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Analyzing the impacts of urban expansion on air pollution in Vietnam using the SEAP platform

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Abstract. The relationship between urbanization and air pollution was discovered in many studies. In this study, we analyzed the impacts of urban expansion on air pollution in Vietnam using remotely-sensed data from 2004 to 2015. In this period of time, Vietnam urban square was increased from 4623 km^2 in 2004 to 5094 km^2 in 2015. Besides, there is a clear difference between the average PM2.5 concentration value of urban areas and non-urban areas in Vietnam, urban PM2.5 values are generally higher than in rural areas for years. In this study, we use the SEAP (big Spatial data Exploration and Analysis Platform) platform to analyze and store data.

1. Introduction

Land cover is an important environmental factor and an important information layer of Earth data. Land cover classification is the process of identifying the physical aspect of the earth's surface. Land cover classification studies are currently being researched by many scientists and research centers all around the world, therefore, many global and local land cover datasets were produced. The datasets used different definitions of urban, however, most of which used the definition of the United Nations Food and Agriculture Organization (FAO) [1]. Besides urban classification, the assessment of urban transformation is an important problem focused on the shift between urban with other land cover classes such as agricultural land, bare land, water surface, trees, etc. [2].

Currently, Vietnam is in an important stage of the urbanization process and economic development. Vietnam government has paid attention to urban system development in accordance with other components such as the administrative system, population, economic, landscape, and residential life [3]. On account of economic reforms and export-oriented industrialization policies, Vietnam's urbanization and the urban population started increasing rapidly. The rapid urbanization process with population growth has led to a major change in land use in most provinces in Vietnam, especially in big cities.

In Vietnam, there are few studies in urban classification and examining impacts of urbanization on the environment with study areas are mainly focused on large cities such as Hanoi, Hochiminh city, Danang, and Can Tho. At the nationwide level, S. Saksena et al established an urban classification for Vietnam by using national census and remote sensing data [4], the research of sustainable urbanization in Vietnam by D. Drakakis-Smith and C. Dixon [5]. Meanwhile, major researches targeted on provincial level including study of urban growth and change analysis using remote sensing and spatial metrics from 1975 to 2003 for Hanoi by Pham Minh Hai and Yasushi Yamaguchi [6], mapping impervious surfaces in the greater Hanoi area, from time series Landsat image from 1988 to 2015 by Hung Q. Ha and Qihao Weng [2], the relationships between surface temperature and land cover in Hochiminh city using remote

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sensing data by Tran Thi Van [7], assessment of urban urbanization and heat island in Hochiminh city using Landsat image by Nguyen Thanh Son et al [8], application of remote sensing in land use change pattern in Danang city by Tran Thi An and Vu Anh Tuan [9], optimizing spatial resolution of remote sensing data for urban detection in Danang city by by Tran Thi Dong Binh et al [10], observing Danang city urbanization and accompanied urban heat island during 1990-2015 using multigenerational Landsat imagery by Dang Trung Tu et al [11], the relation between city planning and urban growth using remote sensing and spatial metrics [12], and assessing the impact of urbanization on urban climate by using remote sensing images by Pham Minh Hai et al [13], research on urban expansion in Can Tho from 1972 to 2007 by Pham Thi Mai Thy et al [14].

Recently, rapid economic growth has negative impacts on the global environment. Air pollution is considered a major factor contributing to climate change, global warming, ozone depletion, and acid rain. In Vietnam, air pollution is rapidly increasing in recent years. A recent report from the Environmental Performance Index (EPI) suggests that the quality of the environment in Vietnam has steadily dropped compared to other nations (EPI 2018) [15]. In this report, Vietnam is ranked 132 out of 180 in the general environmental index with air quality in Vietnam is lagging to a rank of 159.

Vietnam has been suffering from rapid industrialization and urbanization. Along with the development, the effect of air pollution on human health is increasing [16]. The assessment of the effects of air pollution is mainly based on dust pollution. Dust pollution is determined based on the measurement and calculation of the concentration of airborne particles (Particulate Matter concentration - PM) to provide an air quality Index (Air Quality Index) according to the national and international standards [17].

PM consists mainly of airborne dust particles generated from agricultural, mining, construction, road and other related sources. PM can be classified into PM1, PM2.5 or PM10 based on their aerodynamic diameter. PM2.5 consists mainly of vehicle operation, burning coal, oil, and wood, and also includes fine dust particles from sugar and soil. In many countries in Asia including Vietnam, the level of pollution exceeds the value set by the World Health Organization [18]. In fact, exposure to PM with a diameter of less than 2. 5μm is the main cause of respiratory and deadly diseases.

PM is usually measured directly at ground monitoring stations. Therefore, this information is usually collected from a few minutes to several hours and is of high quality. However, this method is limited to geographic coverage. Moreover, the monitoring methods at ground monitoring stations do not represent the dust level at the regional level, which is difficult to assess the variation between regions based on single point observation. This is also the limitation that makes using PM to monitor air quality in a wide range becomes difficult and expensive. Using satellite images to estimate surface PM concentrations is considered to be an effective way. The estimated PM map from satellite imagery provides a platform for developing applications for air quality, human health, and disaster management. The estimation of PM2.5 / PM10 from satellites is able to enhance the accuracy of these estimates and predictions [19]. However, the relationship between PM2.5 / PM10 and other parameters such as aerosol and meteorology (humidity, temperature, wind speed, pressure ...) is complex and different by region, territory. Recent studies point out the potential of using remote sensing satellite imagery for mapping and monitoring air pollution associated with ground stations [20] [21]. The relationship between AOT and PM2.5 / PM10 has been reviewed in different regions with different experimental conditions [22] [23].

In Vietnam, air quality throughout the country's territory is declining, especially in big cities like Hanoi and Ho Chi Minh City. Some recent studies have used remote sensing satellite imagery to predict pollutant concentration. However, the exploitation of satellite information for modeling or estimating air pollution has not been widely studied in Vietnam, although this approach has clearly shown advantages such as cost reduction, quality prediction, etc. Thanh T N Nguyen et al calculated particulate matter concentration mapping from MODIS satellite data [24]. Ngo Tho Hung et al studied air pollution modeling at roadsides using the operational street pollution model [25].

In this study, we use the SEAP (big Spatial data Exploration and Analysis Platform) platform to analyze and store data [26]. The SEAP platform is designed and developed a comprehensive platform for big spatial data exploration and analysis consisting of six components. The data collector component

is designed to collect data from various kind of spatial data sources such as satellites, ground stations, open data source, UAV (Unmanned Aerial Vehicle), sensor networks, and smartphone applications. The data qualification component can evaluate various kinds of spatial data. Data storage and data processing components are built based on the highest performance framework for distributed computing such as Hadoop, Spark, and MongoDB. The service-pool component is developed to provide APIs to the 3rd-party application and to visualize data/services in the Dashboard component.

