DEVELOPMENT OF A PRELIMINARY GENERAL MODEL OF OCCURRENCE OF ALKALI SILICA AGGREGATE REACTION IN CONCRETE STRUCTURES

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Abstract

Main research conducted on the alkali - silica reaction (ASR) have been focused on the modelling of the chemical reaction kinetics, diffusion processes, potential expansion and its subsequent influence on the mechanical properties of concrete. It is emphasized that most of these models consider that the concrete has been already affected by the reaction and therefore they do not provide tools to determine the likelihood that the reaction occurs.

Based on the above scenario, this paper presents the results of a research in which a preliminary model of occurrence of ASR was developed by using geographical information system (GIS) tools, establishing a map of susceptibility of occurrence for the area near Bogota (Colombia). In order to carry out this research, a review of the technical literature on environmental and geographical parameters such as relative humidity and temperature, location of potentially reactive aggregates and cements with high alkali content was conducted.

Keywords: modelling, occurrence, GIS maps, alkali - silica reaction

1 INTRODUCTION

Stanton observed and first diagnosed alkali - silica reaction (ASR) in concrete in 1940, and ever since the phenomenon has been deeply studied worldwide [1]. Progress was rapidly made in a variety of approaches ranging from the identification of reactive components of the aggregates and mineralogical features involved in the chemical reaction to the experimental assessment of the phenomenon. Currently the main ASR research topics are focusing on the mechanisms that control the reaction, performance testing for detecting potential reactivity of aggregates and concretes (especially through the use of SCMs), evaluation of existing concrete structures and model generation [2].

It is important to highlight that ASR models studied by a number of researchers [3] are primarily focused on modelling the kinetics of the chemical reaction and the diffusion processes, which determines the degree of reaction and the potential expansion, as well as its subsequent influence on the mechanical properties of concrete. They aim at modelling the mechanisms of distress induced by the expansion of affected concrete. In other words, most of the existing models have been developed under the premise that the concrete has already been affected by the ASR and do not provide solutions to either prevent the chemical reaction or to retrofit affected structures once ASR takes place.

Under this perspective, it is a priority to propose, test and demonstrate a model of occurrence of the reaction for a proper use of materials and financial resources.

On the other hand, ASR is considered as a mechanism that causes damage and involves a risk, similar to what happens with natural events such as landslides, earthquakes or floods [4]. In this context, one of the most important preventive measures that can be implemented is the development a multi-susceptibility mapping through a multi-criteria assessment through the use of geographical information systems (GIS) tools, which identify geographical areas susceptible to ASR damage.

The susceptibility term must be interpreted as the likelihood of occurrence of a distress mechanism, which in this case is treated by ASR occurrence. Therefore, the susceptibility mapping was made for an area near Bogotá "Sabana de Bogotá" - Colombia (Figure 1), representing the locations based on the likelihood of ASR occurrence. The higher the level of susceptibility, the higher the probability of ASR occurrence.

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Overview of the Sabana de Bogotá

Sabana de Bogota is located in the Department of Cundinamarca and is part of the Eastern Mountains of the Republic of Colombia. Physiographically is formed by a plateau or flat surface with an average height of 2,600 m.s.n.m, which is surrounded by mountains with heights up to 3.600 m.s.n.m. One fifth of the Colombian population lives in this area. It has an important infrastructure development, adequate access roads, industrial complexes and airports.

Geologically, Sabana de Bogota consists of a variety of rocks ranging in age from Late Cretaceous to Quaternary. Generally, there are sandstone deposits with chert, siltstones, claystones type siliceous rock collations and at some locations coal seams. There are also lacustrine, fluvial and fluvial-glacier deposits in the center and on the edges of the Sabana during the last 3.5 million years. There are long synclines along the large and long valleys and narrow anticlines on the mountains among these, with reverse faults bordering many of the anticlines, as well as normal and course faults, which are structures related to the lifting of the Eastern Mountains that affect most of the rocks in the area.

Regarding weather conditions, it varies according to altitude differences. The temperature is lower at higher altitudes, ranging from 8 to 13°C. In the center of Sabana the temperature lies in between 13 to 14°C, and at lower altitudes the temperature increases up to values ranging from 14 to 28°C. The distribution of the relative humidity is according to concentration points determined by topography. The upper area shows values higher than 86%, the central part presents values close to 78% whereas the values of the lower parts are around 68%.

