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Precipitation and Rainwater pH Spatial Distribution in Bahía Blanca and Tandil, Argentina

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Abstract: While the occurrence of rainfall is a regional scale phenomenon, cities influence on precipitation spatial distribution patterns and their characteristics. These influences had been studied for a very long time especially in the Northern Hemisphere. Tandil and Bahía Blanca are middle cities of Argentina located in the south of Buenos Aires province. Both present continental template climate. The aim of this research is to analyze the spatial distribution patterns of precipitation and the rainwater pH values for the period October 2010-September 2011 in Tandil and Bahía Blanca. Gauge rain nets were installed in both cities. In each event of precipitation, amount and pH values were collected. Isohyets plotting were included in the thematic cartography that was made using ArcGis 9.3® software. Although natural rains are generally considered as being weakly acid, the rainwater pH measurements demonstrated that in both cities the rain is alkaline. Regarding to the spatial distribution of the precipitation amounts, the isohyets of the annual records showed that the highest values were registered in areas of higher elevation while the lowest values were presented in both cities downtown, where the high buildings are concentrated.

Key words: Precipitation, pH, Bahía Blanca, Tandil.

1. Introduction

Of all meteorological elements in the urban environment, precipitation and its variability are the most difficult aspects to explain. There is a very large literature about the evidence for increases of precipitation in urban areas in comparison with rural environments but not so for the city itself considering the influence of its site conditions. The three main contributing causes for modification and augmentation of precipitation are: the heat island, the obstacle effect and the pollution products [1]. Regarding the chemical characteristics of precipitation, to know rainwater pH helps to identify if it can contribute to the acidification of water, soil and even to the corrosion of buildings and monuments. The pH measures the concentration of hydrogen ions, indicating acidity, neutrality or alkalinity of a solution. Unpolluted, pure rainwater is slightly acidic due to absorption of the atmospheric CO_2. The pH of water in equilibrium with atmospheric CO_2 is approximately 5.6 and hence only rains events with pH lower than this value are classified as “acid rain”. Rainwater pH varies between 3 and 9 with samples generally having values between pH 4 and 6 [2]. The origin of the acidity is the presence of SO_2 (sulfur oxides), NO_x (nitrogen oxides) and CO_2 (carbon oxides) that once combined with water they form H_2SO_4 (sulfuric acid), HNO_3 (nitric acid) and H_2CO_3 (carbonic acid). Compounds such as SO_2 and NO_x may have a natural or anthropogenic origin.

Natural sources include volcanic emissions, biomass, microbial activity, among others. Anthropogenic sources correspond to emissions from stationary points such as fuel industries while mobile

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ones are represented by the releases from the vehicles combustion [3]. The term “acid rain” was first used in 1850 in England as a result of the air chemistry investigation due to the growth of industrial activity [4]. In the United States since 1920 the chemical composition of precipitation began to be studied while in the northeastern sector of the country the low pH values indicated the occurrence of acid rain [5]. In Mexico there have been numerous studies linking emissions of polluting gases with low pH values that were registered in urban centers [3, 4, 6-8].

However, there are also cases where the pH values correspond to neutral rain water (pH = 7) or alkaline (pH > 7). Generally, this condition is due to the presence of suspended dust basic condition which neutralizes the acidity, as it happens in regions of calcareous soils [2]. In India inland cities it was identified that the rain water is alkaline, while the pH samples that were taken in the Indian Ocean indicated acid rain [9]. In Argentina the researches focused on the subject are rather little. In Buenos Aires a survey conducted by the local government in 2009 reported pH values that indicated the occurrence of acid rain. Otherwise in the city of Tandil, during 2008-2009 there were no precipitation events with pH values lower than 5.6 while the maximums reached about 9 [10]. In the city of Bahia Blanca the pH rainwater was analyzed from 1984 to 1985 and the mean values ranged between 6.5 and 7.2 which indicated that the rainwater was characterized by its neutral condition. Moreover, values greater than 7.6 showed occurrence of rain alkaline [11, 12]. Since then there was a significant growth of the industrial sector commanded by the installation of petrochemical factories. This chemical industry in Bahía Blanca and the mining activity in Tandil caused concern about the current pH rainwater in these cities. That is why this work analyzes precipitation spatial distribution and rainwater pH values in two middle cities with continental template climate in the pampas plain, Argentina.

