Flash flood area mapping using sentinel-1 SAR data: a case study of eight upazilas in Sunamganj district, Bangladesh

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Abstract. Extraction of information from Remote sensing satellites is significant and effective tools for hazard activities such as flooding. Essentially, if the field was under disaster conditions it will be so difficult to do surveying in that region. Flash floods are sudden natural disaster events, which impact an extensive variety of ecological elements and applications associated with natural resources, agriculture, human activities and natural phenomena and economies. The utilization of SAR information gives much more information to control and monitor the flash floods, and additionally the information used for the damage assessment after the disasters. To recognize the region that has been flooded; a few procedures were trailed by Snap and Arc Map software. The fundamental step was flooded area in image its determined during extraction process by sets threshold estimation of radar backscatter which is taken from the calculation binary algorithm (the equitation of band math) to decide if a specified raster pixel is overflowed or not. The outcomes are indicated extend out of flash floods amid to time. On 26th of Mar Flood area was about 4.5%, however, it became around 45% in about month from the disaster beginning. This is evidence of the speed of the flood on the grounds that the nearness of high statures with heavy rains around there and its foundation, on first of May agriculture damages, was around 1037 km2 as result appeared of this flash flood. Therefore, these outcomes are extremely helpful to make an evaluation of situations to save the people lives, property and nature from this natural disaster in the future.

1. Introduction
Early warning of floods and immediate management monitoring systems have a critical responsibility in flood hazard decrease and the response for disaster managing. As significance, real-time satellite-based detection and flood forecasting systems have been evolved at a world wide scale, these days synthetic aperture radar (SAR) information has recognized for the various for floods monitoring and management services. SAR remote sensing is typically implemented through rising objects, by utilizing the different platform, for example, an airplane and space bore, a distinct beam-forming receiver from which an object scene is frequently illuminated through pulses from microwaves on wavelengths wherever from a meter downward to ward millimeters. In this article, Sentinel-1 SAR data are going to utilize for flood monitoring in the Republic of Bangladesh. In fact, The most remote sensing research in this region is using radar data because of the weather conditions, Bangladesh is characterized by cloudy clouds throughout the year, therefore, utilize optical sensor it's not efficient.

The launching Sentinel-1 sar satellite was in April 2014 in an efficient acquisition plan with the standards is to assist to an arrangement for the emergency response time. Consequently, it is capable of
being noted that Sentinel-1 will go behind a systematic and preprogrammed data collection situation, particular efforts with high efficiency to support emergency response through quick mapping of phenomena when required. By concerning most of the aspects of S-1 flood monitoring and management become easier to do this research work. Using data from this sensor can contribute to an effective form of flood management by extracting various maps from its data and from the benefits of using this sensor it can analyze data from early time from the flood events. For the purpose of extracting credibility information, there should be data processing of this information.

A lot of research has been done to study the floods in Bangladesh through many interested in this field in order to facilitate the process of management and control of this natural phenomenon as well as study the impact on the environmental aspects As well as potential impacts on the economy. And then develop a plan for the future to deal with these disasters (Choudhury & Haque, 2016). The flood causes heavy losses in the agriculture sector, where many studies have found potential damage without early warning is more than the case of early information available such as the intensity of this flood and areas able to drowning and others. For example, a report published that shows what percentage of damage is higher in March (75%) and April (70%-90%) compared to May (15%-40%) (CNRS, 2009).

In many research, there are problems related to the rapid provision of flood data for flood management and emergency information interpretation in the study area. One of the reasons, in this case, is to obtain the required licenses to acquire this information. Also sometimes radar is not used to monitor certain areas except for a specific purpose. Such as extracting maps from such data to a particular study area during emergency situations (Pulvirenti, Chini, Pierdicca, & Boni, 2016). In some cases, in emergency situations, the radar is used only for urgent need and for extreme require because of nature and system design of the sensor (Gokon et al., 2015). As a result of these problems, the use of these data may be late, especially at maximum flood time. For the purpose of detecting the largest extension of water on land. Timing is very important therefore data became useless when the water recedes. rapidity is consequently essential in providing information during an emergency. Some SAR images for NRT- Near Real Time flood mapping was established by researcher using past SAR sensors such as ERS-1 and ENVISAT ASAR. Terra SAR-X and CSK Radar is an advanced technology in the process of producing high-precision mapping with detailed information. S-1(Sentinel-1) SAR is new satellites in this area. Due to the modernity of the satellite, it has missed the opportunity monitor floods areas that occurred prior to its launch. Therefore, researchers may use data from different sources for the purpose of studying a specific area (Pulvirenti et al., 2016).