2 METODOLOGY

The methodology used in this research was based on two essential concepts, the first one was the selection and management of variables and models related with ASR, and the second one was the application of Geographic Information Systems (GIS) to the model selected in the first phase. The assessment of the components to be included in the susceptibility analysis was processed using the specialized GIS software called ILWIS, which has free access. This mathematical procedure is supported by spatial and non-spatial data, through the assignment of attributes to each of the variables included in the assessment. Thus, the interaction of the components allows to determine the susceptibility classification mapping through multi-criteria assessment.

Moreover, the internal operations of SIG permit to know numerically which sector of the pilot zone (Sabana de Bogotá) has a higher or lower susceptibility in which the expansive phenomenon takes place in the concrete structures.

3 PROCEDURE FOR DEVELOPING THE SUSCEPTIBILITY MAP

The procedure conducted for developing the susceptibility map of occurrence of RAS is described below.

Initial stage – Required information

This stage consists of creating a data inventory. It should be noted that the GISs are built with external information, which in turn must be very precise in order to achieve reliable and accurate results. For the development of the susceptibility mapping, data of the main determining factors on ASR occurrence such as: geology (source of aggregates), relative humidity and temperature are compiled.

It is noteworthy that the analysis of the alkali content (sodium equivalent) for cements is a very important factors in ASR occurrence; however, past experiments have demonstrated that local Colombian commercial cements have a high alkali content [5] Therefore, in this research, this factor was classified as a constant, and thus it was not included in the susceptibility model.

Second Stage –cartographic model and digitization

It consists of building a sequence in the creation of the data that will be provided to the GIS. As a first step, it is proceeded to digitize all data collected through mapping to RASTER models with format TIF or IMG, generation of database tables and after obtaining the data, it is proceeded to build a cartographic model

Third Stage – Construction of the information layers

The most important information layers to create the susceptibility mapping are shown hereafter (Figure 2).

- Geology: Detailing the geographical distribution of geological units present in the area;

- Relative humidity (%): Detailing the spatial distribution of relative humidity divided into four categories (Table 1).
- Temperature (°C): Detailing the spatial distribution of relative temperature divided into two categories (Table 2).

Fourth Stage – weighting geological units "map of reactive aggregates"

Different attributes of geological units were assigned with a weighing factor, considering their importance with respect to the presence of geological units of minerals, rocks and other substances potentially ASR reactive.

The classification proposed by RILEM [6] was used. CLASS I (reactivity with alkali is unlikely to happen: they do not contain detectable amounts of reactive components described in this standard), CLASS II (they cannot be classified definitively as class I or class III) and CLASS III (aggregates samples containing components classified as potential sources, and with sufficient amounts, to trigger ASR damage in concrete). Figure 3 shows the potential reactive aggregates found in Sabana de Bogotá.

It should be noted that under Figure 3 scheme, the geographic location where the aggregates are extracted or exploited from, is relatively close to the centre of consumption or important civil works.

Fifth Stage – Assignment of "weights".

In the susceptibility analysis it is considered that each of the layers of information used has a different level of importance to explain ASR occurrence. In order to state such differences, it is required to assign "weighing factors" to each of the mapping used, by using heuristic method, which is actually based on categorizing and weighing factors according to their expected influence in ASR generation. It is clear that the heuristic analysis introduces a degree of subjectivity that disables the comparison among documents produced by different researchers. Therefore, the weighing factors were assigned in the tables connected to the mapping of reactive aggregates, humidity and temperature in raster data type. A table with a weight column is created showing the weighing factors used for the different classes proposed (Table 3).

Sixth Stage – Rename parameter maps to weighing maps.

The combination of each mapping parameter along with the weighing factors resulting from the table created in the previous stage is called renumbering. In this way, the mapping classes are changed to mapping values with their respectives weighting factors (Figure 4).