2. Study Area

Bahía Blanca city (38 43' S-62°15' W) has a population of 291.327 [13] and it is the most important city of the southwest of Buenos Aires province (Fig. 1). It is located 5 km away from the cost shore and in the lower basin of the Napostá creek, which cross into the city. The altitude range is about 80 m from the shore area to the highest point of the city which corresponds to a 76 m terrace. From a production based mainly on agricultural and livestock, the city has established itself as an urban supplier of goods and services the surrounding area. Its geographical position and availability of raw materials make it important settlement agribusiness and petrochemical sector.

Tandil city (37°19' S, 59°07' W) is located in the south centre of Buenos Aires province (Fig. 1). It is surrounding by Tandilia Hills from south to west and has an altitude range of 300 m, descending from southwest to northeast. It has a population of 116.916 [13] and a diversified economy with representation from different economic sectors: applied rock extraction (until 2012), food processing and metalworking, financial services, schools of all levels, businesses, health centers and tourism in recent years. It is connected with major regional and national centers for national and provincial routes.

Both cities are located in the template climate with continental’s characteristics [14, 10]. They present important annual differences in their temperature and precipitation. Moreover, both cities are influenced by cold and warm frontal advances from High Pressure Cells of Pacific and Atlantic oceans. The spatial distribution of temperature and precipitation are different by the degradation of the climate to an arid region from east to west. Regarding the soil characteristics, the pampas plain soils are mainly composed of sand, important amounts of $CaCO_3$ concentrations and little organic matter. Also, they are heavily affected by eolic erosion, mostly by the strong

