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# Evaluation of flood risk in Sorocaba - Brazil, using fuzzy logic and geotechnology

# Avaliação do risco de inundação em Sorocaba - Brasil, usando lógica e geotecnologia fuzzy

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**ABSTRACT**

Floods are natural processes capable of destroying cities and lives, causing immeasurable impacts on humanity. The increase in the occurrence of such tragedies is remarkable. Factors interfering with it may be population growth and a fast urbanization. The city of Sorocaba, in São Paulo state, Brazil, is an example of this problem. This study aimed to evaluate the degree of flood risk in urban areas, suggesting an alternative evaluation and a prevention method to decision-making on territorial planning. Therefore, fuzzy logic combined to geotechnology was used for the analysis and identification of areas with a higher degree of relevance to flooding. The evaluated areas have a high risk of flooding during January, but care should be improved for the period between November and March.

**Keywords**: Fuzzy Matrix, Urban planning, GIS.

**RESUMO**

As inundações são processos naturais capazes de destruir cidades e vidas, causando impactos incomensuráveis sobre a humanidade. O aumento na ocorrência de tais tragédias é notável. Os fatores que interferem podem ser o crescimento populacional e uma rápida urbanização. A cidade de Sorocaba, no estado de São Paulo, Brasil, é um exemplo desse problema. Este estudo teve como objetivo avaliar o grau de risco de inundação em áreas urbanas, sugerindo uma avaliação alternativa e um método de prevenção à tomada de decisão no planejamento territorial. Portanto, a lógica fuzzy combinada à geotecnologia foi utilizada para a análise e identificação de áreas com maior grau de relevância para o alagamento. As áreas avaliadas têm um alto risco de inundação durante janeiro, mas os cuidados devem ser melhorados para o período entre novembro e março.

**Palavras-chave:** Matriz Difusa, Planejamento Urbano, SIG.

## 1 INTRODUCTION

The considerable increase in floods and their impacts on the world's population has motivated a greater number of scientific research seeking to develop and evaluate flood identification and prevention techniques (Murdukhayeva *et al.* 2013; Wang, 2015). This increase results from population and industrial growth, as well as accelerated urbanization and uncontrolled exploitation of land, water and forest resources, which increases damage.

In China, about two-thirds of the lands are classified as flood risk areas, including approximately 50% of the population and 70% of properties with a considerable annual economic loss by floods (Zou *et al*. 2013). A study conducted in Brazil identified a significant number of buildings and 11% of the evaluated area as susceptible to flood in the city of São Borja in southern Brazil (Righi and Robaina, 2012).

The study of urban flooding has been aided by geoprocessing techniques, geographic information system and remote sensing, using high resolution images and a greater and detailed exploration of the urban topography. There is also the application of fuzzy logic to forecast river levels and runoff (Neal *et al*. 2011; Lohani; Kumar and Singh, 2012; Tsakiris, 2014; Ravazzani *et al*. 2014).

Fuzzy logic was introduced in the 1960s as a theory capable of dealing with uncertainty. Among the approaches of fuzzy logic, there are fuzzy relationships, also known as fuzzy matrix, which represents the degree of association between elements belonging to two or more sets formed by matrices (Zadeh, 1965; Chen, 1995; Chen and Hoang; Lee, 2003; Ross, 2004).

Given the ability of floods to cause a series of disturbances to society, especially in cities with an irregular planning and densely populated areas, they represent a major line of studies seeking to establish measures and models which prevent floods.

This study aimed to subsidize flood evaluations in urban areas by developing an evaluation system based on fuzzy logic and geotechnology in order to assess the risk of flooding in the urban areas of the city of Sorocaba, São Paulo, Brazil.

## 2 METHODOLOGY

### 2.1 STUDY AREA

The city of Sorocaba is located 87 km from the São Paulo state capital. Currently, the city has an estimated population of 637,187 inhabitants, a population density of 1,304 inhabitants/km², and a land area of 450.382 km² (Figure 1).

