Calibration of water quality index (WQI) based on Resolution nº 357/2005 of the Environment National Council (CONAMA)

Calibração do índice de qualidade da água (IQA) com base na Resolução nº 357/2005 do Conselho Nacional do Meio Ambiente (CONAMA)

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Abstract: Environmental monitoring studies in the Hydrographical Basin of Pardo River, RS, Brazil, in the time series from 2007 to 2009, showed no agreement between the water quality evaluation obtained through the Water Quality Index (WQI - NSF), which ranged from "regular" to "good", and the Environment National Council (CONAMA) Resolution 357/2005, which was bad ("class 4"), highlighting as critical variables for this classification the thermotolerant coliforms and the phosphate concentration, indicating process of water eutrophication, related to the large amount of nutrients and organic load from domestic sewage and excess fertilizers used in agriculture. **Aim**: This research aimed to calibrate the WQI - NSF for the Pardo River Basin, based on the CONAMA Resolution 357/2005. **Methods**: Using the database (2007 a 2009) from the Laboratory of Limnology of the University of Santa Cruz do Sul (UNISC), RS, corresponding to the environmental monitoring studies realized in the Hydrographical Basin of Pardo River new weights of the relative importance of the variables used to calculate the WQI were attributed, by means of principal component analysis. **Results**: There was a significant agreement between the results of the assessment of water quality using the CONAMA Resolution 357/2005 and the new WQI calibrated. **Conclusion:** The results certify the use of the calibrated WQI in environmental monitoring programs in lotic systems belonging to Guaíba Hydrographical Basin, RS.

Keywords: Water Quality Index (WQI), eutrophication, Hydrographical Basin of Pardo River, Resolution 357/2005 of CONAMA.

Resumo: Estudos de monitoramento ambiental na Bacia Hidrográfica do Rio Pardo, RS, Brasil, na série temporal 2007 a 2009, mostraram que não há concordância entre a avaliação da qualidade da água obtida através do Índice da Qualidade da Água (IQA - NSF), que oscilou entre boa e regular, e da Resolução 357/2005 do Conselho Nacional de Meio Ambiente (CONAMA), que foi ruim (classe 4), destacando como variáveis críticas para esta classificação os coliformes termotolerantes e a concentração de fosfato, indicando processos de eutrofização da água, relacionados ao aporte de nutrientes e carga orgânica oriundos de esgotos domésticos e de fertilizantes utilizados na agricultura. **Objetivo:** A presente pesquisa objetivou calibrar o IQA - NSF para a Bacia Hidrográfica do Rio Pardo, baseando-se na Resolução 357/2005 do CONAMA. **Metodologia**: Usando o banco de dados (2007 a 2009) do Laboratório de Limnologia da Universidade de Santa Cruz do Sul (UNISC), RS, correspondente aos estudos de monitoramento ambiental realizados na Bacia Hidrográfica do Rio Pardo, novos pesos da importância relativa das variáveis usadas para calcular o IQA foram atribuídos, por meio de análise de componentes principais. **Resultados**: Houve uma significativa concordância entre os resultados da avaliação da qualidade da água utilizando a Resolução 357/2005 do CONAMA e o novo IQA calibrado. **Conclusão**: Os resultados obtidos certificam o uso do IQA calibrado em programas de monitoramento ambiental em sistemas lóticos da Bacia Hidrográfica do Guaíba, RS.

Palavras-chave: Índice de Qualidade da Água (IQA), eutrofização, Bacia Hidrográfica do Rio Pardo, RS, Resolução 357/2005 do CONAMA.

1. Introduction

When it comes to environmental management programs, the monitoring of water quality stands out as an important instrument to manage the water resources once that enables to increase its prognostic capacity, aiding managerial decision-making and offering conditions to predict risk situations (Tundisi, 2000). However, in Brazil, the information about water quality for many hydrographical basins is still not enough or inexistent, according to the National Agency of Waters (ANA, 2005).

Considering the physical and chemical methods proposed to evaluate water quality in Brazil, the most widely used one is the Water Quality Index (WQI), originally developed by the National Sanitation Foundation in the United States (NSF, 2010). The index was adapted to Brazilian waters by several entities, for instance, the Sinos River Basin Monitoring Committee located in the state of Rio Grande do Sul, RS (COMITESINOS, 1993). The WQI was created after an opinion poll formed by many experts from the environmental sector. Each specialist had selected relevant variables to evaluate water quality. The variables were: thermotolerant coliforms (TTC), biochemical oxygen demand (BOD), phosphate (PO_4^{-3}), nitrate (NO_3^-), dissolved oxygen (DO), hydrogenionic potential (pH), total dissolved solids (TDS), temperature (T) and turbidity (TU). The definition of the relative quality for each variable was established by variation curves that are able to relate the respective value of each variable to a grade, ranging from 0 to 100, in which 100 stands for the best quality (NSF, 2010).