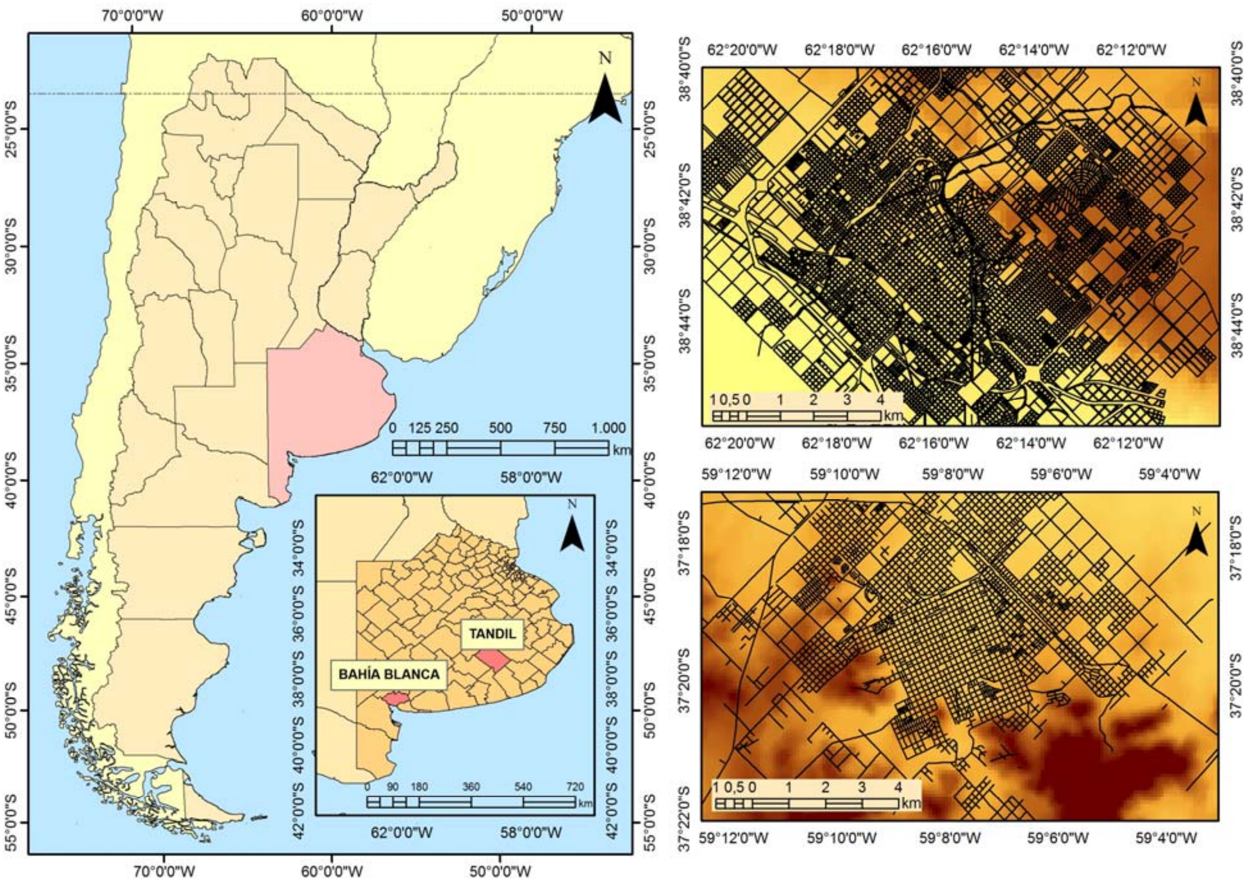

Fig. 1 Study area location and cities topographic features.

West winds which are very usual in this region [12].

3. Data and Methods

Synoptic charts from the National Weather Service were used to analyse the weather conditions. Both urban areas have rain gauges network to study the precipitation spatial distribution: Bahía Blanca had 14 but 11 of them measured pH and Tandil had 10.

The amounts of precipitation were registered and rainwater pH was measured with digital pH testers. Statistics were made with this data. Thematic maps were elaborated with the annual rainfall values for each measuring station using the IDW (inverse distance weight) interpolation method with ArcGis 9.3. Although Kriging is highly used to estimate rainfall distribution, it was applied the IDW method since it also presents very good results [15-17]. Some authors have concluded that this technique also has a good predictive skill [18-20] and is better to represent a rainfall behavior with significant differences in the extreme values, as it is the case of the cumulative amounts series.

In the study sites, the rain gauges networks were planned to cover the city different site conditions. Due to the possibility of their installation it was achieved a sampling density of 14 rain gauges over 100 km^2 in Bahía Blanca and 10 rain gauges over 61 km^2 in Tandil. In Bahía Blanca, the central area with denser edification is covered by the sampling station number 1 and the city park area corresponds to the sampling station number 2. While rain gauges number 3 and 13 were located at higher altitudes, 7 and 8 were in lower terrains near the shore. Tandil center is represented between sampling stations 7 and 8 and rain gauge 6 is located in the highest area of the city. The others were located taking in account the different land cover conditions.

4. Analysis of the Precipitation Amounts

4.1 Precipitation Amount and Spatial Distribution in Bahia Blanca

The analysis of the cumulative rainfall amounts for the study period shows a difference of 97.6 mm between the highest and the lowest record. The first one is in the south of the city. This area, due to its location, is the most exposed to frontal systems approaches from the south-eastern quadrant. Another cell of higher values is identified in the north area, the one of the highest altitude of the city. The lowest records are registered by the stations in the central area, where the buildings are located (Fig. 2).

In Fig. 3 it is shown that summer has the biggest difference between the highest and lowest amounts. While in the rain gauge 8 there were collected 163.8 mm, the lowest cumulative amount during summer (117 mm) was registered in the sampling station 2. It is important to consider that in this season the rain cell storm events are more frequent. With regard to spring, the highest amount (173.5 mm) was registered in the area of most altitude (rain-gauge 3) while in the city centre there was registered the minimum value (135.8 mm). Conversely, the difference between the extreme values in the winter season was less significant. The highest record was 21.5 mm in rain gauge 3 while the rain-gauge 12 had the lowest register: 16 mm. During fall, in rain gauge 3 there were registered 99 mm as a maximum and 73 mm in rain-gauge 12.