Seventh Stage – Susceptibility index calculation

After obtaining the susceptibility mapping, a susceptibility index is finally obtained through a weighted linear summation [7] of the different weighing factors of the classes, according to the following expression:

$$I = \sum_{j=1}^{n} w_j x_{ij}$$

Where I is the susceptibility index; w_j is the weighing factor *j*; x_{ij} is the weighing factor of the class *i* of the parameter *j* (Figure 5).

Finally, indexes are classified into a few equal intervals of susceptibility, which are standardized and of intuitive interpretation. The result of this weighted linear summation is the susceptibility mapping by multi-criteria assessment (Figure 6).

4 RESULTS AND DISCUSSION

According to the obtained map, 35.68% of the territory of Sabana de Bogotá presents susceptibility values of ASR occurrence, ranging from very high to high, 38.37% ranges from moderately high to moderate susceptibility, 22.41% ranges from moderately low to low susceptibility and 3.54% presents very low or no susceptibility. Table 4 details the results found.

The final susceptibility mapping of ASR occurrence for Sabana de Bogota allows to differentiate clearly the existence of two zones: very high to moderate susceptibility values prevailing in the centre; and low or zero susceptibility values prevailing on the outer locations. This division is influenced by the distribution of aggregates lithotypes.

5 CONCLUSIONS

The conducted research using heuristic methods corresponds to a first approach to the modelling of ASR occurrence. The creation of a susceptibility mapping is not the final step; it is a tool that must be used to take decisions during a planning process. This particular research project shows that 36% of Sabana de Bogota has a high-risk of ASR occurrence in concrete structures, mainly in the areas adjacent to Bogota.

In order to refine the obtained information, it is necessary to conduct a laboratory campaign with Colombian aggregates potentially susceptible to the ASR and with Colombian cements, such as the accelerated mortar bar test (ASTM C 1260) and the concrete prisms test (ASTM C 1293).

Although the efforts of the scientific community on modelling ASR chemical reaction, models aimed at predicting ASR occurrence are very limited. With this vision, proposing, testing and demonstrating a statistical type model for the occurrence of the reaction is a necessity from the point of view of prevention and decision-making

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TABLE 1. Relative Humidity Ranges.

Category	*Humidity*
Low	<60%
Moderate	60% – 75%
High	75% – 90%
Very High	>90%

TABLE 2. Temperature Ranges.

Category	*Temperature*
Low	<15°C
High	>15°C

TABLE 3. Weighing Values “Weights”.

Attribute	*Classification*	*Weight*
Potentially reactive aggregates	Class I	1
	Class II	2
	Class III	3
Humidity	Low	1
	Moderate	2
	High	3
	Very High	3
Temperature	Low	1
	High	3

TABLE 4. Percentage of susceptibility levels of occurrence of RAS in the Sabana de Bogotá.

Susceptibility	*Area (Km^2)*	*%*
Very Low	150.5	3.5
Low	202.2	4.8
Moderate Low	751.4	17.7
Moderate	718.1	16.9
Moderate High	914.3	21.5
High	1151.5	27.1
Very High	366.3	8.6