Another guiding tool used to evaluate water quality is the CONAMA Resolution 357/2005 by the Environment National Council (Brasil, 2005), which establishes classification about the water bodies in Brazil to be framed, providing environmental guidelines. This resolution categorizes the fresh waters into five different classes according to its usage; ranging from "very noble uses", such as drinking water, up to lower standards, such as navigation and landscaping. Therefore, for each class of water usage, there is a series of physical, chemical and microbiologic permissible maximum values that must be addressed.

Under this context, the Laboratory of Limnology of the Santa Cruz do Sul University (UNISC), RS, has been frequently performing environmental monitoring at the Hydrographical Basin of Pardo River and its surroundings. In the time series from 2007 to 2009, the monitoring had

showed a significant discrepancy between results of the assessment of water quality using WQI and CONAMA Resolution 357/2005. These differences could be explained because the WQI presented low weight of relative importance to some variables in the calculus of its index, such as thermotolerant coliforms and phosphate, when applied to the Hydrographical Basin of Pardo River, compared to CONAMA Resolution 357/2005, which identified these variables as the most important ones, once it characterize the main environmental problem detected at the Basin; process of eutrophication. Other environmental monitoring studies have emphasized the particularities found in the southern Brazilian lotic system, such as those developed on the hydric systems at Guaiba's Hydrographical Region, which includes the water bodies from Pardo River Basin, having showed evident signs of eutrophication (Hermany et al., 2006; Lobo et al., 2004 a, b, c, 2010; Salomoni et al., 2006, 2011; Wetzel et al., 2002).

In this context, the current research aimed to calibrate the WQI for the Pardo River Basin, based on CONAMA Resolution 357/2005, using the environmental variables database in the time series 2007 to 2009, obtained from the environmental monitoring studies realized in eight sampling stations distributed over the Hydrographical Basin of Pardo River, RS, Brazil.

2. Material and Methods

2.1. Characterization of the study area

The Hydrographical Basin of Pardo River is located in the central region of Rio Grande do Sul State (Figure 1) between the geographical coordinates: 28° 50' and 30° 00' south latitude and 52° 15' and 53° 00' west longitude. The Basin is an integral part of the Hydrographical Region of Guaíba, corresponding to the "G 90" Basin, the State's official classification (COMITEPARDO, 2010).