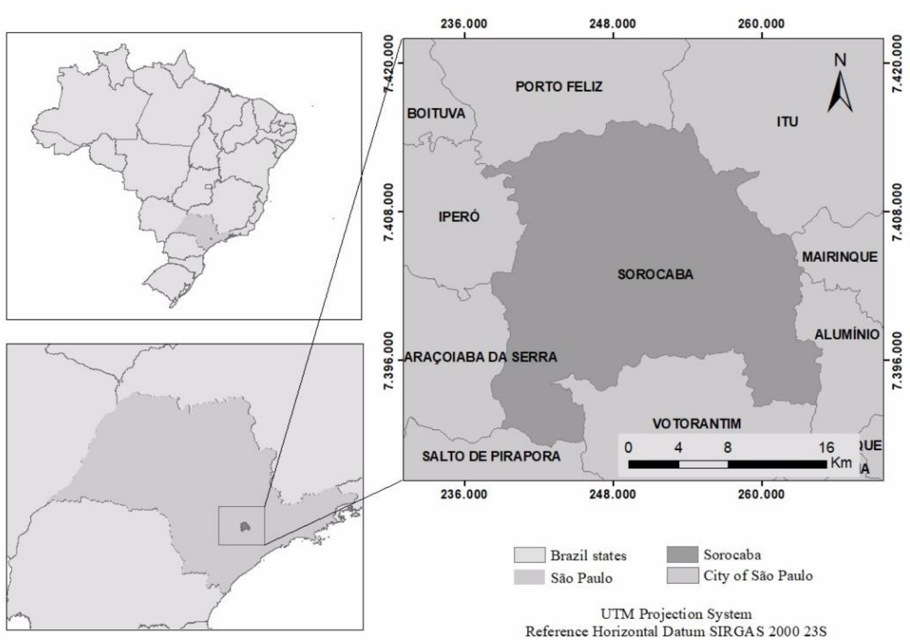


Figure 1: Location of the city of Sorocaba, São Paulo state, Brazil.

According to the Köppen climate classification (1936), the city's climate is classified as altitude tropical with a dry winter (CWA). It is characterized by hot summers and dry winters. The city presents a consolidated urban area with a diverse commercial and industrial area and a large daily circulation of population, an established transport system and a well-developed road network.

Because it is located in a valley along the Sorocaba river, the difficulty in circulation through these areas can be observed during rainy periods in addition to the accumulation of water inside houses and shops. There were even death records in urban areas in 2015.

### 2.2.1 Select of sample points

To evaluate the flood risk areas of that city, sixteen points were chosen at random within its urban area. Among them, three areas that flooded in November 2014, January and March 2015 were included (Figure 2).