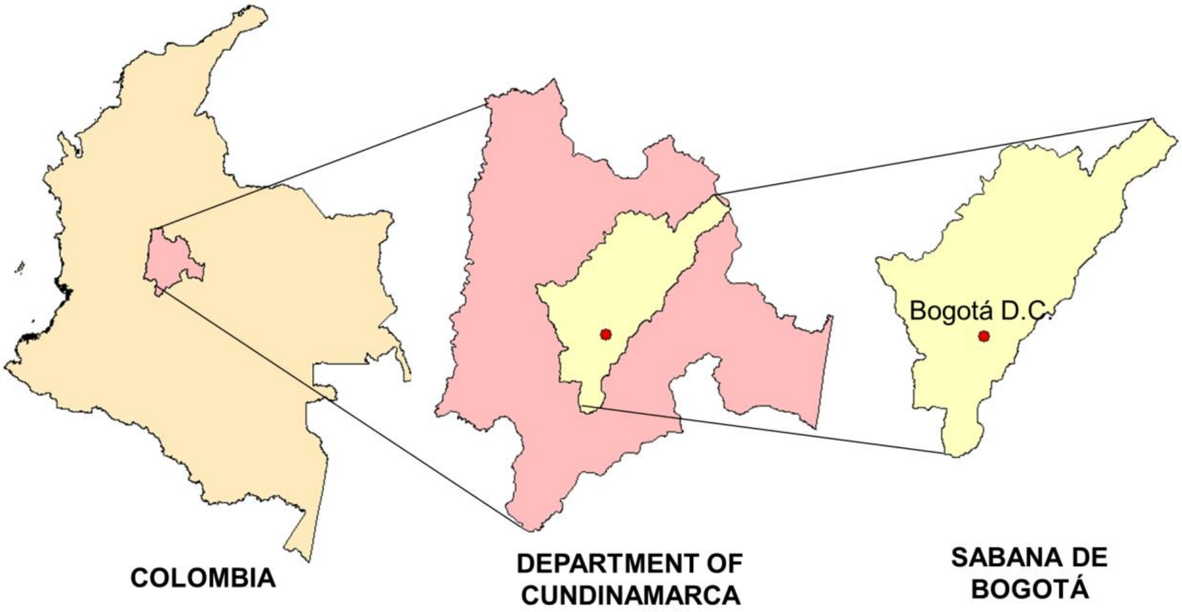

FIGURE 1: Location of the study area.