The Basin's drainage area is 3.636,8 km², 115 km long and 35 km wide. The intense agricultural exploration and the deforestation of the hillsides have caused problems of erosion. The hydric pollution, as a result of the human and animal dejects, and for the use of the pesticides and fertilizers is another (COMITEPARDO, 2010). The Table 1 presents the location of the sampling stations of the Hydrographical Basin of Pardo River.
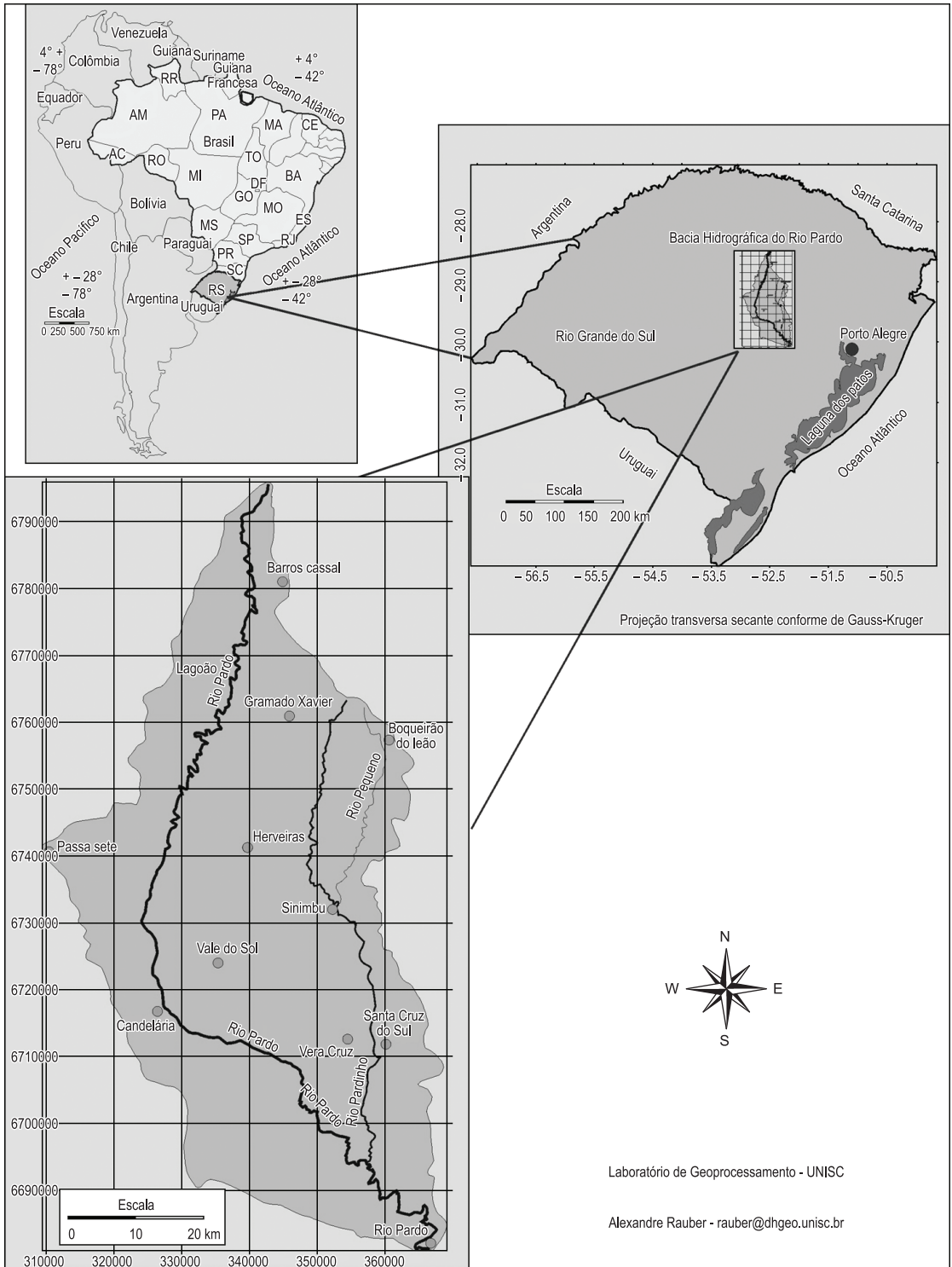
Figure 1. Location Map of the Hydrographical Basin of Pardo River, RS, Brazil.

2.2. Methodology

For the current research, it was utilized a database supplied by the Santa Cruz do Sul University (UNISC), obtained from samples collected on eight sampling stations, occurred on monthly excursions, from 2007 to 2009, distributed over the Hydrographic Basin of Pardo River (on Table 1). The physical, chemical and microbiological variables considered for the organic pollution were: TTC, BOD, PO_4^{-3}, NO_3^-, DO, pH, TDS, T and TU. The techniques utilized for the determination and collection of the samples are described in APHA (2005).

The WQI's calibration was performed by using multivariate analyses, mainly the Principal Components Analysis, following the methodology described on Manly (2008), adopting the statistical software PAST (Hammer et al., 2010) and BioEstat 5.0 (Ayres et al., 2010). Next, the water quality at the Basin of Pardo River was measured by applying the calibrated WQI, having the evaluation based on the software IQAData (Posselt and Costa, 2010). This software, especially developed to calculate the WQI, enables the user to apply the NSF's original model or to select variables judged as the most important ones for each use to build different WQI models. Finally, after having a new WQI calculus, the new results of the Basin's water quality assessment were compared to CONAMA Resolution 357/2005 in order to verify if those divergences related to water quality had already been settled.

3. Results and Discussion

3.1. Preliminary evaluation of Pardo River Basin water quality

For comparative purposes, CONAMA Resolution 357/2005 presents five classes of water quality: "special", "class 1", "class 2", "class 3" and "class 4". Meanwhile, the WQI presents five categories of water quality, which are: "excellent", "good", "regular", "bad" and "very bad". So, the water quality correspondence expected would be between the CONAMA's class "special" and "1" to the WQI's categories "excellent" or "good"; the CONAMA's class "2" and "3" to the WQI's category "regular" and the CONAMA's class "4" to WQI's categories "bad" or "very bad".

The Figure 2 presents the comparative maps of water quality in the eight sampling stations of the Pardo River Basin, according to CONAMA Resolution 357/2005 and WQI. During the four seasons in 2007, significant differences in the results were observed once that 100% of the stations

were classified as "class 4" based on CONAMA Resolution 357/2005, while WQI showed only one station presenting "bad" quality, ranging, in general, from "bad" to "regular".