This paper has four main objectives including:

1) Estimating the urban expansion of Vietnam from 2004 to 2015;
2) Analyzing the air pollution of Vietnam from 2004 to 2015;
3) Understanding the impacts of urban expansion on air pollution in Vietnam from 2004 to 2015;
4) Using the SEAP platform for spatial and environmental data analysis and storage.

2. Study area and data

2.1. Study area

Vietnam is located in Southeast Asia region with about 4,550 km land border shared with China in the north; Laos and Cambodia in the west; and by the South China Sea (the East Sea of Vietnam). The country has a north-to-south distance of 1,650 kilometers from 8º27' North to 23º23' North. The mainland of Vietnam is occupied by mountains and hills with three-quarters of the overall area. Its deltas cover only one-fourth of the country's territory and are separated into several parts. The delta regions are the focal points of urban (accounting for more than 90% of regional cities) [27].

Vietnam has a diverse terrain that reflects the history of geological changes amid a tropical monsoon climate with winter monsoon from November to March and summer monsoon from May to September. The meteorological conditions and monsoon have a strong influence on emissions impact and dispersal of air pollution in Vietnam [27].

2.2. Data

2.2.1. MODIS data. MODIS (Moderate Resolution Imaging Spectroradiometer) is the main instrument on Terra (EOS AM-1) and Aqua (EOS PM-1) spacecraft. Terra has orbits from North to South and across the equator around 10:30 am. While Aqua satellite has orbit from South to North and across the equator around 1:30 pm in the afternoon. The repetition cycle of satellites is about 16 days with 4 images are collected during a day. It has a viewing swath width of 2,330 km and views the entire Earth surface every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385 μm, and it acquires data at three spatial resolutions - 250m, 500m, and 1,000m, with temporal resolutions: daily, 8 days, 16 days, monthly, quarterly, yearly [28].

The MODIS MOD13Q1 products (MODIS / Terra Vegetation Indices 16-Day L3 Global 250 m SIN Grid V006) provide consistent, spatial and temporal time series of global vegetation conditions. Gridded vegetation index maps depicting spatial and temporal variations in vegetation activity are derived at 16-day and monthly intervals in support of accurate seasonal and inter-annual monitoring of the Earth's terrestrial vegetation [29]. NDVI data was extracted from MOD13Q1 data consist of 23 periods of the 16-day cloud-free composite in 2004, 2008, 2012 and 2015.

MODIS Level 2 aerosol products (MOD04/MYD04) provide 2 types of images with different resolutions including 10x10km (MOD04_L2/MYD04_L2) and 3x3km (MOD04_3K/ MYD04_3K). The MODIS level-2 atmospheric aerosol product (MOD04_L2) provides full global coverage of aerosol properties from the Dark Target (DT) and Deep Blue (DB) algorithms. The DT algorithm is applied over the ocean and dark land (e.g., vegetation), while the DB algorithm in Collection 6 (C6) covers the entire land areas including both dark and bright surfaces. Both results are provided on a 10x10 pixel scale (10 km at nadir) [30].

2.2.2. VIIRS data. The Visible Infrared Imaging Radiometer Suite (VIIRS) is one of the key instruments on-board the Suomi National Polar-Orbiting Partnership (Suomi-NPP) spacecraft. Suomi-NPP is in the same trajectory as the A-Train vessels (CloudSat, CALIPSO, and Terra MODIS), but at higher altitudes: about 824 km with passing time the equator around 13:30 pm (GMT). VIIRS contributes significant enhancements to the operational environmental monitoring and numerical weather forecasting, with 22 imaging and radiometric bands covering wavelengths from 0.41 to 12.5 μm, providing 23 environmental data records including aerosol, cloud properties, fire, albedo, snow and ice, vegetation, sea surface temperature, ocean color, and nigh-time visible-light-related applications [31].

The VIIRS sensor includes a day/night band (DNB) which collects standard panchromatic image data by day and low light imaging data at night. Nighttime light data in 2015 were calculated from VIIRS NTL data (Stray Light Corrected Nighttime Day/Night Band Composites Version 1) [32].

There are two main types of VIIRS aerosol optical depth products: the Intermediate Product (IP) and the Environmental Data Record (EDR). VIIRS aerosol data products are processed from data records (VIIRS Sensor Data Records (SDRs)). Product for optical depth (AOT/AOD) with 6km spatial resolution (for EDR) and 750m spatial resolution (for IP) are created in the daytime for the whole global surface, except in cloudy areas and very bright surfaces [33].

2.2.3. Night light data DMSP-OLS. The Version 4 Defense Meteorological Satellite Program - Operational Linescan System (DMSP-OLS) night-time light imagery is free to download from the NOAA website. The DMSP-OLS night-time lights serve as one of the most widely recognized global satellite data products and have proven valuable in a wide range of scientific applications. The well-known product is the stable lights, an annual cloud-free composite of an average digital brightness value for the detected lights, filtered to remove ephemeral lights and background noise [32]. The global coverage night-time light datasets with 500m spatial resolution from 2004, 2008 and 2012 were extracted for Vietnam's territory.

2.2.4. Population data. The Gridded Population of the World (GPW) collection represents the distribution of the human population on a global surface [34]. Population data of this research is taken from the GPWv4 global population dataset (GPW Version 4, Population Count) with a 1 km spatial resolution from 2005 to 2015. GPWv4 population density map for Vietnam was processed in 2005, 2010, and 2015.

2.2.5. EstISA impervious surfaces data. The spatial distribution and density of constructed impervious surface area (ISA) include roads, parking lots, buildings, driveways, sidewalks and other manmade surfaces for global scale at a resolution of one kilometre [35]. The estimate of ISA is derived solely from the brightness of satellite observed night-time lights and population count. The ISA for Vietnam in 2005 and 2010 were separated from global data.

2.2.6. Inland water data. The MODIS land-water mask at 250-meter spatial resolution (MOD44W) is a complete global map of surface water derived from Terra MODIS in combination with the Shuttle Radar Topography Mission Water Body Data (SWBD). A lot of masks are applied to solve known issues caused by terrain shadow, burn scars, cloudiness, or ice cover in oceans [36]. Vietnam data was processed for 2004, 2008, 2012, and 2015.