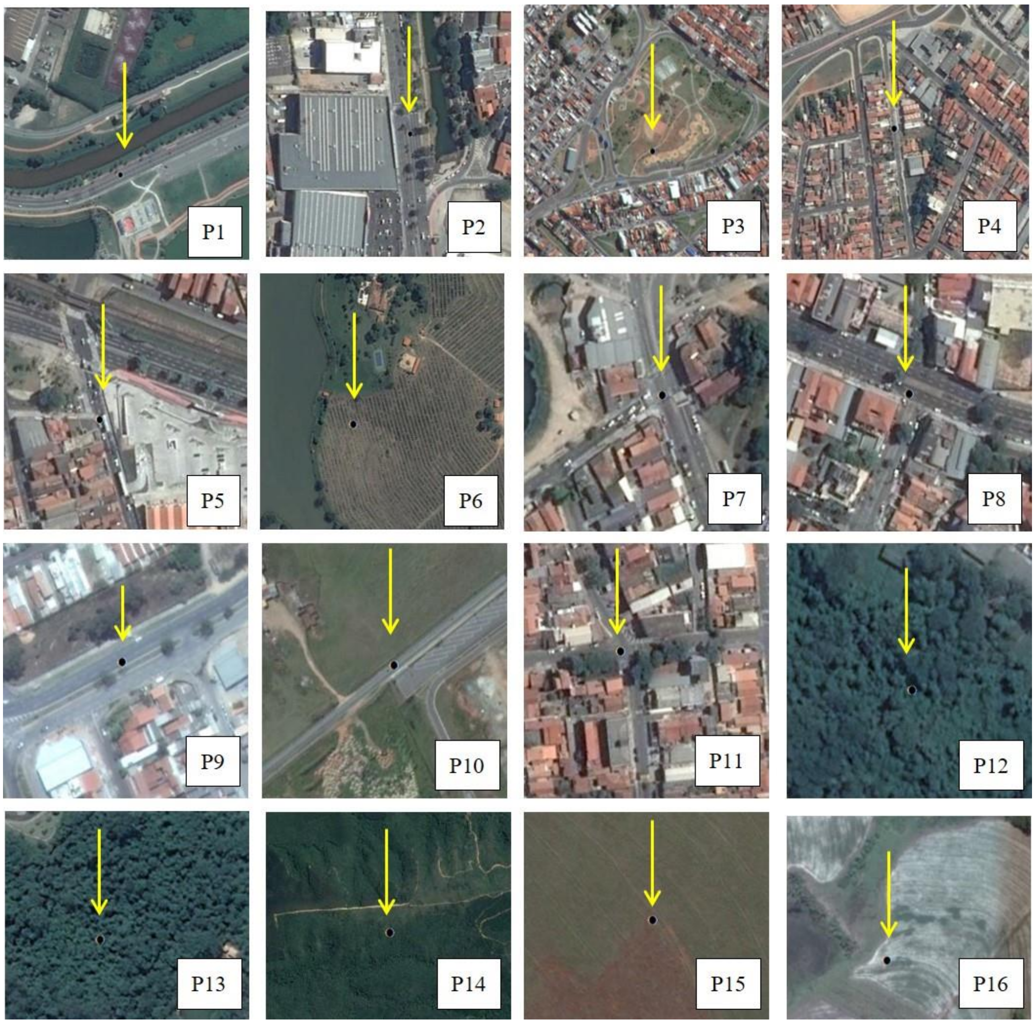


Figure 1: Location of sampling points in the city of Sorocaba, São Paulo state.

### 2.2.2 Mapping of soil type and slope

Based on GIS techniques, thematic maps of the soil and slope of Sorocaba were plotted. The soil map was delimited from the soil map of the state of São Paulo plotted by Oliveira et al. (1999) at the Agronomic Institute of Campinas.

The slope was determined from SRTM imaging obtained from the Brazilian morphometric database TOPODATA (INPE, 2015). To determine the slope, the software ArcGIS 10.3, Slope tool, was used. Then, the slicing of declivity was performed as established by Ross (1994).

Rainfall data were obtained from the Center for Integrated Agricultural and Meteorological Information (in portuguese - Centro Integrado de Informações Agrometereológicas) (CIIAGRO, 2015) using historical averages for the period between November 1994 and March 2014, including all months of the year, according to Table 1.

Table 1: Average of monthly precipitation time series in Sorocaba between the years 1994 and 2014.

| Months | Average precipitation monthly (mm) |
|---|---|
| January | 273.0 |
| February | 157.0 |
| March | 115.0 |
| April | 57.2 |
| May | 58.2 |
| June | 49.0 |
| July | 52.0 |
| August | 26.6 |
| September | 56.6 |
| October | 91.7 |
| November | 116.4 |
| December | 184.0 |

### 2.2.3 Land use identification

For the identification of land use, geographic coordinates of each area evaluated were entered into Google Earth Pro. Then, the occurrences were identified and recorded for these areas, providing the basis for fuzzy relationships.

### 2.2.4 Fuzzy relationships

The fuzzy relationships matrix had as input variables slope, land use and soil type adapted to the determination of Ross (1994), which classifies the types of each variable into high, medium and low fragility. The variable rainfall was adapted to the values established by Crepani *et al*. (2001).

From such adaptations, the memberships was determined for each input inserted into the variables in the interval [0,1], providing the opportunity to standardize such variables within the fuzzy system (Table 2 and 3).

Brazilian Journal of Development

Table 2: Definition of memberships for slope, soil and land use.

| Membership | lope (%) | Soil | Land use |
| --- | --- | --- | --- |
| 0.9 | 0 -7 | - | Hydrography<br>Residential área<br>Earthmoving<br>Exposed soil |
| 0.7 | > 7 - 10 | - | Short-term agricultural |
| 0.5 | > 10 -20 | Argisol | Reflorest |
| 0.3 | > 20 - 30 | Red Oxisol | Pasture |
| 0.1 | > 30 | - | Shrub vegetation |

Table 3: Definition of memberships for rainfall.

| Membership | Rainfall (mm) |
| --- | --- |
| 0.9 | 273-200 |
| 0.7 | 199-125 |
| 0.5 | 124-100 |
| 0.3 | 99-50 |
| 0.1 | $\leq$ 49 |

Then, the importance of each variable was determined in relation to flood risk. That is, among analyzed variables, the contribution to the risk of flood was evaluated (Table 4).