Floods are such most common natural disasters in Bangladesh, causing many losses, especially in agricultural land. Flooding typically effects about 20.5% of the extent of Bangladesh (Paul & Routray, 2010). Bangladesh is characterized by a large number of rivers and the largest area of the country’s land is floodplains where it constitutes a percentage 80% of total lands. (Brammer, 1990). Rapid flooding began in the northeastern part of Bangladesh on 28 March 2017 due to heavy rains in Meghalaya, India. Floods in these areas have severely damaged agricultural crops. As the region plays a major role in food production at the national level, the overall food security of the country may be harmfully affected. Therefore, there was a need to do a flood map to monitor floods and bear future damage.

For the rapid floods in Bangladesh in 2017, there were six territories in the north-eastern part. The most affected area is Sonamgang where more economic damage and property losses such as agricultural land in this area. We select eight different sub-regions of the Sonamgang district and have attempted to demonstrate the flood dynamics and their physical impact on the ecosystem of this area to estimate damage and potential losses. Therefore, now season of the rain in Bangladesh is very difficult to locate the data required for this type of study by the student on flood observation, and high-quality data will often be not free. In this study, it uses data available on the Internet for the purpose of obtaining results, as well as using information disseminated by the government to verify the validity of the results.

The intend of this research is to use radar data available to detect flood areas in Bangladesh and the potential impact on the ecosystem by processing and analyzing these data using different software.
And then make assessments of the agricultural land damaged as a result of this natural phenomenon. Government data is used to validate the results. This type of research contributes effectively to the management of floods and helps to keep the population and the economy from the potential dangers of flooding. In this study two objectives, these are such the following Detection Flash Flood area using Sentinel-1 SAR data. Assessment damages of agricultural lands.

1.1 Study Area
Study area selection is very important according to events which help to find out the potentiality of students for their research work where data choice is another major criterion. We become succeeded to choose a very good study area according to the natural event where we used a very useful data sets to complete the research. The flash flood of early 2017th of then orth-eastern part of Bangladesh is chosen as an event with the fitting location which filled the criteria for a flash flood. Sentinel-1 C-SAR dataset was chosen to do the research which is very much compatible with the area due to the rainy season of the study area. We selected eight Upazilas of Sunamganj district as our study area. During this flash flood Sunamganj district was affected by the flood from the other five districts.

Sunamganj is in the upper Meghna River basin (having an area about 70,000 km2 with 132 sub-basins) which starts draining from Manipura and Meghalaya hills of India. From here at the Amalshid point it enters Bangladesh where it is subdivided into Surma and Kushiyara from where it meets, it takes the name Meghna.

Sunamganj which is an important district of the north-east region usually gets a flashy runoff from the hilly topography of India just upward of this district. The total area of this district is 3747.18 km2 and it includes a total of 14 sub-districts, 87 union parishads, 1629 mouzas and 2887 villages (BBS, 2011). Heavy Rainfall at upper Meghna basin causes a flashy runoff which runs the water maximum through the area circulated in the map 1. During the flash flood 2017, the heavy rainfall in Meghalaya triggered the flood, as well as the monsoon rainfall, also contributed to becoming dangerous. The maximum area of Sunamganj is within a Haor area consisting of medium lowland, lowland and very lowland. Most of the area is flooded but most severely affected sub-districts are Sunamganj Sadar, Chhatak, Dharmapasha, Jagannathpur, and Tahiripur. Due to some limitations of data we used eight different Upazilas as our study area of this research.

1.1.1 History. Sunamganj district was individual of the section of previous Sylhet region. It come out as a district on the 1st March 1984. The district is full of boars and horses. Its headquarters is located at the river bank of the Surma where a commercial center (meaning ‘Ganj’) was expanded in this area in the name of a Shipahi Sunamuddin, who fought for the sovereignty of the nation in 1957. This properly the source of the name district to be Sunamganj.

1.1.2 Relative Location. It is surrounded on the west by Netrokona district, on the south by Habiganj and Kishoreganj districts, on the east by Sylhet district and on the North by India.