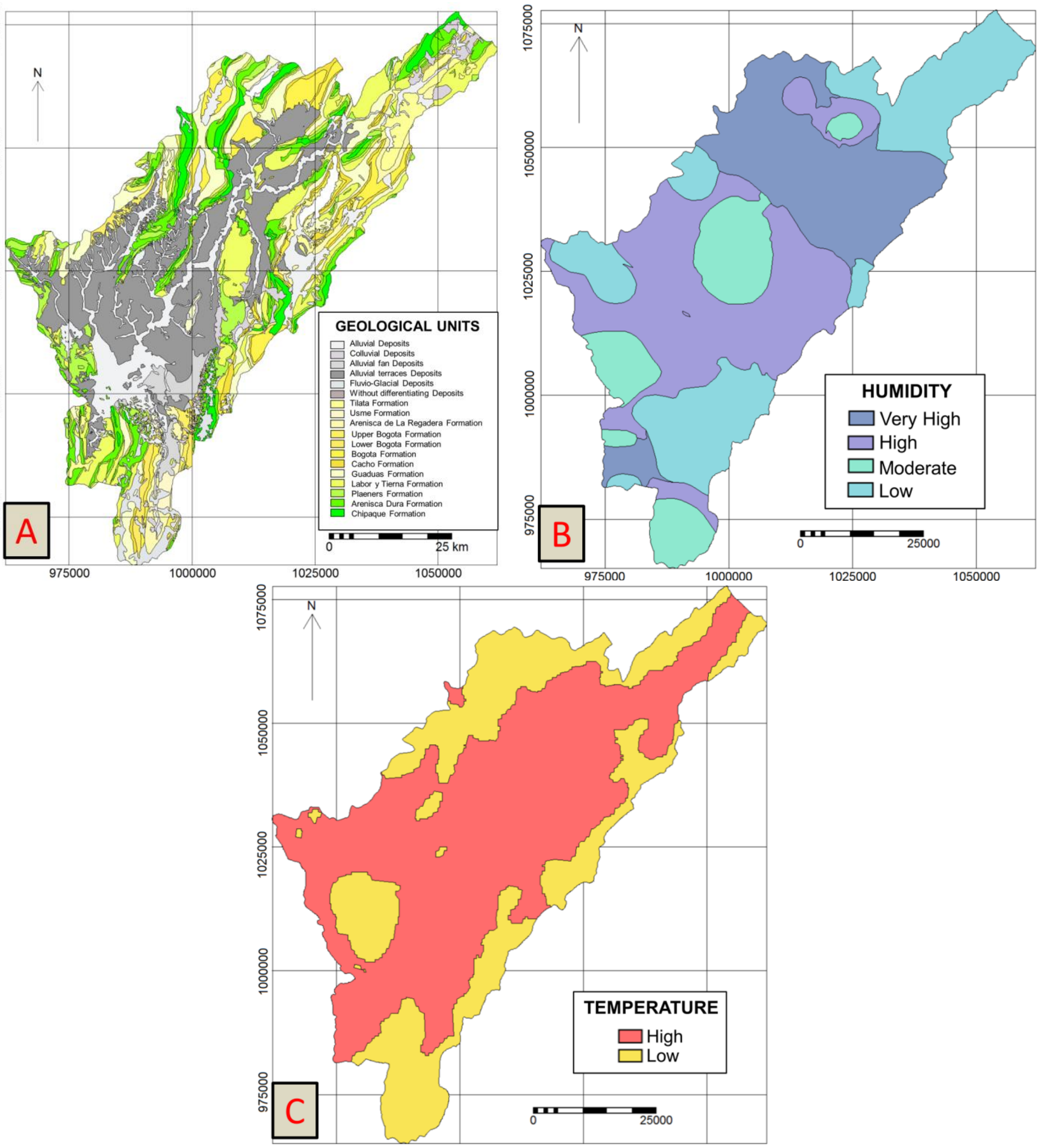

FIGURE 2: Information layers: a) Geological Map, b) Humidity Map, c) Temperature Map.

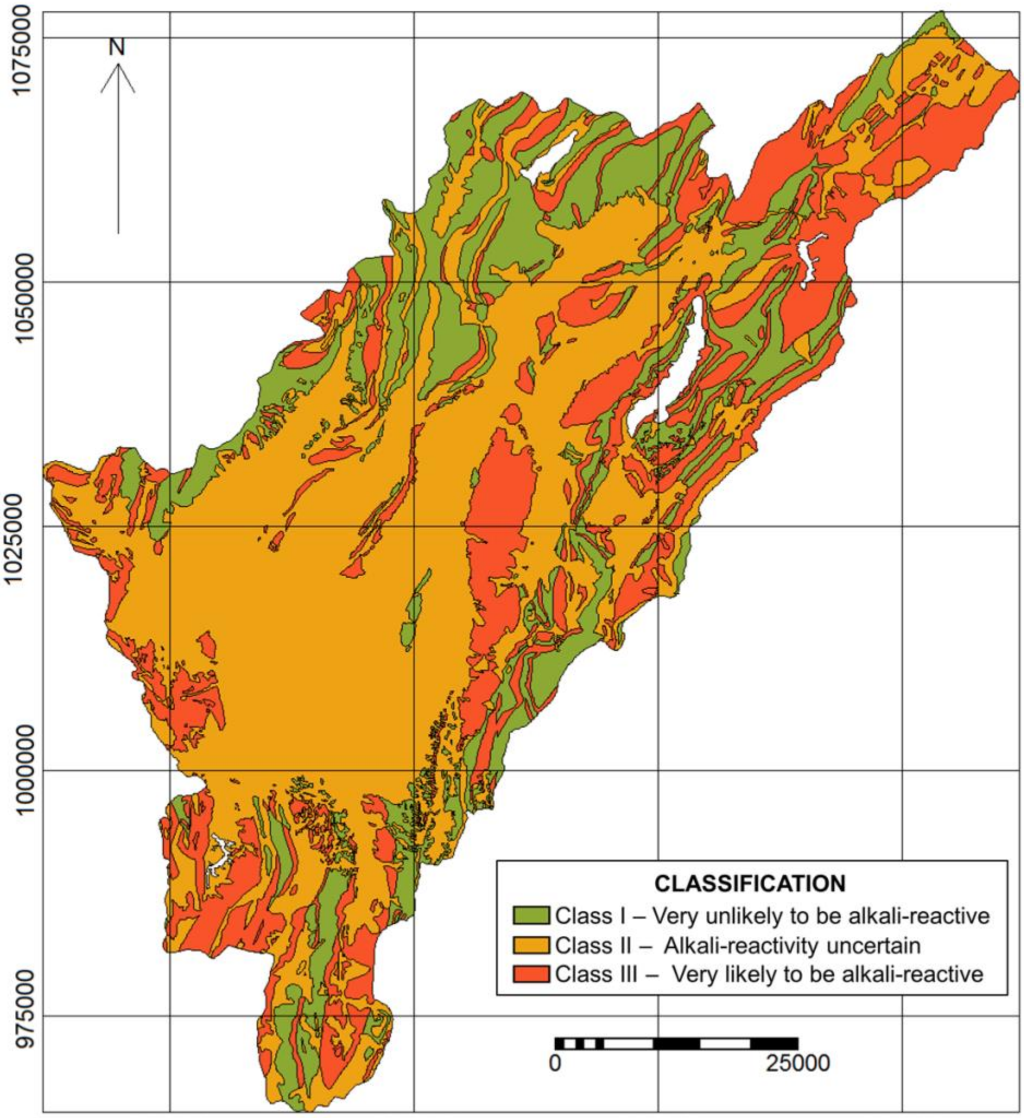

FIGURE 3: Potentially reactive aggregates in the Sabana de Bogotá.