The Figure 3 shows the comparison of water quality classification between CONAMA Resolution 357/2005 and WQI in 2008. It is possible to observe that according to CONAMA Resolution 357/2005, all sampling stations can be classified, at least in one season of the year, as belonging to "class 4". When the WQI was applied, the water quality varied from "good" to "regular" in every sampling station.

The comparison of water quality on the eight sampling stations in 2009, using CONAMA Resolution 357/2005 and WQI, is presented in Figure 4. Over 50% of the sampling stations showed, in at least one season of the year, CONAMA's "class 4". Meanwhile, according to WQI, only 25% of the stations were classified as "bad" water quality, at least in one season of the year.

In general, considering the time series from 2007 to 2009, it can be observed that there is no agreement between the water quality obtained with the WQI, which ranged from "good" and "regular", and CONAMA Resolution 357/2005, which was "bad" ("class 4"). It was verified that the critical variables, that is, those that propitiate the water inclusion on "class 4" were: TTC, PO_4^{-3}, TU and DO.

3.2. The calibration of the WQI

The Table 2 presents the eigenvalues that correspond to the principal components variances. This way, the coefficients of the variables (eigenvectors) to be extracted must belong to one of the first three principal components because they showed a cumulated variance >50,0% and eigenvalues above 1, according to the methodology described on Manly (2008).

Table 1. Location of the Sampling Stations over the Hydrographical Basin of Pardo River, RS, Brazil.