Table 4: Weight of the variables regarding flood risk.

| Variables | Weight |
| --- | --- |
| Slope | 0.3 |
| Soil | 0.5 |
| Land use | 0.7 |
| Rainfall | 0.9 |

Using Microsoft Excel 2010, a state matrix of the assessed areas was designed. A matrix containing rainfall levels, land use, soil type and slope of the respective areas was then designed.

Then, a flood risk matrix was designed based on maximum-minimum composition (Perre, Romero and Borges, 1986). Initially, the degree of importance of the variables was compared with types of rainfall, land and soil use, and slope observed for each area by selecting the minimum value between them and subsequently the maximum value among all variables for each point.

In this risk matrix, the closer to 1, the greater the risk of flooding in the area analyzed. The closer to 0, the lower the risk of flood.

## 3 RESULTS AND DISCUSSION

In Sorocaba, episodes of flooding are recorded between November and February. In the case of points 1 to 3, there were flooding of shops, banning of areas, deaths and accidents. The episodes observed in Sorocaba are confirmed by Monteiro (2009). This author adds soil compaction, breaking of buildings, water supply and sanitation as other factors resulting from chaos in urban areas during high rainfall periods.

It was observed that the analyzed all areas were more susceptible to flooding during January.

In short, January corresponds to the highest average monthly rainfall for the region since 1994, and therefore should receive a greater attention by both the city's inhabitants and the public bodies (Table 5).

Table 5: Fuzzy degree of relevance of flood risk in the city of Sorocaba, São Paulo state.

| Areas | RISK/MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Fev | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| P1 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P2 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P3 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P4 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P5 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P6 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P7 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P8 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P9 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P10 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P11 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P12 | 0.9 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| P13 | 0.9 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| P14 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P15 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| P16 | 0.9 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |

Importantly, the observed average rainfall for January in Sorocaba is ten times the rainfall observed for August, confirming the influence that this variable has on the potential risk of flooding during the first month of the year. For Monteiro (2009), the rainfall volume becomes important for daily life in different ways. However, at the same time, rainfalls increase the damage when they occur intensely in densely occupied spaces.

Although it seems obvious that the occurrence of flooding is associated with longer periods of rainfall, it must be emphasized that such episodes are associated with other characteristics evaluated in this study. That is, floods, although dependent on intense rainfalls, are directly related to soil use, soil type and slope (Figure 3 e 4).