4.2 Precipitation Amount and Spatial Distribution in Tandil

During the study period the annual cumulative rainfall shows difference of 136 mm between the areas of Tandil city. The Fig. 4 shows the spatial distribution of the annual precipitation, the higher values are concentrated in the northwest of the city and west from the centre, the first one is located outside the city boundaries and the second one is located in the highest area. Meanwhile the lowest values are recorded in the city centre and in the north.

It is important to consider that in this area there is the highest building concentration of the city and both

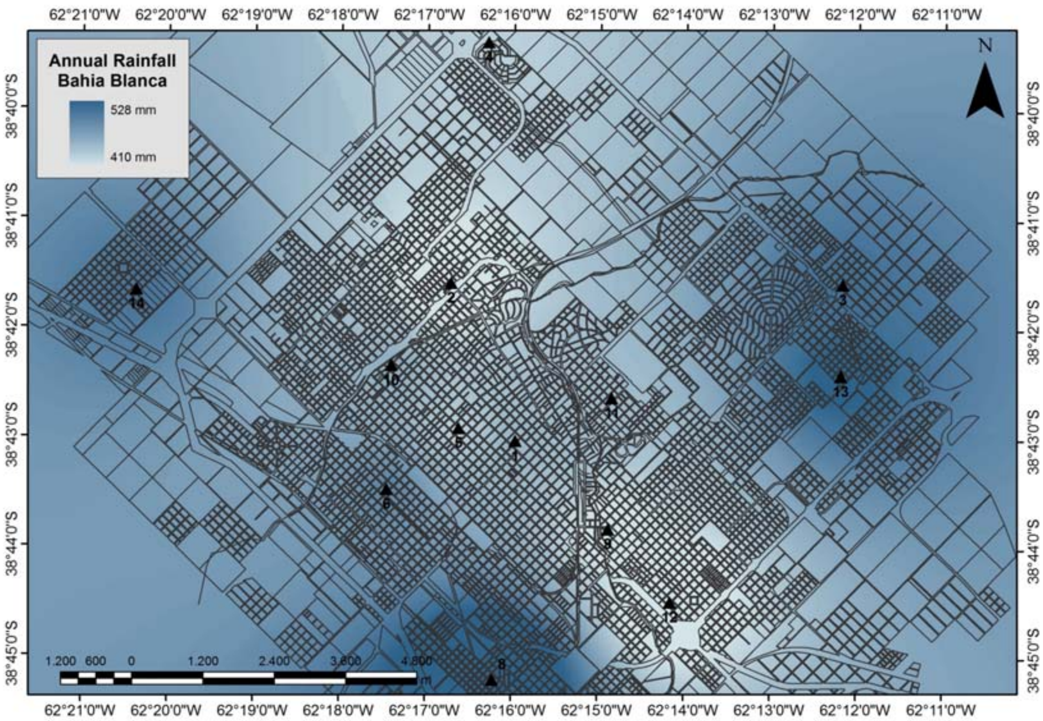

Fig. 2 Location of the sampling stations and total rainfall for the period October 2010-September 2011, Bahía Blanca.

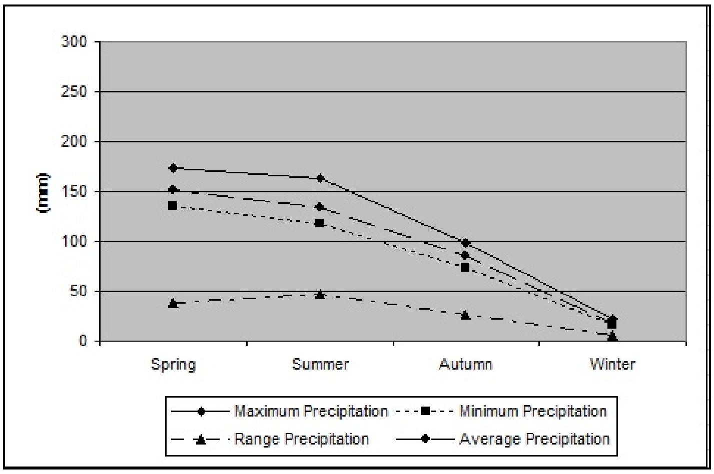

Fig. 3 Seasonal rainfall in Bahia Blanca. October 2010-September 2011.