| Sampling Station	Locality	District	UTM Coordinates	
Po1 (Pardo River)	Passo da Lage	Barros Cassal	338708	6773567
Po2 (Pardo River)	Entre Rios	Vera Cruz	356207	6694479
Pi3 (Pardinho River)	Balneário Engelmann	Sinimbu	349333	6735397
Pi4 (Pardinho River)	Linha Sete de Setembro	Santa Cruz do Sul	358416	6719537
Pi5 (Pardinho River)	Vila Progresso	Vera Cruz	356361	6702401
Po6 (Pardo River)	Aldeia São Nicolau	Rio Pardo	366111	6686782
Po7 (F. Alves Stream)	Ponte RS 287	Vale do Sol	344875	6713071
Pi8 (Pequeno River)	Sinimbu Alto	Sinimbu	352862	6735771
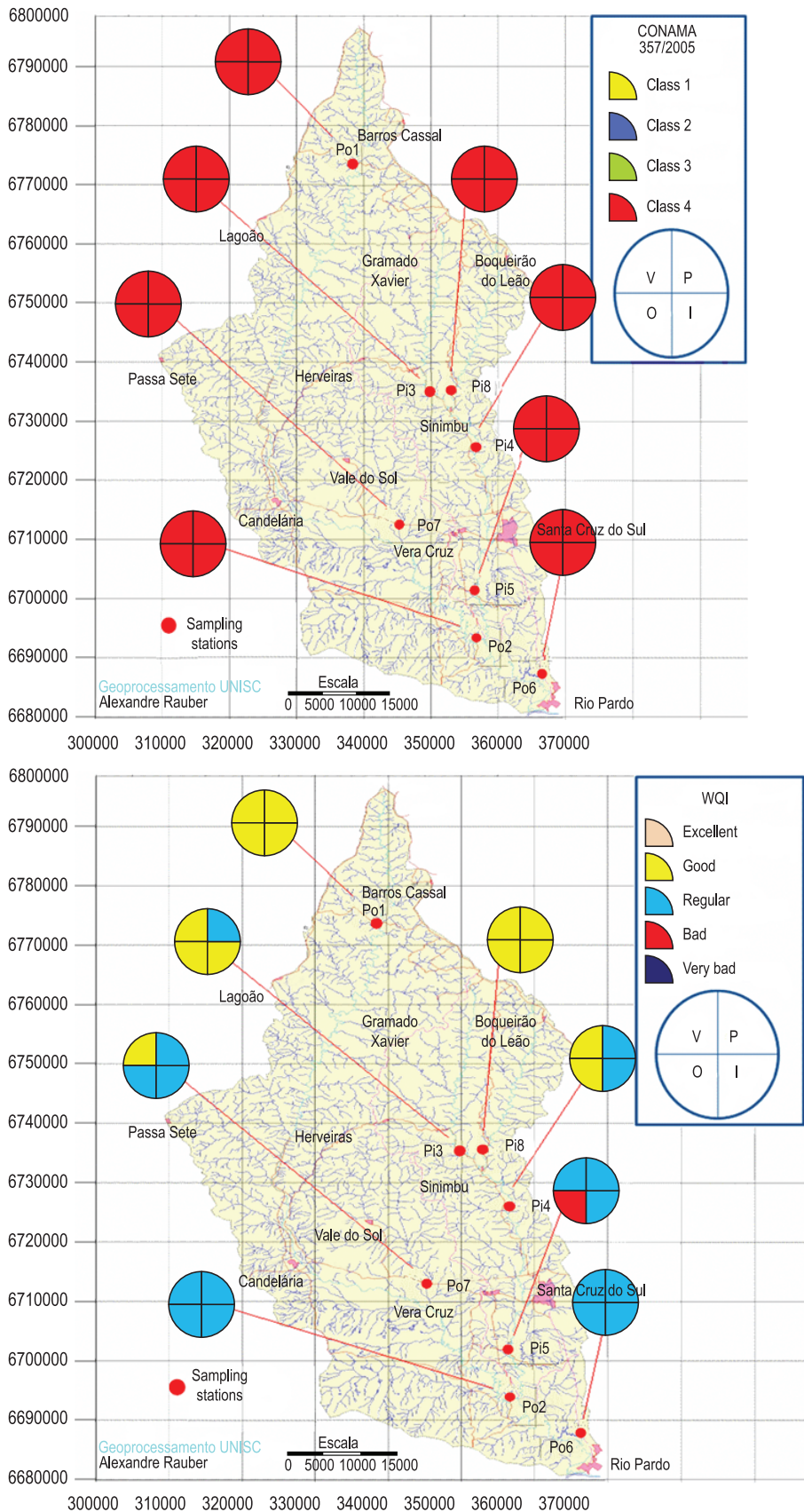
Figure 2. Comparative Maps of water quality on the eight sampling stations in the Hydrographical Basin of Pardo River according to CONAMA Resolution 357/2005 and WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) in 2007.
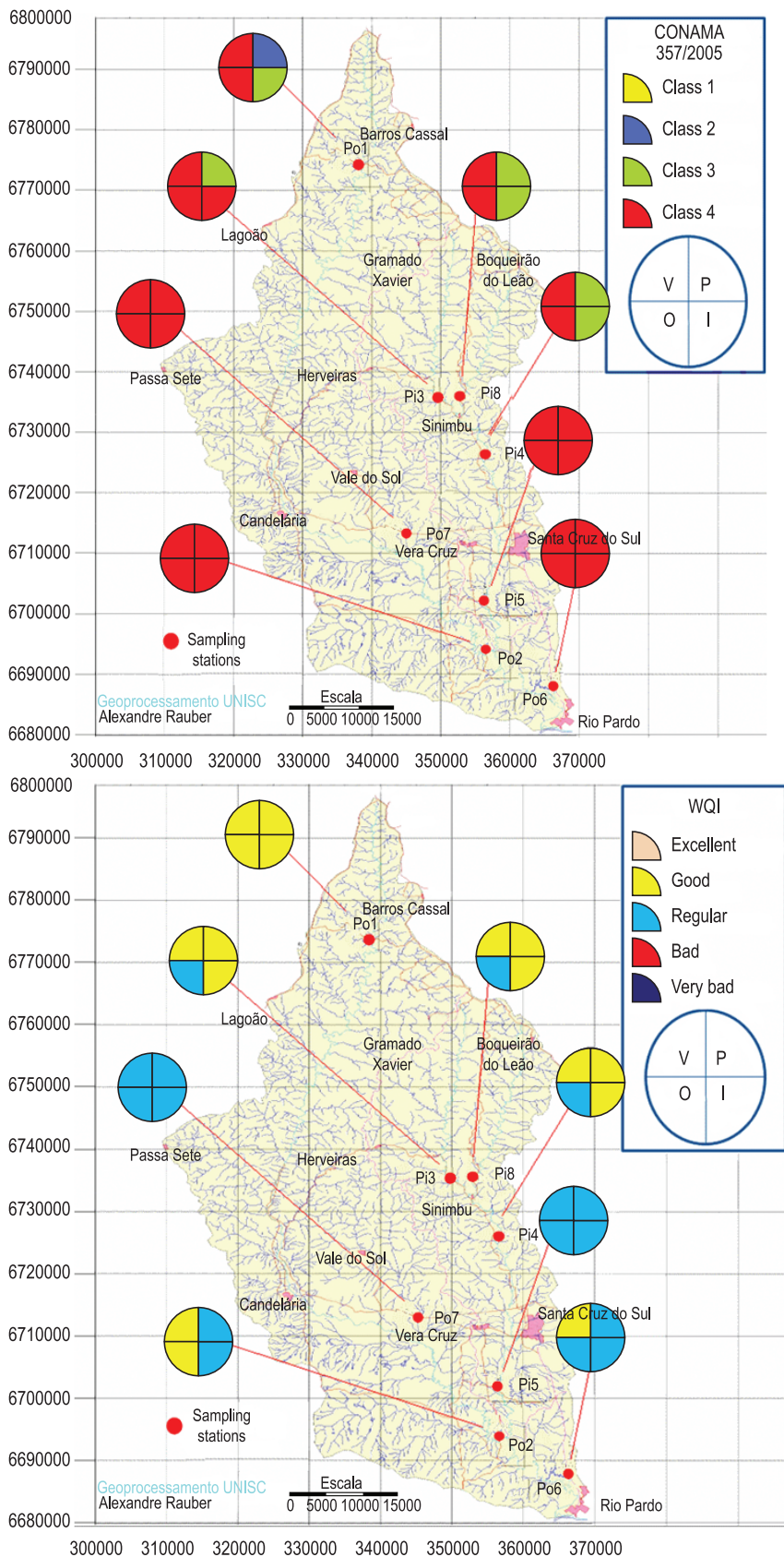
Figure 3. Comparative Maps of water quality on the eight sampling stations in the Hydrographical Basin of Pardo River according to CONAMA Resolution 357/2005 and WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) in 2008.