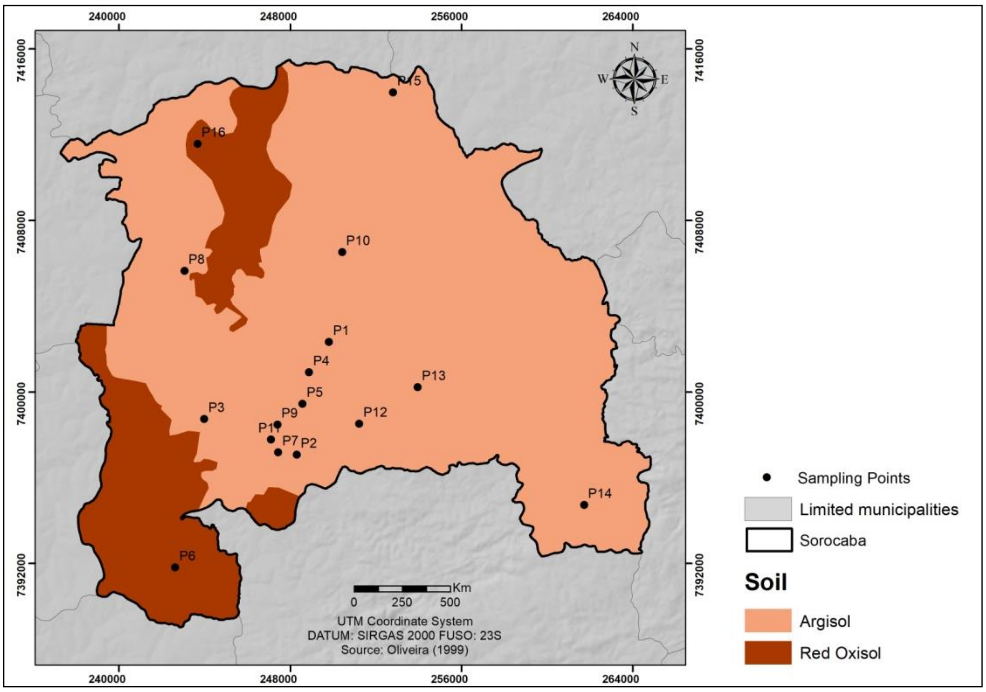


Figure 3: Types of Soils in the Sorocaba city.

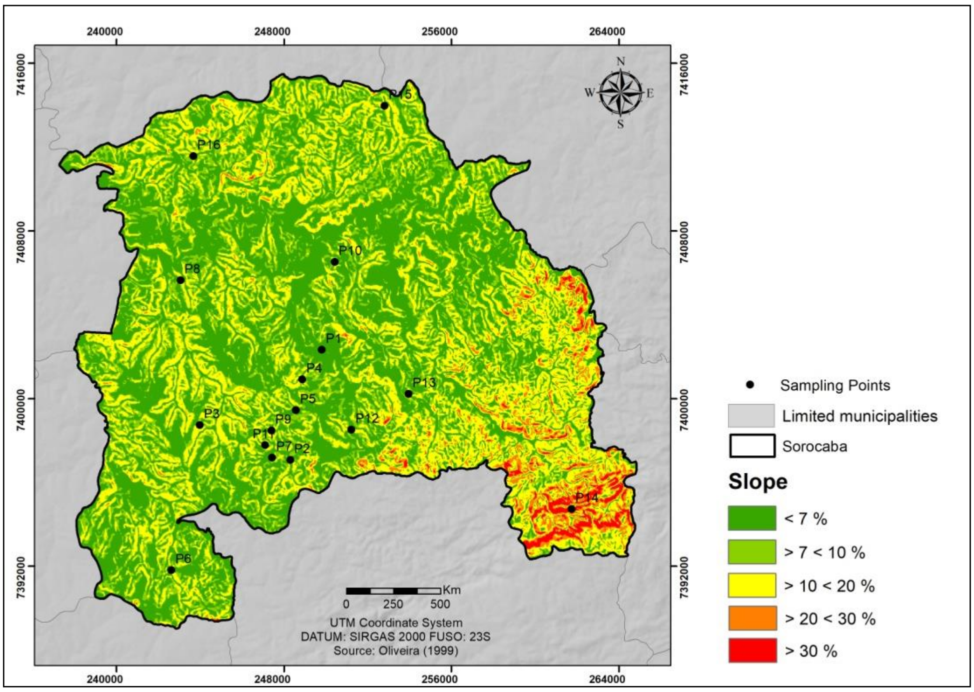


Figure 4: Degrees of ground slope in the Sorocaba city.

The evaluanted points are located in dense urban áreas, which make the land surface impermeable. When there are deposited wate, clogged draind and lack of vegetation, the risk of flooding increases in these áreas. Such factors must be taken into account to redouble the city's alert during high intensity rainfalls ( Calder and Aylward, 2006; Bradshaw, 2007; Paix at AL. 2013).

Considering the results presented, it can be estimated that the fuzzy degree of relevance to flooding for areas should be set at 0.7. For the points P1 to P11, the increase in the degree of relevance to flood occurred only during January. The results allow stating that floods are more likely to occur during summer, similar to England, China and Japan (Pall, 2011; Quan, 2014; Morita, 2014).

The points 12 and 13 showed a minimized flood risk for the months between March and November. This is associated with soil use since these areas are characterized by the presence of forests and low rainfalls (Bradshaw, 2007). The soil of these areas, although they are classified as weaker soils, presents covered areas preventing the occurrence of erosion, leaching and slides. On the other hand, they facilitate the flow.

It was identified that urban areas, even with a low degree of relevance to rainfall, present higher flood risks compared to forested (P12 e P13) and agricultural areas (P6, P15 e P16), especially due to the environmental characteristics of these environments.