2.2.7. AERONET data. AERONET (AErosol RObotic NETwork) is an optical ground-based aerosol monitoring network and data archive supported by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire) established with collaborators from agencies, research institutes, universities, scientists, and national partners [30]. AERONET provides globally distributed observations of spectral aerosol optical depth (AOD) products. AOD v3 data are analyzed for three data quality levels: Level 1.0 (unscreened, in real time), Level 1.5 (cloud-screened and quality controlled), and Level 2.0 (quality-assured, yearly).

3. Methodology

3.1. Urban classification method

Vietnam urban map was estimated based on a methodology proposed in our previous research, which includes two main parts: threshold determining and urban mapping.

3.1.1. Calculate the appropriate threshold. To calculate the appropriate thresholds of input data, we processed the following steps:

Step 1: Select sample polygons based on Google Earth and Landsat ETM + images.

Step 2: The number of sample pixels for each class (except the urban class) was calculated.

In total, 540 pixels of urban class and 1046 pixels of other classes are chosen to calculate thresholds, according to the principle that the values of the urban class are the highest priority. Particularly, the threshold of population density was calculated based on the Vietnam regulation of urban classification.

3.1.2. Urban classification. Data pre-processing step: input datasets were resampled to the same spatial resolution of 500m and extracted the study area using the boundary map of Vietnam.

Data processing step: the candidate maps were produced from population data. The result maps were calculated by excluding less nighttime light, less impervious surface, more greenness, and water areas from potential urban areas based on thresholds.

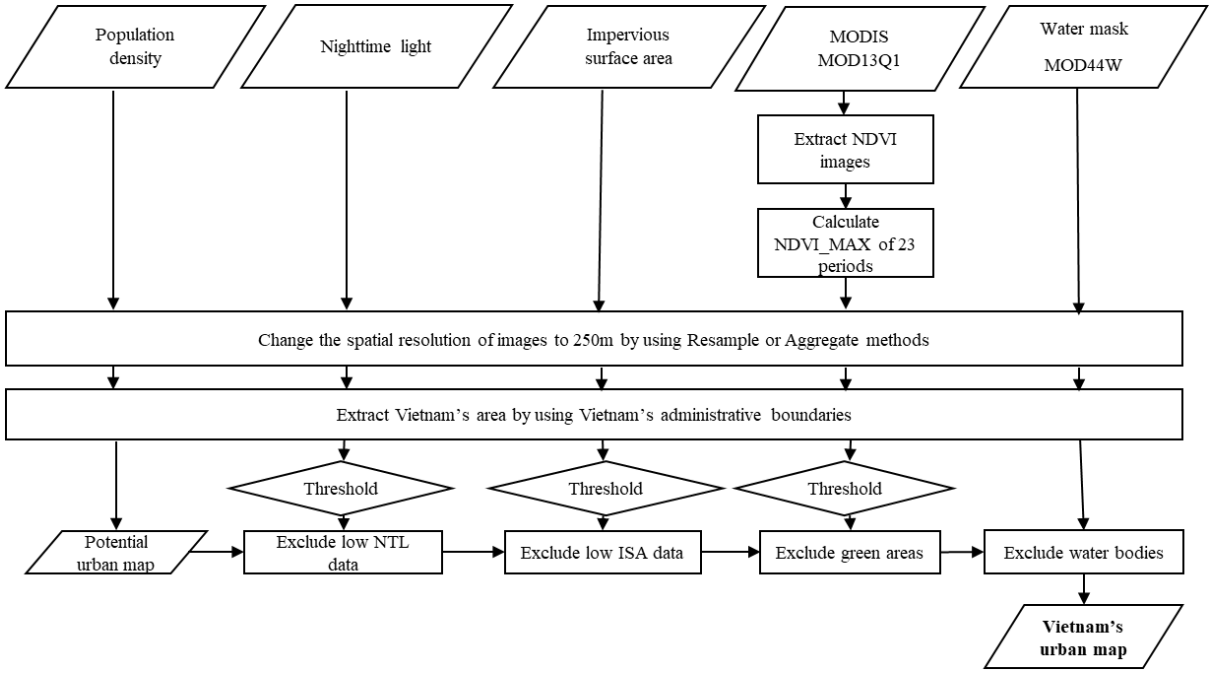


Figure 1. Vietnam urban mapping

3.2. Estimating the PM2.5 method

In the research, we focus on building the PM 2.5 estimation model in Vietnam using the regression method as shown in Figure 2.

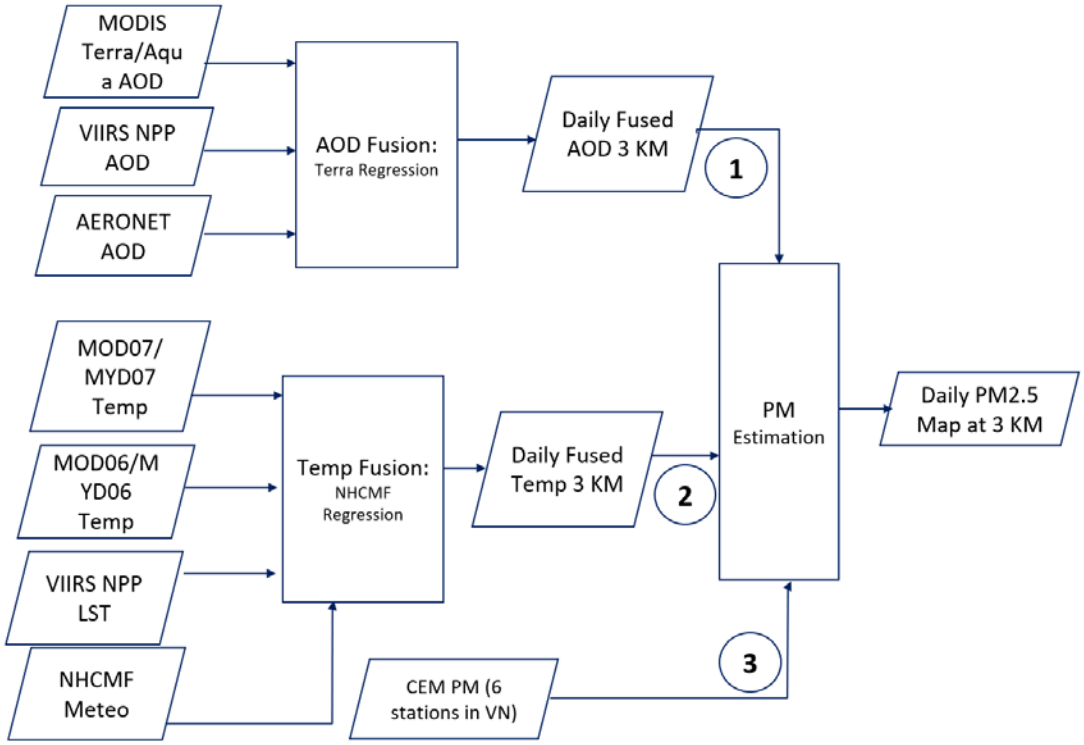


Figure 2. PM2.5 estimation model

3.2.1. AOD and Temperature fusion. The objective of this part is to merge multiple satellite AOD and Temperature products to obtain a new consistent AOD dataset with high quality and data coverage. This section presents Terra Regression the method used to integrate aerosol data (using Terra AOD as the target variable). The idea of this method is based on data quality in which satellite data that has the highest quality which is taken as a correlation with AERONET data is used as the response variable in the linear regression model.