The Table 3 presents the eigenvectors used to interpret the principal components. The most important variables are the ones with the highest weight, either negative or positive, once that the weight signs indicate if the correlation is positive or negative.

The variables that showed the highest percentage of sampling stations classified by CONAMA Resolution 357/2005 as having "class 4" were TTC and PO_4^{-3}, representing the highest weight on the formula to calculate the WQI. As for the TTC variable, it was extracted the highest weight of the main component 1, 0,5029. Meanwhile, for the PO_4^{-3}, variable, it was extracted the highest value of the main component 2, 0,3518 (Table 3).

For the variables TU and DO, which also showed divergences with CONAMA Resolution 357/2005, the highest coefficients were extracted, but considering the rule of being lower than the coefficient of highest weight, that corresponds to the thermotolerant coliforms variable. On the other hand, for the BOD, NO_3^-, TDS, pH and T variables, the coefficients of lowest weight were extracted, because these variables not showed divergences in relation to CONAMA Resolution 357/2005.

Thus, considering the selected eigenvectors a new table of weights for the calculation of WQI was built (Table 4).

Once the summation (S) of the parameter weights (w_i) is 1, it is necessary to perform a mathematical transformation of the coefficient values by dividing each of the coefficient values by the total sum of the coefficients, obtaining the new weights for the selected parameters.

It can be observed that thermotolerant coliforms and phosphate variables showed the highest relative weights, corresponding to 23,0% and 16,0% of the total sum of the WQI weights, respectively, representing an increase of 7,0% and 6,0% comparatively to the anterior weights, confirming the importance of being the critical variables of the study.

As to the temperature variable, the new calibrated weight was reduced by 7,0%. This reduction can be explained through the fact that in the calculus of the WQI, the temperature is obtained by subtracting the measured value from the "reference site", known as a free site from the anthropogenic influence (Ziglio et al., 2006). However, on the Hydrographic Basin of Pardo River the reference sites have not

Table 2. Eigenvalues (the eigenvalues correspond to the principal components variances. This way, the coefficients of the variables (eigenvectors) to be extracted must belong to one of the first three principal components because they showed a cumulated variance >50,0% and eigenvalues above 1, according to the methodology described on Manly (2008)).

	Eigenvalues	% total of variance	Cumulated eigenvalue	% cumulated
Component 1 =	1,8836	20,9	1,8836	20,9
Component 2 =	1,7732	19,7	3,6568	40,6
Component 3 =	1,284	14,3	4,9408	54,9
Component 4 =	0,9716	10,8	5,9124	65,7
Component 5 =	0,884	9,8	6,7964	75,5
Component 6 =	0,8552	9,5	7,6516	85,0
Component 7 =	0,6755	7,5	8,3271	92,5
Component 8 =	0,4198	4,7	8,7469	97,2
Component 9 =	0,2531	2,8	9	100,00

Table 3. Eigenvectors (the eigenvectors are used to interpret the principal components. The most important variables are the ones with the highest weight, either negative or positive, once that the weight signs indicate if the correlation is positive or negative).