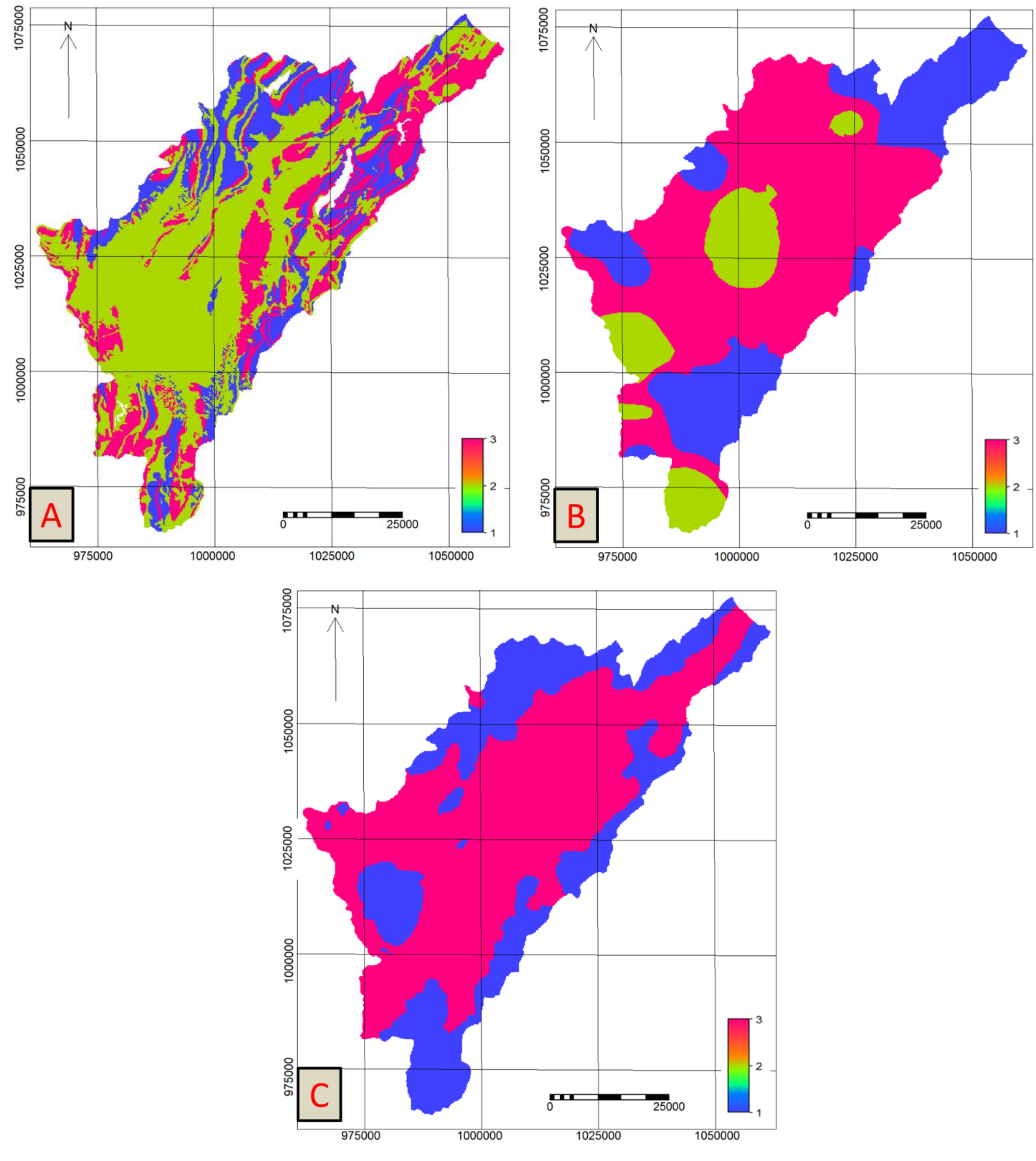

FIGURE 4: Weighing Maps: a) Potentially reactive aggregates, b) Humidity, c) Temperature.