Based on the validation results, MODIS Terra AOD data is the best quality will be kept as the response variable. MODIS Aqua and VIIRS NPP AOD data will be built a regression model as the following equation:

$$AOD_{MODIS\ Terra} = a * AOD_{MODIS\ Aqua} + b$$
$$AOD_{MODIS\ Terra} = c * AOD_{VIIRS\ NPP} + d$$

Where $AOD_{MODIS\ Terra}$, $AOD_{MODIS\ Aqua}$ and $AOD_{VIIRS\ NPP}$ are AOD value of MODIS Terra, MODIS Aqua and VIIRS NPP respectively, *(a,b)* and *(c,d)* are *(slope, intercept)* of the regression model.

After having built several regression models, MODIS Aqua and VIIRS NPP regression images are then estimated using the regression relationship:

$$AOD_{MODIS\ Aqua\ regress} = a * AOD_{MODIS\ Aqua} + b$$
$$AOD_{MODIS\ VIIRS\ regress} = c * AOD_{VIIRS\ NPP} + d$$

Finally, MODIS Terra, MODIS Aqua regress and VIIRS NPP regress images are combined using the Maximum Likelihood Estimation method.

Similar to aerosol data, temperature data from satellite images are also combined using NHCMF Regression (using Temperature data from the National Centre for Hydro-Meteorological Forecasting as target variable). MODIS Terra and Aqua Temperature data will be built a regression model as the following equation:

$$Temp_{NHCMF} = a * Temp_{Aqua} + b$$
$$Temp_{NHCMF} = c * Temp_{Terra} + d$$

3.2.2. PM estimation. AOD data and satellite temperature were validated compared to ground AOD data from AERONET stations and the temperature from CEM stations and calculations also showed a high correlation between AOD data. A recent study of Thanh et al shows that AOD and PM have a high correlation with Temperature [24]. Then, we have developed a model that helps predict the PM concentration value from AOD data and known Temperature. The model gives us the relationship of PM and other parameters through a certain function f with an acceptable error ε.

$$PM=f(AOD, Temp)+\varepsilon$$

3.3. Using the SEAP platform

The SEAP platform includes six components as shown in Figure 3. The first component is the Data Collector to gather spatial data from various data sources. After that, data is evaluated by the component called Data Qualification. In the next step, qualified data will be stored in high-performance storage which is the component called Data Storage. Processing component includes various analyzed spatial data libraries to calculate data. This component can analyze data automatically or manually by the user in the Dashboard component. The next component is Service-Pool which includes all the spatial data services and analyzed spatial data services for the 3rd-party application. End-users can manage all the data and data services visualized in the Dashboard. They also can use the Dashboard for uploading, qualifying data, storing, analyzing, and visualizing their data in the platform. The 3rd-party application can use the Service-Pool for developing their own application.

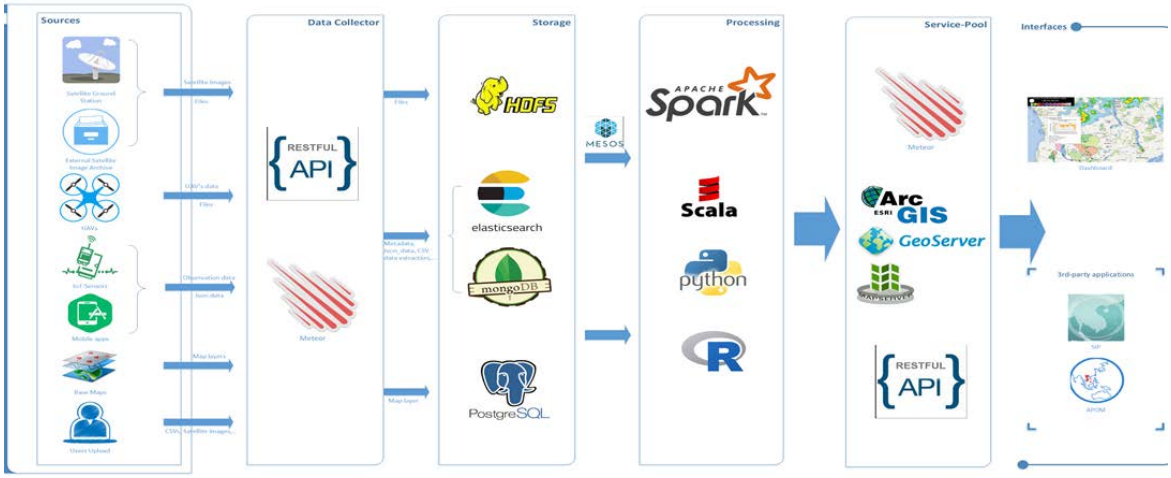


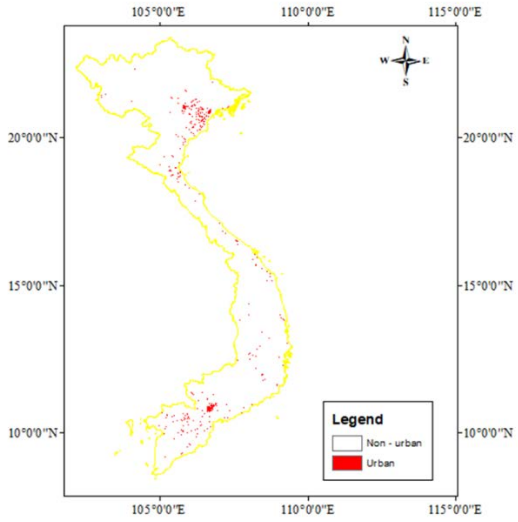
Figure 3. The architecture of the SEAP platform