This increases the understanding of disordered occupation and loss of vegetation areas as factors that trigger flood events in major urban centers (Yin et al. 2011). It is also possible to associate them with the death counts recorded for a major avenue, with a wide circulation of people, confirming the need for control measures.

## 4 CONCLUSIONS

The use of fuzzy relationships and geotechnology proved to be effective in detecting such pattern and in identifying the months most prone to the occurrence of floods. This suggests an increased awareness from November to February. The identified flood risk showed a spatial conformity since urban areas are more susceptible to such events.

This study provides information for the local government to plan preventive measures to minimize floods in most propitious areas. This study is also a warning to the entire population of Sorocaba. Improvements in territorial planning, especially regarding disordered urban occupation, reforestation of strategic points and long-term risk studies are therefore recommended.

## REFERENCES

Bradshaw, C.J.A., Sodhi, N.S., Peh, K.S. and Brook, B.W. (2007) 'Global evidence that deforestation amplifies flood risk and severity in the developing world', *Global Change Biology*, 13(11), pp. 2379–2395. doi: 10.1111/j.1365-2486.2007.01446.x.

Calder, I.R. and Aylward, B. (2006) 'Forests and floods - in support of an evidence-based approach to watershed and integrated flood management', *Water International*, 31(4), pp. 544–547. doi: 10.1080/02508060608691957.

CIIAGRO - Centro Integrado de Informações Agrometereológicas (2015). *Série histórica de pluviosidade mensal de Sorocaba – SP*. Available at: http://www.ciiagro.sp.gov.br/ciiagroonline/Quadros/QChuvaPeriodo.asp/(Accessed: 3: 21 jun. 2015).

Chen, S.-M. and Wang, J.-Y. (1995) 'Document retrieval using knowledge-based fuzzy information retrieval techniques', *IEEE Transactions on Systems, Man, and Cybernetics*, 25(5), pp. 793–803. doi: 10.1109/21.376492.

Chen, S.-M., Horng, Y.-J. and Lee, C.-H. (2003) 'Fuzzy information retrieval based on multi-relationship fuzzy concept networks', *Fuzzy Sets and Systems*, 140(1), pp. 183–205. doi: 10.1016/s0165-0114(02)00464-5.

Crepani, E. Medeiros, J.S., Hernandez Filho, P., Florenzano, T.G., Duarte, V. and Clemente Faria Barbosa, C. (2001), *Sensoriamento Remoto e Geoprocessamento aplicados ao zoneamento ecológico econômico e ao ordenamento territorial*. São José dos Campos: INPE.

IBGE - Instituto Brasileiro de Geografia e Estatísticas (2013). *Sorocaba. Dados gerais.* Available at: http://cod.ibge.gov.br/2351E/ (Accessed: 21 jun. 2015).

INPE - Instituto Nacional de Pesquisas Espaciais (2015) -. *TOPODATA: Banco de dados geomorfométrico do Brasil*. Available at: http://www.dsr.inpe.br/topodata/ (Accessed: 21 jun. 2015).

Köppen, W. (1936) 'Das geographische system der climate', in: Köppen, W.; Geiger, R. (Eds.). Handbuch der Klimatologie 1936. Berlin: Gebrüder Borntraeger, pp.32- 44.

Lohani, A.K., Kumar, R. and Singh, R.D. (2012) 'Hydrological time series modeling: A comparison between adaptive neuro-fuzzy, neural network and autoregressive techniques', *Journal of Hydrology*, 442-443, pp. 23–35. doi: 10.1016/j.jhydrol.2012.03.031.

Monteiro, A. (2009) 'As cidades e a precipitação. Uma relação demasiada briguenta', *Revista Brasileira de Climatologia*, 5(5), pp. 7–25.

Morita, M. (2014) 'Flood risk impact factor for comparatively evaluating the main causes that contribute to flood risk in urban drainage areas', *Water*, 6(2), pp. 253–270. doi: 10.3390/w6020253.

Murdukhayeva, A., August, P., Bradley, M., LaBash, C. and Shaw, N. (2013) 'Assessment of Inundation risk from sea level rise and storm surge in northeastern coastal national parks', *Journal of Coastal Research*, 291, pp. 1–16. doi: 10.2112/jcoastres-d-12-00196.1.