| Components	Eigenvectors								
	TTC	PO_4^{-3}	TU	DO	BOD	NO_3^-	TDS	pH	T
Component 1 =	**0,5029**	0,1109	0,5589	**−0,4494**	**0,1885**	−0,0389	0,2842	**−0,1071**	0,3018
Component 2 =	0,0298	**−0,3518**	**0,2577**	−0,0235	−0,3034	**−0,146**	−0,5817	−0,5924	**0,0756**
Component 3 =	0,1282	0,1792	0,0679	0,4453	0,2722	0,7378	**−0,1381**	−0,2448	0,2262
Component 4 =	−0,3849	0,1901	−0,0308	−0,1648	−0,4281	0,1043	−0,0253	0,1749	0,7498
Component 5 =	−0,3927	0,5242	−0,1368	−0,3821	0,4496	−0,1228	−0,2215	−0,3671	−0,0722
Component 6 =	0,2186	0,6979	0,1943	0,1547	−0,5342	−0,0359	−0,0952	0,0091	−0,3281
Component 7 =	0,3085	0,1752	−0,1229	0,4145	0,2912	−0,5564	−0,3234	0,1965	0,3869
Component 8 =	−0,511	−0,0234	0,7356	0,2871	0,1869	−0,1105	−0,0243	0,2398	−0,0977
Component 9 =	−0,153	0,0509	−0,0539	0,3845	−0,0886	−0,2895	0,6307	−0,5622	0,133
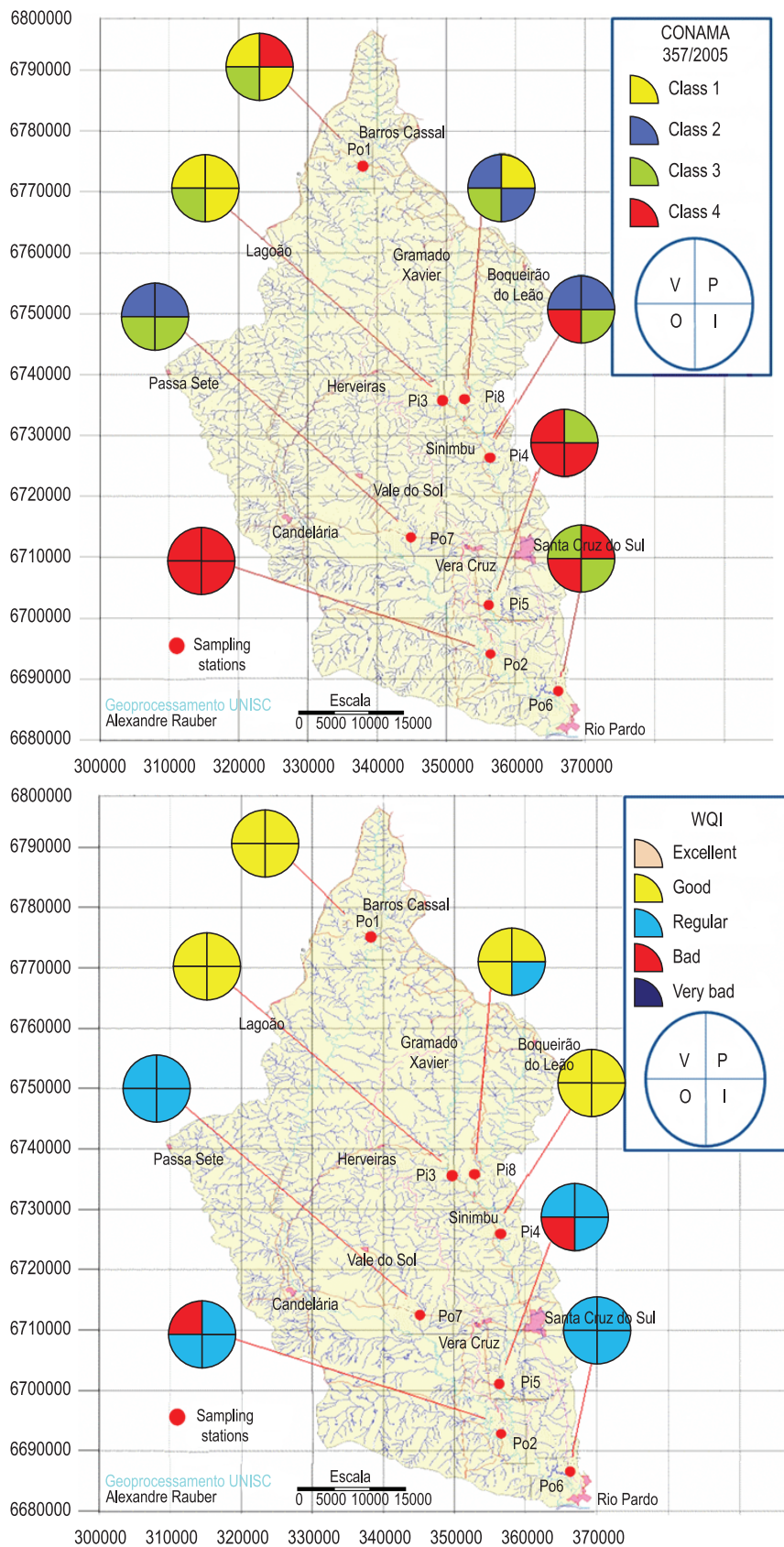
Figure 4. Comparative Maps of water quality on the eight sampling stations in the Hydrographical Basin of Pardo River according to CONAMA Resolution 357/2005 and WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) in 2009.