4. Results and discussion

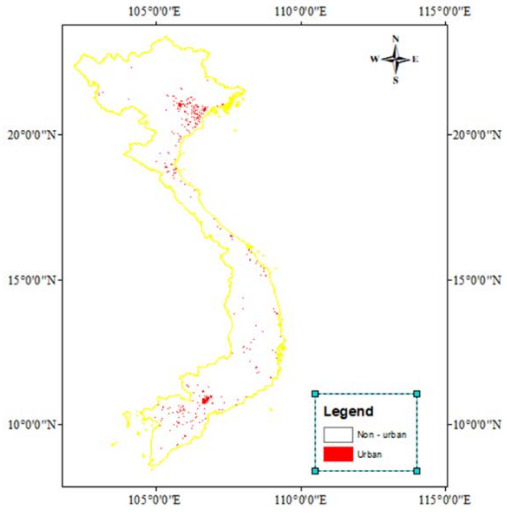
4.1. Urban expansion review

Based on the proposed urban classification method, Vietnam urban maps in 2004, 2008, 2012, and 2015 were obtained. From these urban maps, it can be seen that the expansion of urban areas in Vietnam during the 2004-2015 period is very quick. The urban area increased from 4623 km^2 in 2004 to 5094 km^2 in 2015 or 471 km^2 in this period. Vietnam urban core is focused on two largest cities: the capital of Hanoi and Hochiminh city. It confirms the dominance of the two urban systems. The results are shown in Figure 4.

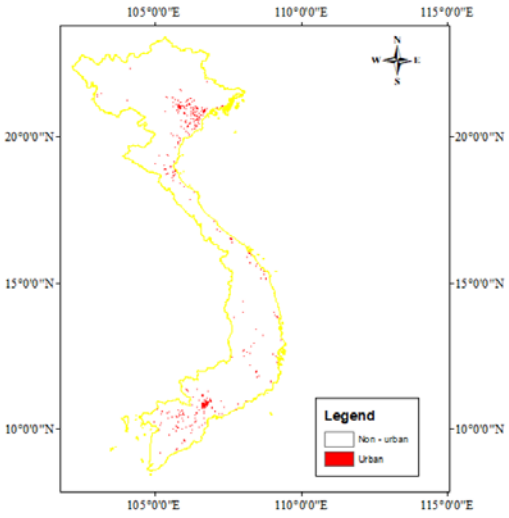
The study uses Precision, Recall, and F1 score (the harmonic mean of precision and recall) measures to quantify accuracies of urban maps. In our previous research [37], Precision, Recall, and F1 score for 2008-map are 89.29, 70, and 78.48, respectively, and for 2015-map are 89.29, 86, and 87.61, respectively.



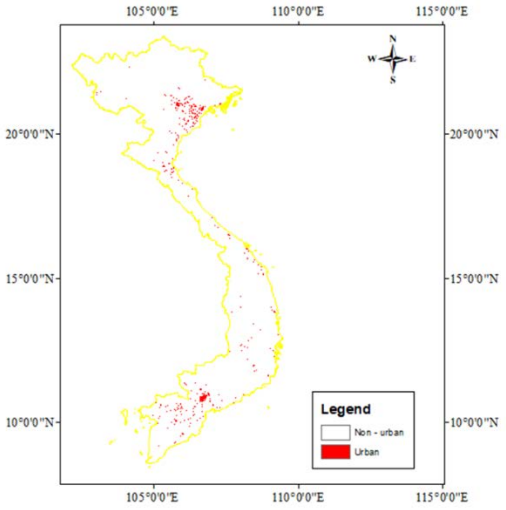
(a) Vietnam's urban map in 2004: 4623 km^2



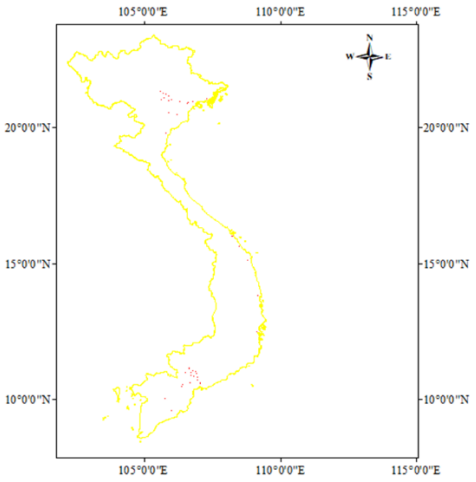
(b) Vietnam's urban map in 2008: 4860 km^2



(c) Vietnam's urban map in 2012: 5041 km^2



(d) Vietnam's urban map in 2015: 5094 km^2



(e) Vietnam's urban expansion in 2004-2015 period: 471 km^2

Figure 4. Vietnam urban maps in the 2004-2015 period

4.2. Assessing air pollution

The high PM2.5 value potentially carries information about regional-scale variability, which is especially important for highly populated urban areas. As the results shown in Figure 5, PM2.5 concentration is clearly different from urban to non-urban areas with a high average value of PM 2.5 is concentrated in some large urban areas such as Hanoi and Hochiminh city. The northern of Vietnam has higher PM2.5 value than other regions because of the monsoon effect. The north/northeast monsoon (winter monsoon) brought smoke pollution from the Chinese mainland into Vietnam's territory.

Figure 6 shows the average PM2.5 concentration in Hanoi in 2004, 2008, 2012 and 2015. The average concentration in 2004 and 2008 has a high variation by space, in which low concentrations are concentrated in some mountainous areas such as Ba Vi and Soc Son. In particular, urban areas such as Ba Dinh and Tay Ho also have low concentrations compared to other areas. This is due to the fact that these areas have little land cover variation and many trees reduce pollution levels. In addition, Tay Ho and Ba Dinh areas are also influenced by West Lake and Red River which reduces significant pollution levels.

High average PM2.5 concentrations areas are concentrated in suburban districts such as Me Linh, Gia Lam, Thanh Tri, Ha Dong ... This is attributed to the merger between Hanoi and Ha Tay in 2008, which has made the real estate market strong during this period, construction activities are strong in the peri-urban areas.

The average PM2.5 concentration in 2012 and 2015 has no spatial variation. In addition, the concentration of PM2.5 in this period also decreased significantly compared to previous years. Recorded at the monitoring station in Hanoi (Figure 7) in 2012 also shown a sharp decrease compared to previous years. The average concentration in Hanoi exceeds national standards in almost years [38].

4.3. Correlation between urban expansion and air pollution

The rapid urbanization process along with population and economy growth in Vietnam has been affecting the living environment, especially air pollution. The charts shown in Figure 8 describe the correlation between PM2.5 concentration of urban and non-urban areas.

