall by typhoon Yolanda in relation to the distance to Manila Center.

(a) Euclidean distance from center of Manila. (b) Magnified view of central Manila showing populated areas (>20,000 km^{-2}) and hourly rainfall. (c) Relationship between the distance from the center of Manila and population density for each time band. (d) Relationship between the distance from the center of Manila and hourly rainfall for each time band.

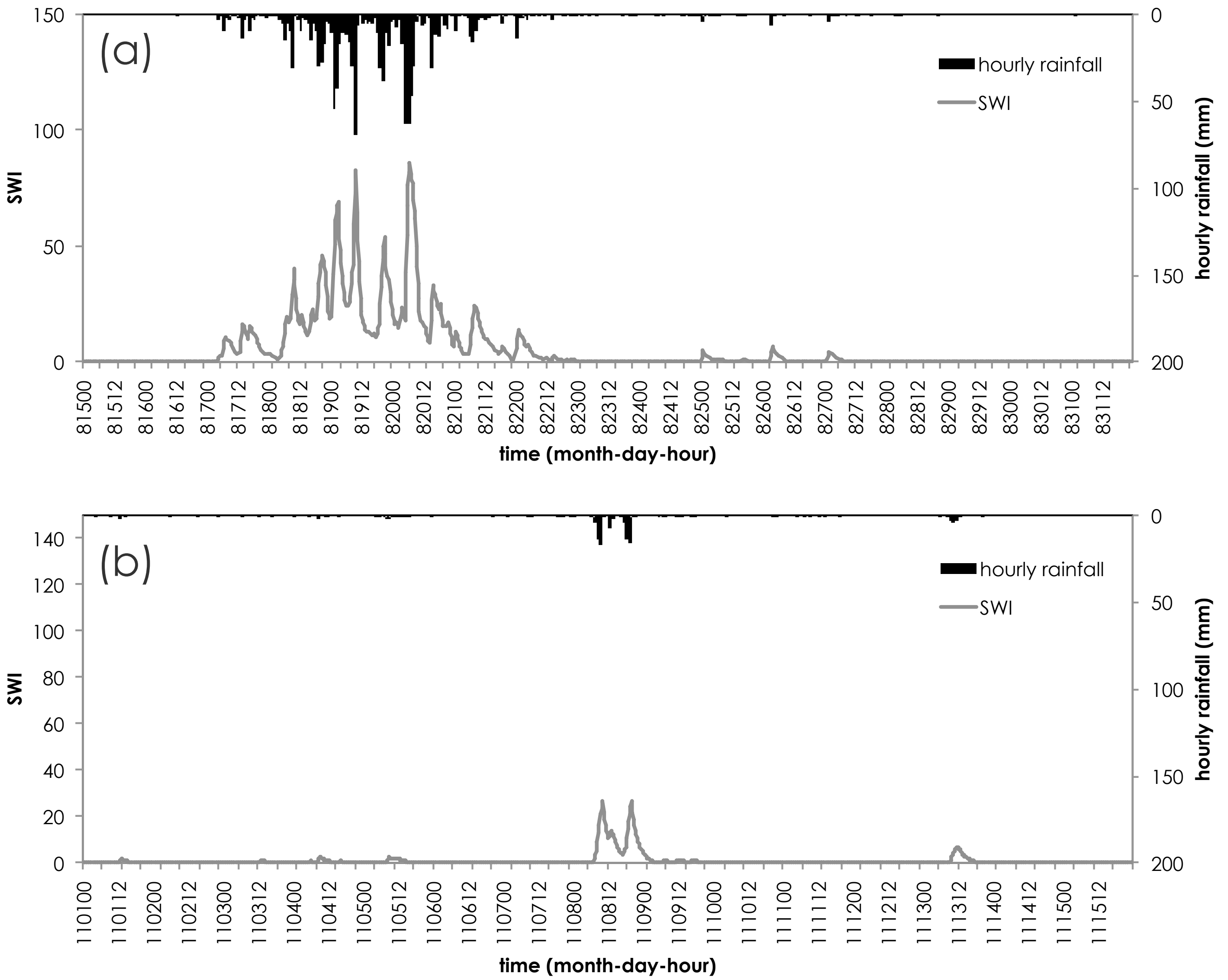

Fig. 12. Example of temporal changes in hourly rainfall and the soil water index at station SANGLEY POINT in Cavite, near Manila center. (a) Aug. 15-31, 2013. (b) Nov. 01-15, 2013.