1.1.3 Absolute Location. It lies between 24°34’ and 25°12’ north latitudes and between 90° 56’ and 91° 49’ East longitudes. The entirety area of the district is 3747.18 Sq. km. (1446.00 sq. miles) of which 71.28 sq. km. (27.52 sq. miles) are under forest (Figure 1).
Historical Assessment of Flash Flood in Study Area:

In every year there is some area become under flash flooded in Sunamganj. Some become destructive and some caused fewer damages. Here is most dangerous flash flood assessment given below:

Table 1. Historical Flash Flood of Sunamganj

| Year | Flood water entered the Haor | Inundated the Boro crops | Extent of damage | Damaged Boro crop in hector | Cost of damaged crops in (Million BDT) |
|------|-----------------------------|--------------------------|------------------|-----------------------------|--------------------------------------|
| 1996 | 16 March                    | 18 March                 | 75%              | 29,822                      | 41                                   |
| 1998 | 20 May                      | 23 May                   | 40%              | 11,579                      | 23                                   |
| 1999 | 03 May                      | 06 May                   | 45%              | 10,950                      | 9.7                                  |
| 2000 | 28 April                    | 30 April                 | 70%              | 1,355                       | 4.2                                  |
| 2001 | 27 April                    | 30 April                 | 75%              | 4,963                       | 19                                   |
| 2002 | 14 April                    | 18 April                 | 70%              | 21,677                      | 70                                   |
| 2004 | 13 April                    | 15 April                 | 90%              | 95,402                      | 348                                  |

Source: Bangladesh Bureau of Statistics Report 2011

Heavy rain falls as well as the surge of water from the upstream Meghalaya mountains in India have guide to the deluge of enormous parts of agriculture lands of Haors and low-lying territories of the northeast part of Bangladesh. Research limitations of the study refer to those characteristics of research design/methodology which can impact or influence the interpretation of the results of the research. These are the restrictions on generalizable ability, applications to practice, and usefulness of...
results that are the ways in which you primarily chose to enterprise the study or the method used to establish internal and external validity. For our research, there are some limitations:

- First of all, time is the most precious to any research work as in our research also.
- The high-frequency band containing SAR data.
- Extraction of DEM from C-SAR data set due to the vegetation of the area.
- Limited research on this matter/event using Sentinel-1 SAR data.
- Current event.
- Verified secondary data limitations.
- Field observation limitation due to the far area from researchers.

2. Methodology

2.1. Image data and pre-processing:

The dataset used in the present research space-born images (Table 2) and vector data, including:

i. Collection of secondary data as ‘Reports of DDM on Damage Information and Relief Distribution on Flash Flood, May 01, 2017’ to do the socio-economic damage of the flood-affected areas.
ii. Four Sentinel-1 (S1) SAR images utilized for flood mapping, because of the S1 mission advantage to provide frequent and timely data.
iii. One Landsat-8 image (path 136, row 043) that were used for detection of agricultural lands and water bodies, during the winter period, at the flooded area.
iv. vector file used to subset the study area in the images.

Processing and analysis Digital image of the satellite data was carried out using SNAP (v.3) and ERDAS IMAGINE (2014) software, and the editing of the spatial information and map exportation was made using ArcGIS (v.10.4.1).

| Satellite   | Instrument | Mod/Path                  | Acquisition Date | Use                             |
|-------------|------------|----------------------------|------------------|---------------------------------|
| Sentinel-1   | C-SAR      | IW_GRDH_1SDV (VV, VH)     | 26/03/17         | To see the area before flood    |
| Sentinel-1   | C-SAR      | IW_GRDH_1SDV (VV, VH)     | 07/04/2017       | Flooded area observation and mapping |
| Sentinel-1   | C-SAR      | IW_GRDH_1SDV (VV, VH)     | 19/04/2017       | Flooded area observation and mapping |
| Sentinel-1   | C-SAR      | IW_GRDH_1SDV (VV, VH)     | 01/05/2017       | Flooded area observation and mapping |
| Landsat 8    | OLI        | LC81360432017026LGN01     | 26/01/2017       | Landuse-Landcover detection     |
One of the main benefits of utilizing SAR imagery, away from its all-weather capability, also its ability to recognize and distinguish water from different features known through the high distinction that exist. Waters features surface have high reflection characteristic for the energy, their reply is low (low backscatter coefficient in SAR images) and thus look like a shady area. The another type of ground appears a large amount of radar energy through the surface roughness (high backscatter coefficient in SAR images) and this produce the high contrast among surfaces between land and water (Vilches, J.P. 2013).