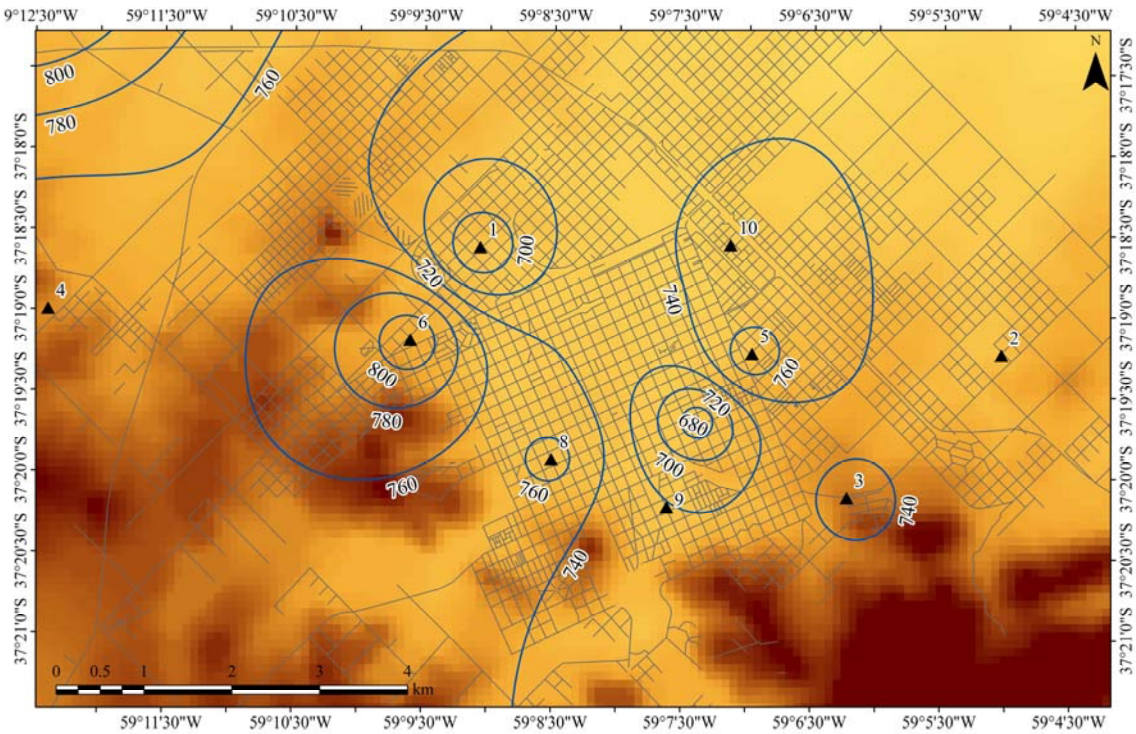

Fig. 4 Location of the sampling stations and total rainfall for the period October 2010-September 2011, Tandil.

sites are placed downwind. The seasonal analysis shows that autumn and winter present the lowest values in average precipitation and minor differences (Fig. 5). Spring presents the biggest differences between maximum and minimum precipitation: 31 mm and the majority of the precipitation events. Summer has the highest cumulative rainfall: 257 mm and in fewer events. All the seasons present higher values in the surrounding areas and lowest in the city centre.