Neal, J., Schumann, G., Fewtrell, T., Budimir, M., Bates, P. and Mason, D. (2011) 'Evaluating a new LISFLOOD-FP formulation with data from the summer 2007 floods in Tewkesbury, UK', *Journal of Flood Risk Management*, 4(2), pp. 88–95. doi: 10.1111/j.1753-318x.2011.01093.x.

Oliveira, J.B., Camargo, M.N., Rossi, M. and Caldeira Filho, B. (1999). *Mapa pedológico do Estado de São Paulo: Legenda expandida*. Campinas: Instituto Agronômico/EMBRAPA.

Paix, M.J., Lanhai, L., Xi, C., Ahmed, S. and Varenyam, A. (2011) 'Soil Degradation and Altered Flood Risk as a Consequence of Deforestation', *Land Degradation & Development*, 24, pp. 478–485. doi: 10.1002/ldr.1147.

Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D. and Allen, M.R. (2011) 'Anthropogenic greenhouse gas contribution to flood risk in England and wales in autumn 2000'. *Nature*, 470(7334), pp. 382–385. doi: 10.1038/nature09762.

Perre, M.A., Romero, R.H.C. and Borges, T.H.N. (1986) 'Relações e restrições fuzzy', *Semina: Ciências Exatas e Tecnológicas*, 7(2), pp. 93–99. doi: 10.5433/1679-0375.1986v7n2p93.

Quan, R. (2014) 'Risk assessment of flood disaster in Shanghai based on spatial–temporal characteristics analysis from 251 to 2000', *Environmental Earth Sciences,* 72(11), pp. 4627–4638. doi: 10.1007/s12665-014-3360-0.

Ravazzani, G., Gianoli, P., Meucci, S. and Mancini, M. (2014) 'Assessing downstream impacts of detention basins in urbanized river basins using a distributed Hydrological model', *Water Resources Management,* 28(4), pp. 1033–1044. doi: 10.1007/s11269-014-0532-3.

Righi, E. and Robaina, L.E. de S. (2012) 'Risco à inundação no médio Curso Do Rio Uruguai: Estudo De Caso No Município de São Borja - RS', *Revista Brasileira de Geomorfologia,* 13(3). doi: 10.20502/rbg.v13i3.198.

Ross, J.L.S. (1994) 'Análise Empírica da Fragilidade dos Ambientes Naturais Antropizados', *Revista do Departamento de Geografia*, (8), pp. 63–74. doi: 10.7154/rdg.1994.0008.0006.

Ross, T.J. (2004) *Fuzzy logic with engineering applications.* 2nd edn. Chichester, United Kingdom: John Wiley & Sons.

Tsakiris, G. (2014) 'Flood risk assessment: Concepts, modelling, applications', *Natural Hazards and Earth System Science*, 14(5), pp. 1361–1369. doi: 10.5194/nhess-14-1361-2014.

Wang, L.-N., Chen, X.-H., Shao, Q.-X. and Li, Y. (2015) 'Flood indicators and their clustering features in Wujiang river, south china', *Ecological Engineering,* 76, pp. 66–74. doi: 10.1016/j.ecoleng.2014.03.018.

Yin, J., Yu, D., Yin, Z., Wang, J. and Xu, S. (2013) 'Modelling the combined impacts of sea-level rise and land subsidence on storm tides induced flooding of the Huangpu river in Shanghai, china', *Climatic Change,* 119(3-4), pp. 919–932. doi: 10.1007/s10584-013-0749-9.

Zadeh, L.A. (1965) 'Fuzzy sets', I*nformation and Control,* 8(3), pp. 338–353. doi: 10.1016/s0019-9958(65)90241-x.

Zhang, J., Zhou, C., Xu, K. and Watanabe, M. (2002) 'Flood disaster monitoring and evaluation in china', *Environmental Hazards,* 4(2), pp. 33–43. doi: 10.3763/ehaz.2002.0404.

Zou, Q., Zhou, J., Zhou, C., Song, L. and Guo, J. (2013) ‘Comprehensive flood risk assessment based on set pair analysis-variable fuzzy sets model and fuzzy AHP’, *Stochastic Environmental Research and Risk Assessment*, 27(2), pp. 525–546. doi: 10.1007/s00477-012-0598-5.