The three of SAR images downloaded from Sentinel-1 C-band contain an image during the flood and another one before the flood event, which is called “Reference Image”. SAR polarization is a very significant factor in flood detection. It is proven in several previous studies (Henry, Chastanet, Fellah, & Desnos, 2006; Horritt, Mason, & Luckman, 2001). These HH-polarized images are more suitable for flood detection than VV-polarized images. This is mostly due to the fact that HH-polarization gives the highest distinction in backscatter values between dry and wet forested areas. In this case, the available image during the flood had an Intensity VV and VH polarization. The VV polarization was better because the medium incident angle of the data makes suitable for flood detection. Therefore, VV polarization is used in this study.

To differentiate the region of the flood, few processes were followed by ArcMap and Snap software. Before doing any processing on Remote Sensing imagery, pre-processing should be applied in order to be the result accurate and useful. Therefore, the first step was preprocessing by snap software. A subset study area was done, and then radiometric calibration was applied. Then, a speckle filter (Lee filter with window size 7 by 7) was applied. Speckle filter appears the images clearer because it organizes construct the image without “salt and pepper” that is texture in an image. After that, a geometric correction was also applied that was followed (WGS1984) word coordinate.

2.2. Image processing:
The second step was extracted “flood image” and groups verge value (that was established manually) of radar backscatter which is followed (band math equation) from the algorithm of binary to select whether a pixel of raster given is flooded or not. Low values of the backscatter matched to the water, and high values matched to the non-water class. The final result was a grayscale image contain single band continuous data that generated from math band way by using this formula: $255 \times (\text{single band} < \text{number color of grayscale})$. The results as in (Figure 4). After that, extracting water body and agricultural lands by using Landsat 8 image in ArcMap, and then classify flood area by using reclassify tool in ArcMap toolbox. After that, producing agricultural damage maps was done by Clip and Erase tools in ArcMap toolbox.

![Figure 2. Preprocessing steps](image-url)
3. Results and Discussion:
Due to the frequent suffering of the flood of this area, it’s very important for research. Regarding all the assessment we chose to do some analysis in this area about flood monitoring. As a low land area and full of different big water bodies known as Haor and Labor locally. On March 28, 2017, the most severe flood in the history of this area started. By this devastating flood occurred due to heavy monsoon rainfall both in Meghalaya, India and North-eastern part of Bangladesh. The rainfall recorded by BMD as 9000mm which is broken all the earlier records. Due to this heavy rainfall both in BD(North-eastern) and hilly part of India, total 6 districts of Bangladesh are suffering from a flood.
The most affected and damaged area is Sunamganj District of Bangladesh by this flood. In this regard, it's known as Sunamganj Flood 2017. By analyzing the Sentinel -1 images we got the total flooded area at different times images are given below (Table 3):

**Table 3. Flood area on different dates**

| Acquisition Images | Date of Images | Total Flooded Area (km-sq) | Percentage of Extend Flood on Study Area |
|--------------------|---------------|-----------------------------|-----------------------------------------|
| 26/3/2017          |               | 120.2                       | 4.5%                                    |
| 07/04/2017         |               | 1099.1                      | 41.5%                                   |
| 19/04/2017         |               | 1022.9                      | 38.6%                                   |
| 01/05/2017         |               | 1195.2                      | 45.1%                                   |

The images that obtained during flood event on four different dates that were used to analyse the flood and to produce the flood mapping. In addition to, examine the extent of the flooded area it is easy to collect and established the damages of agricultural activity suffered by the flood. In these results are appeared to extend to flood area during to time (Figure 5,6,7,8). the area that have been flooded was on 26th of Mar about 4.5%, then it was became near 45% in only one month (Table 4). This is verification of the alacrity of the flood since of the occurrence of high heights with quantity of
rains in that area. Also, noted on 19 April that flood was moved inside the area with decreasing the flood in that time.