Assessment of urban expansion impact on air quality is conducted by analyzing satellite PM2.5 concentrations separately for urban and rural areas in Vietnam (Figure 8.a). There is a clear difference between the average PM2.5 concentration value of urban areas and non-urban areas, urban PM2.5 values are generally higher than in rural areas for years. In 2004, the average satellite PM2.5 in urban areas was 25.142, meanwhile, this average in rural areas was only 21.056. In 2015, PM2.5 values were 22.945 and 20.054 for urban and non-urban areas, respectively.

In the two largest cities of Vietnam, Hanoi and Hochiminh city, the values of PM2.5 concentration are usually higher than the average value over the country. For example, in 2015, PM2.5 values of urban areas in Hanoi and Hochiminh city are 25.782 and 25.462, compared with 22.954 of Vietnam.

However, in smaller regions such as Hanoi (Figure 8.b) or Hochiminh city (Figure 8.c), the difference of PM2.5 values in urban and non-urban areas are very small. Therefore, it can be said that for low-resolution data such as MODIS data, the study area must be large enough to be able to assess the difference in air pollution indicators.

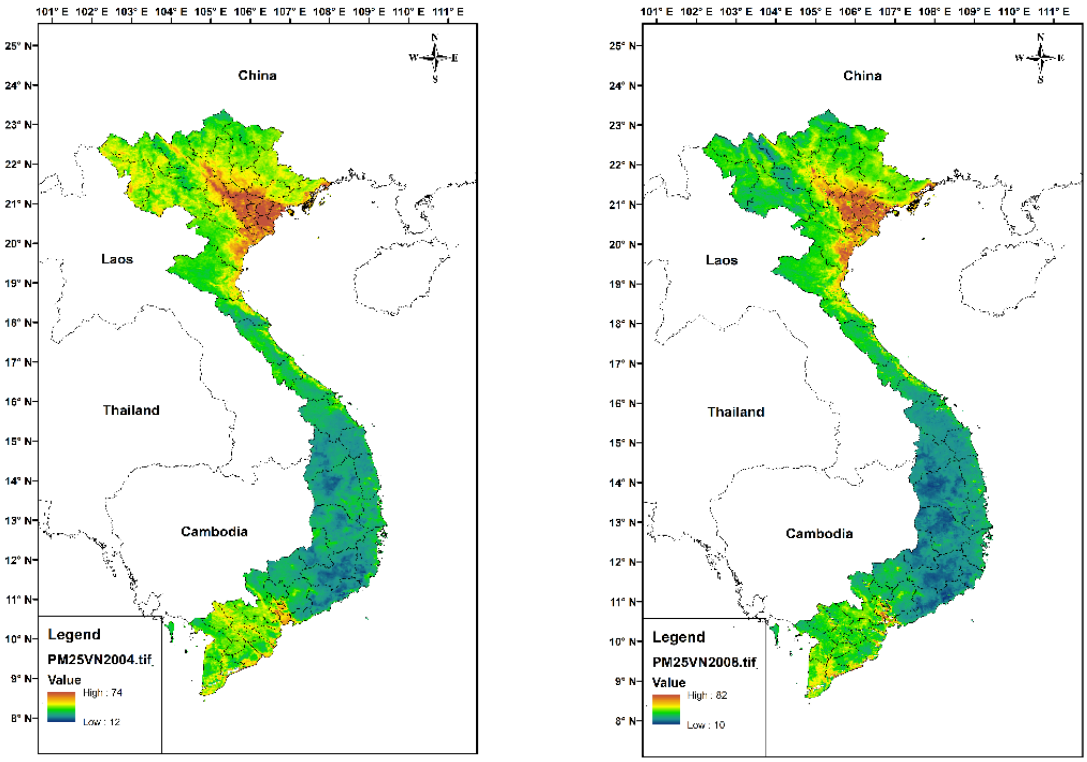


Figure 5. The average PM2.5 concentration in 2004 (a), 2008 (b), 2012 (c), and 2015 (d) in Vietnam