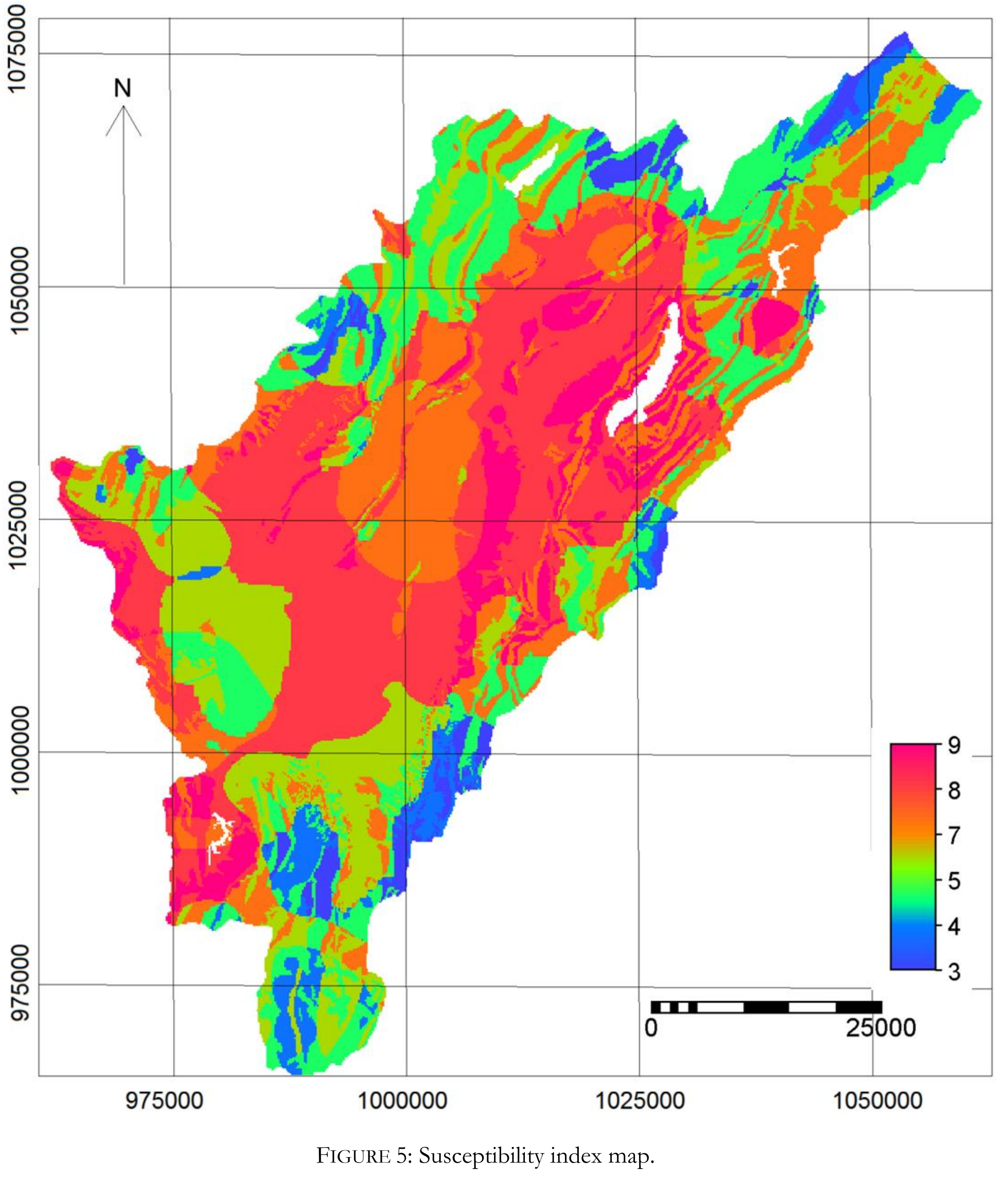

FIGURE 5: Susceptibility index map.