Figure 5. Flood area in 26th Mar

Figure 6. Flood area on 7th April
Figure 7. Flood area on 19th April

Figure 8. Flood area on 1st May
Flood event was affected in total Land-cover and Land-use, but this study is focused on the agricultural land because it is the largest area. Actually, occurred great damage in the agricultural land the flooded area of which is damaged partially or fully (Figure 9,10,11,12). The flooded agricultural land area calculated from images is given below results:

Table 4. Assessment of damage for agricultural land calculated by images

| Acquisition Date of Images | Total Flooded on Agricultural Area (km-sq) | Percentage of Extend Damage on Agricultural Lands |
|-----------------------------|--------------------------------------------|--------------------------------------------------|
| 26/3/2017                   | 102.6                                      | 4.9%                                             |
| 07/04/2017                  | 941.6                                      | 45.1%                                            |
| 19/04/2017                  | 880.1                                      | 42.2%                                            |
| 01/05/2017                  | 1037.6                                     | 49.7%                                            |

Figure 9. agriculture damage 26th Mar
Figure 10. Agriculture damage 7th April

Figure 11. Agriculture damage 19th April
The assessment of flood 2017 is given below from secondary data as a table noted that fully damaged on 1st of May to agricultural lands are very close from the result was extracted in this study. Therefore, on 1st of May agricultural damage was about 1037 km² (Table 4), on the other hand in DDM report was 102436 Hec (1024.360km²). That is evidence of the accuracy of the results in this study (Table 5).

Table 5. The assessment of.. flood 2017 from DDM 1st Of May

| Districts     | Affected Upazilas | Affected Unions | Affected HH | Fully Damaged Agricultural Land (Hec.) | Damaged House |
|---------------|-------------------|-----------------|-------------|----------------------------------------|---------------|
|               |                   |                 |             | Fully                                  |               |
|               |                   |                 |             | Partially                              |               |
| Sunamganj     | 11                | 88              | 172,617     | 102,436                                | 2,600         |
|               |                   |                 |             |                                        | 15,000        |
| Sylhet        | 13                | 105             | 212,570     | 26,715                                 | 20            |
|               |                   |                 |             |                                        | 10            |
| Netrokona     | 10                | 86              | 167,180     | 19,566                                 | 0             |
|               |                   |                 |             |                                        | 0             |
| Kishoreganj   | 13                | 56              | 148,687     | 45,256                                 | 0             |
|               |                   |                 |             |                                        | 0             |
| Habiganj      | 08                | 64              | 74,440      | 15,953                                 | 46            |
|               |                   |                 |             |                                        | 51            |
| Moulvibazar   | 07                | 50              | 74,594      | 9,914                                  | 194           |
|               |                   |                 |             |                                        | 284           |
| Total         | 62                | 518             | 850,986     | 219,840                                | 1,860         |
|               |                   |                 |             |                                        | 15,345        |

Source: DDM Report on Damage Information and Relief Distribution on Flash Flood, May 01, 2017

Flood begin on 28th March influence six regions in the north-eastern part of BD. increasing water run over and breached embankment in many places and flooded enormous areas of agriculture crops. It damaged almost for harvesting Boro rice in about 219,840 hectares in this area.
4. Conclusion:
In this study, it has shown the advantages and challenges of the use of very high-resolution SAR imagery of the new satellite Sentinel-1 for the analysis of flood situation. With the new capabilities of the ESA Sentinel-1 mission, C-band SAR-based flood mapping can be improved to detect the flooded area. This study was done in two stages.

i. Extraction of areas that have been flooded Using Sentinel-1 radar data.
ii. Make an assessment of the agricultural land affected as result of this flood.

Extraction of features from Remote sensing satellites is significant and effective tools for hazard activities such as flooding. Actually, if the field was under disaster conditions it will be so difficult to do surveying in that region. Radar systems are more useful in data providing and observation of floodplains than optic systems since flood occurs mostly on cloudy days. With new possibilities in the measurement of polarization, wavelength, spatial accuracy and other characteristics provided by new sensors available to delight new approaches to flood monitoring based on space. The main unresolved issue relates to the increase of delightful SAR interpretation to an incidence that would allow recording and at the end to follow the assessment of flood phenomena randomly. The new mission provides superior spatial and temporal resolution, resulting in higher accuracy flood maps and providing the possibility to map the temporal dynamics of each flood more accurately.