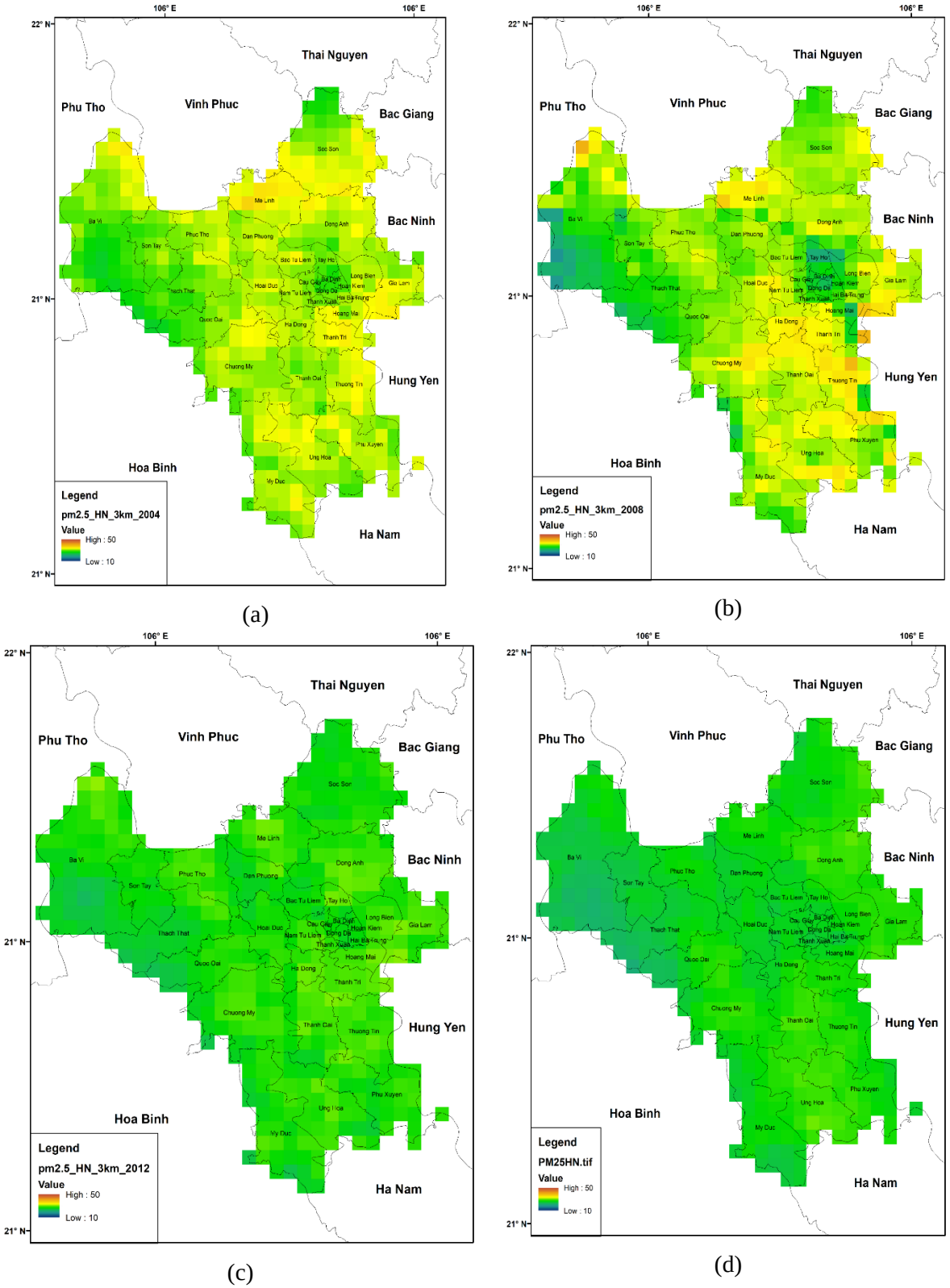


Figure 6. The average PM2.5 concentration in 2004 (a), 2008 (b), 2012 (c), and 2015 (d) in Hanoi

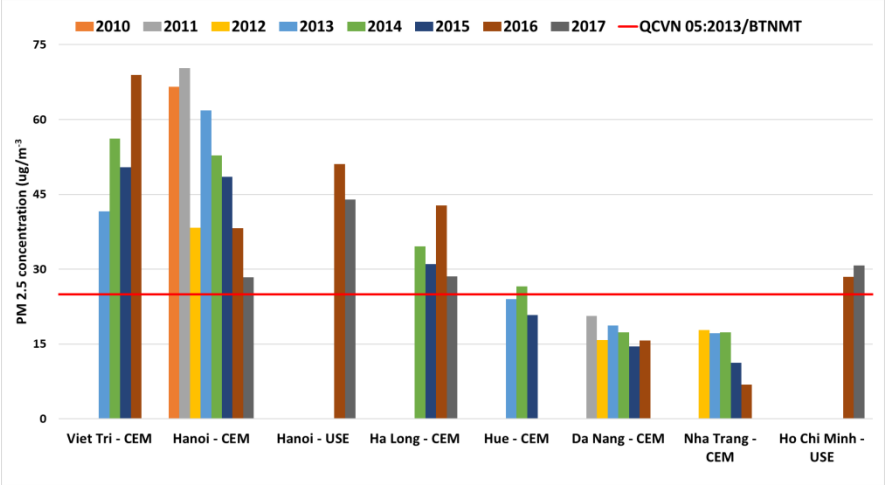
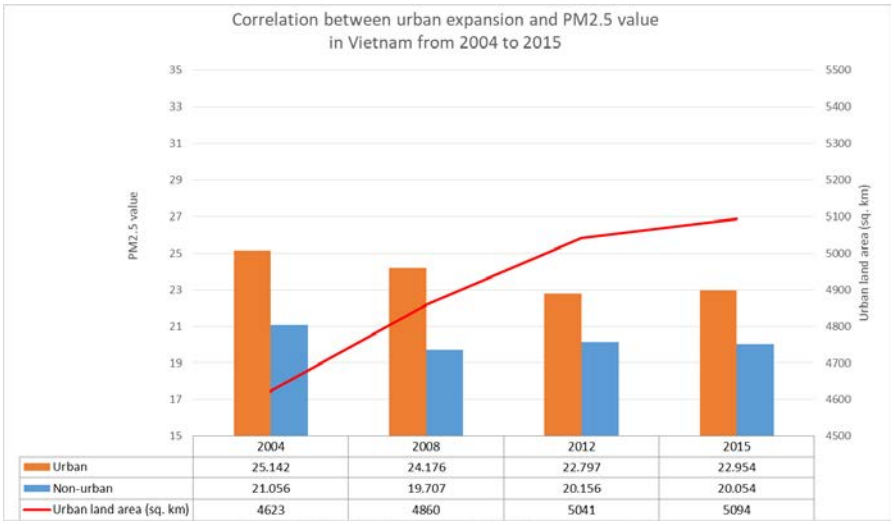
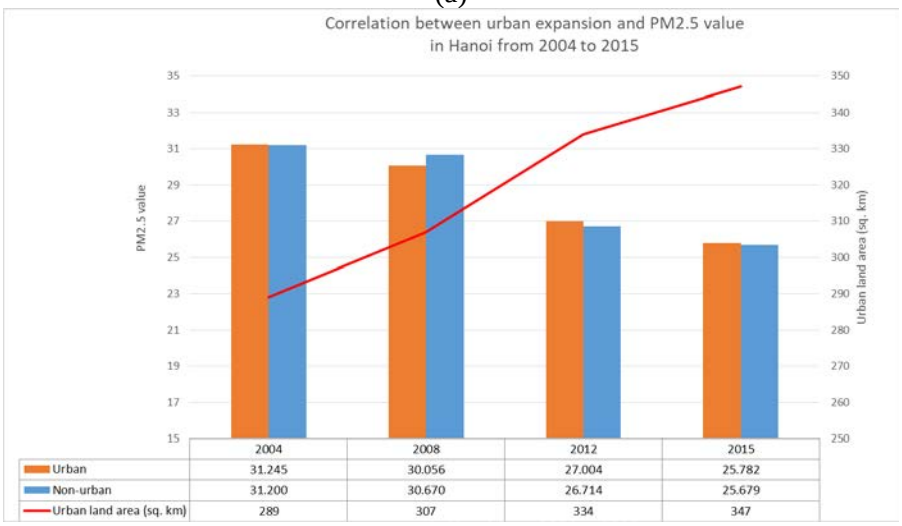


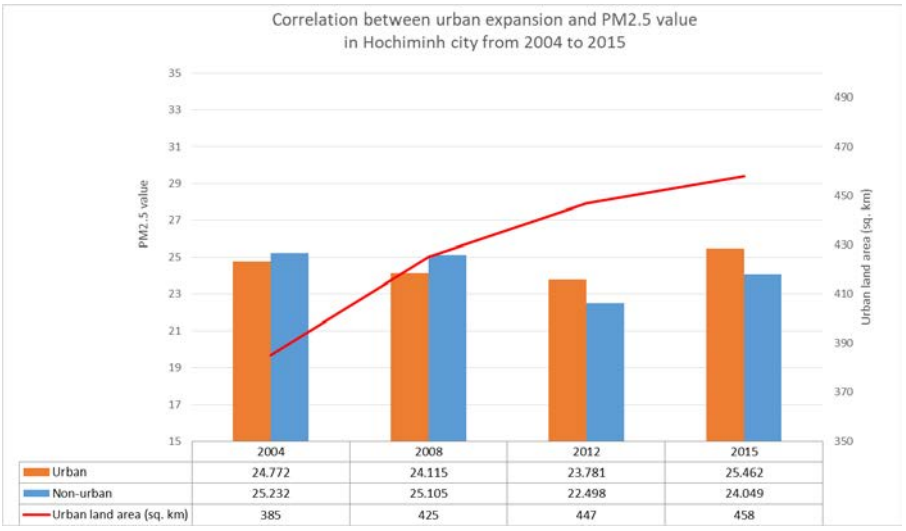
Figure 7. The average PM2.5 concentration at 8 stations in Vietnam (2010 – 2017)