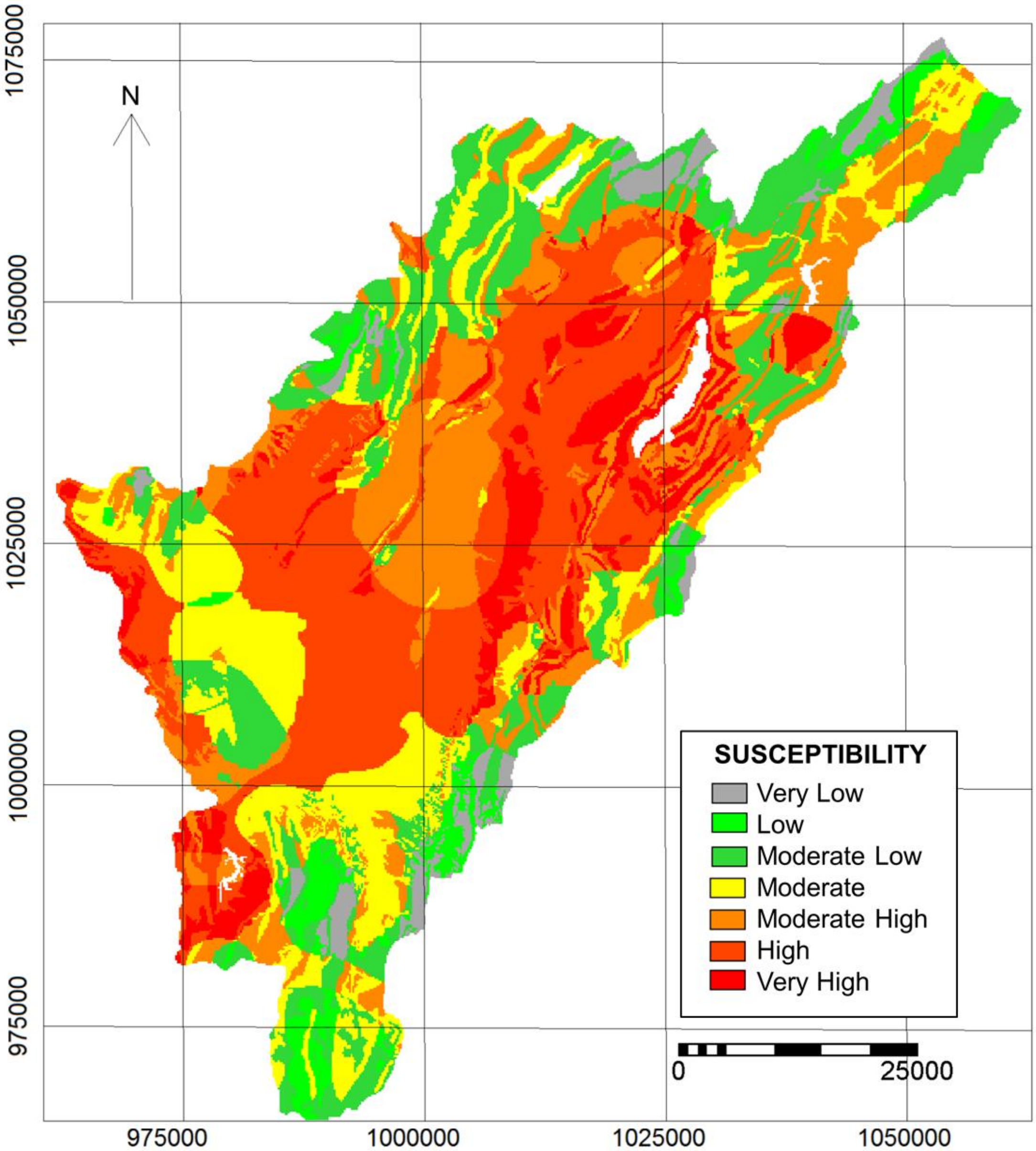

FIGURE 6: Susceptibility Map of occurrence of alkali - silica reaction of the Sabana de Bogotá.