References

[1] Brammer, H. (1990). Floods in Bangladesh I: Geographical to the 1987 and 1988 floods background. The Geographical Journal, 156(1), 12–22. https://doi.org/10.2307/635431
[2] Choudhury, M. U. I., & Haque, C. E. (2016). “We are more scared of the power elites than the floods”: Adaptive capacity and resilience of wetland community to flash flood disasters in Bangladesh. International Journal of Disaster Risk Reduction, 19, 145–158. https://doi.org/10.1016/j.ijdrr.2016.08.004
[3] Gokon, H., Post, J., Stein, E., Martinis, S., Twelve, A., Mück, M., … Matsuoka, M. (2015). A Method for Detecting Buildings Destroyed by the 2011 Tohoku Earthquake and Tsunami Using Multitemporal Terra SAR-X Data. IEEE Geoscience and Remote Sensing Letters, 12(6), 1277–1281. https://doi.org/10.1109/LGRS.2015.2392792
[4] Henry, J. B., Chastanet, P., Fellah, K., & Desnos, Y. L. (2006). Envisat multi-polarized ASAR data for flood mapping. International Journal of Remote Sensing, 27(10), 1921–1929. https://doi.org/10.1080/01431160500486724
[5] Horritt, M. S., Mason, D. C., & Luckman, A. J. (2001). Flood boundary delineation from Synthetic Aperture Radar imagery using a statistical active contour model. International Journal of Remote Sensing, 22(13), 2489–2507. https://doi.org/10.1080/01431160116902
[6] Paul, S. K., & Routray, J. K. (2010). Flood proneness and coping strategies: The experiences of two villages in Bangladesh. Disasters, 34(2), 489–508. https://doi.org/10.1111/j.1467-7717.2009.01139.x
[7] Hejazi, F., Shoaei, M. D., Tousi, A., & Jaafar, M. S. (2016). Analytical model for viscous wall dampers. Computer-Aided Civil and Infrastructure Engineering, 31(5), 381–399.
[8] Pulvirenti, L., Chini, M., Pierdicca, N., & Boni, G. (2016). Use of SAR data for detecting floodwater in urban and agricultural areas: The role of the interferometric coherence. IEEE Transactions on Geoscience and Remote Sensing, 54(3), 1532–1544. https://doi.org/10.1109/TGRS.2015.2482001
[9] Vilches, J. P. (2013, March). Detection of Areas Affected by Flooding River using SAR images. In Seminar: Master in Space Applications for Emergency Early Warning and Response (p. 40).
[10] Martinis, S., Twele, A., & Voigt, S. (2009). Towards operational near real-time flood detection using a split-based automatic thresholding procedure on high-resolution Terra SAR-X data.

[11] Giustarini, L., Vernieuwe, H., Verwaeren, J., Chini, M., Hostache, R., Matgen, P., ... & De Baets, B. (2015). Accounting for image uncertainty in SAR-based flood mapping. International Journal of Applied Earth Observation and Geo information, 34, 70-77.

[12] L. Pulvirenti, N. Pierdicca, M. Chini, and Guerriero, (2013) “Monitoring flood evolution in vegetated areas using COSMO-SkyMed data: The Tuscany 2009 case study,” IEEE J. Sel. Topics Appl. Earth Observer. Remote Sens., vol. 6, no. 4, pp. 1807–1816, Aug. 2013.

[13] Serpico, S. B., Dellepiane, S., Boni, G., Moser, G., Angiati, E., & Rudari, R. (2012). Information extraction from remote sensing images for flood monitoring and damage evaluation. Proceedings of the IEEE, 100(10), 2946-2970.

[14] Martinis, S., Kersten, J., & Twele, A. (2015). A fully automated Terra SAR-X based flood service. ISPRS Journal of Photo grammetry and Remote Sensing, 104, 203-212.

[15] Psomiadis, E., Migiros, G., Parcharidis, I., & Poulos, S. (2004). Short period change detection of Sperchios lower delta area using space radar images. Bulletin of the Geological Society of Greece, 36(2), 919-927.

[16] Henry, J. B., Chastanet, P., Fellah, K., & Desnos, Y. L. (2006). Envisat multi-polarized ASAR data for flood mapping. International Journal of Remote Sensing, 27(10), 1921-1929.

[17] Parcharidis I., Lagios E., Psomiadis E., (2001). "Multitemporal hazard assessment in a high flash flood risk area using RS/GIS techniques: The case study of Hymittos Mt. (Athens)" 9th International Congress of the Geological Society of Greece, 5, 2055-2062 (2001)