5. Analysis of the Rainwater pH

5.1 Rainwater pH Values in Bahía Blanca

The mean pH values for the 11 sampling stations are presented in Table 1. From October 2010 to September 2011 mean pH values for all sites range between 7.87 and 8.55. The maximum values for each site are larger or equal to 8.0, indicating the presence of alkaline precipitation. Regarding to the spatial distribution of mean pH values, the higher ones are

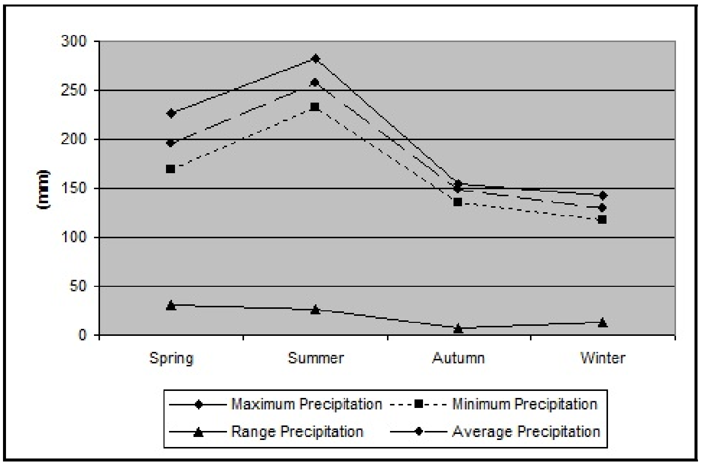

Fig. 5 Seasonal rainfall in Tandil (October 2010-September 2011).

Table 1 pH values obtained in Bahía Blanca sampling stations (October 2010-September 2011).

Station	Mean pH value	Maximun absolute value	Minimun absolute value
1	7.87	8.80	7.02
2	7.92	8.32	7.32
3	8.08	9.20	6.95
4	8.55	9.70	8.11
5	8.04	8.62	7.8
6	8.11	9.00	7.66
7	7.91	9.18	7.01
8	7.90	8.56	7.12
9	8.08	9.08	7
10	7.58	8.31	7.23
11	8.10	8.90	7.23

located in the north area, from the east to the west. It should be mentioned the presence of the 76 m terrace that occupies the north, northeast and eastern borders of the city which is constituted of sediments with high concentration of $CaCO_3$. On the other hand, the lower mean pH values extend from the south to the city downtown. One possible reason of this decline may be the dispersion of contaminants from the industrial park over the south and southwestern sectors of the city.

5.2 Rainwater pH Values in Tandil

The pH mean values in Tandil range between 7.27 and 7.07 (Table 2). The maximum absolute values are higher than 8 and there are located in the northwest of the city the same area where the maximum rainfall

Table 2 pH values obtained in Tandil sampling stations (October 2010-September 2011).

Station	Mean pH value	Maximun absolute value	Minimun absolute value
1	7.07	7.66	6.58
2	7.16	7.61	6.70
3	7.27	7.73	6.88
4	7.20	8.00	6.40
5	7.16	7.82	6.55
6	7.16	8.04	6.35
7	7.15	7.67	6.79
8	7.25	7.80	6.38
9	7.14	7.93	6.70
10	7.12	7.77	6.35

values were placed. This area also presents the most important differences between maximum and minimum absolute values. The pH minimum mean values are located in the north and east of the city where the most important industries are placed. The downtown has low values in relation with its surroundings.

6. Conclusion

Regarding the spatial distribution patterns of precipitation for the period October 2010-September 2011, both cities present the highest precipitation values in the highest areas (north-northeast in Bahía Blanca and southeast-south in Tandil). On the other hand, the lowest ones were registered in the central area where the high buildings are concentrated. The possible reason of that maximum rainfall do not occur in the centre of the cities might be the obstacle effect produced by the buildings, which causes larger rainfall amounts drop before reaching this area depending on the wind direction.

The pH values indicated that in both cities the rainfall is alkaline. As it was mentioned, the carbonate-rich soils contribute to raise pH values and the typical West winds that travel over the pampas soil, introduce large amounts of alkaline cations to the atmosphere.

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