(a)



(b)

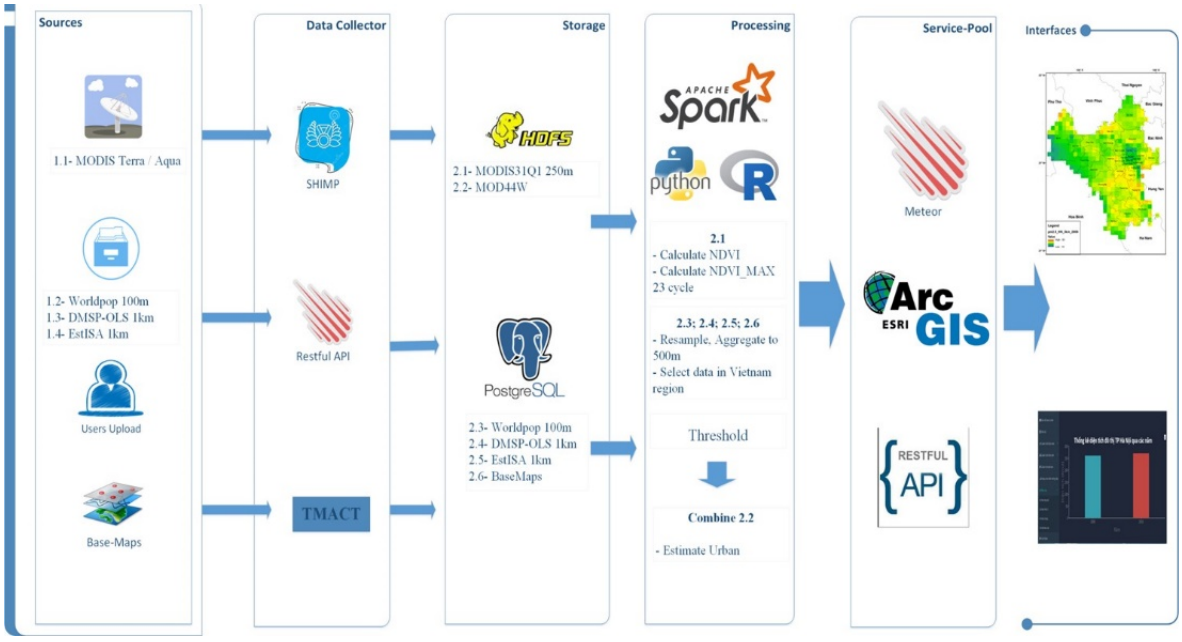


(c)

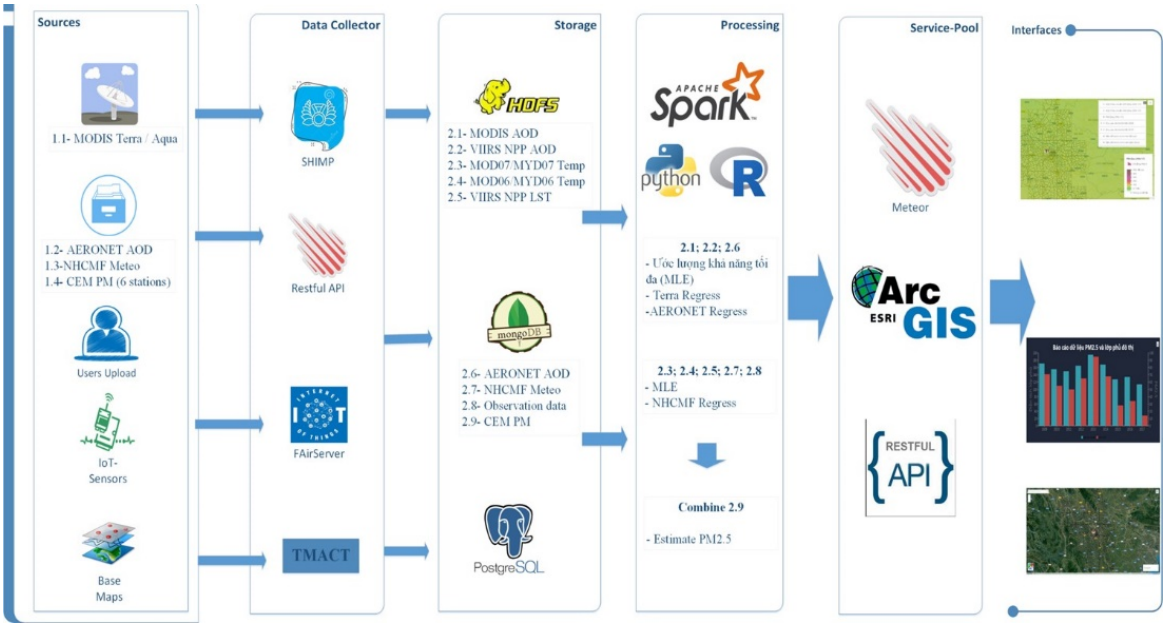
Figure 8. Correlation between urban expansion and PM2.5 concentration in Vietnam (a), Hanoi (b), and Hochiminh city (c)

4.4. Using the SEAP platform to analyse and storage data

Figure 9 demonstrates the implementation of the urban monitoring system and air quality monitoring system on the SEAP platform



(a)



(b)

Figure 9. The urban monitoring system (a) and the air quality monitoring system (b) based on the SEAP platform

5. Conclusion

Vietnam has been involving with rapid urbanization for years. The processes of urban expansion and spatial development have a huge impact on air pollution throughout the country's territory. The air quality index is different from urban areas to rural areas. In this research, we proposed an optimized urban classification method in Vietnam to calculate a time-series of urban maps from 2004 to 2015, built an appropriate model to estimating air quality index in Vietnam, evaluated the correlation between urban expansion and air pollution in Vietnam from 2004 to 2015. The data of this study were analyzed and stored by the SEAP platform.

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