Table 4. Eigenvectors transformation (once the summation (S) of the parameter weights (wi) is 1, it is necessary to perform a mathematical transformation of the coefficient values by dividing each of the coefficient values by the total sum of the coefficients, obtaining the new weights for the selected parameters).

Variables	Eigenvector	Actual weight	Calibrated weight (wi)
Thermotolerant coliforms	0,5029	0,16	**0,23**
Phosphate	0,3518	0,10	**0,16**
Turbidity	0,2577	0,08	**0,12**
Dissolved oxygen	0,4494	0,17	**0,20**
Biochemical oxygen demand	0,1885	0,11	**0,08**
Nitrate	0,1460	0,10	**0,07**
Total dissolved solids	0,1381	0,07	**0,06**
Ph	0,1071	0,11	**0,05**
Temperature	0,0756	0,10	**0,03**
Σ	2,2171	1	1

been defined yet, emphasizing that even the water quality of the headwaters has been already found contaminated (Lobo et al., 2010). According to Ziglio et al. (2006), the establishment of reference sites "free from anthropogenic influences", strongly dependent on the offer of trustable criteria of selection, have been one of the main problems pointed out by the "Water Framework Directive" (European Union, 2000), which aims the rational use of water resources along with the conservation, protection and improvement on the quality of the aquatic systems. Sharp changes on the temperature of the water has been usually originated by industrial wastes, however this is not the prevalent characteristic of the waters in the Basin of Pardo River.

3.3. Comparison of the water quality evaluation of the Pardo River Basin, according to CONAMA Resolution 357/2005 and the calibrated WQI

The change in water quality becomes evident when one observes the comparative maps of water quality from the eight sampling stations, between CONAMA Resolution 357/2005 and the calibrated WQI. In 2007 (Figure 5) it is possible to observe that there was an important adequacy of the results of the calibrated WQI with the CONAMA Resolution 357/2005. The sampling stations Pi5, Po2 and Po6 during the four seasons of the year, Po1 and Pi4 during summer, winter and spring, Pi3 and Pi8 during summer and spring and Po7 during spring, the water quality was "bad" according to WQI, in agreement with the CONAMA Resolution 357/2005, which classified these sampling stations as belonging to "class 4".

The Figure 6 shows the comparative maps for the year of 2008, between the calibrated WQI and the CONAMA Resolution 357/2005. Sampling stations Pi5 during the four seasons of the year,

Po7 during autumn, winter and spring, Po2 and Pi8 during autumn and Po6 during autumn and winter, were classified as "bad" using the WQI and belonging to "class 4", following CONAMA Resolution 357/2005. Sampling stations Pi8 and Pi4, during winter and spring, were also found in agreement between WQI and CONAMA Resolution 357/2005, presenting "regular" water quality and belonging to "class 3", respectively. Likewise, sampling station Po1 was classified as "class 3" during winter and "class 2" during spring by CONAMA Resolution 357/2005, presenting "regular" water quality according to WQI.

The Figure 7 shows the comparative maps in 2009, between the calibrated WQI and the CONAMA Resolution 357/2005. In general, the quality of water changed from "good" to "regular" and "regular" to "bad" in most sampling stations. It can be observed a significant agreement between the results obtained with the WQI and CONAMA Resolution 357/2005, where the sampling stations Po2 during all seasons of the year, Pi4 and Po7 during summer and spring, Pi3 and Pi8 during summer, spring and winter, Po6 during spring and summer, Po1 during summer and winter and Pi5 during summer, autumn and winter showed the same water quality during all seasons of the year.

4. Conclusion

The principal component analysis demonstrated to be an adequate tool for the calibration of the weights utilized in the formula to calculate the WQI. These new calibrated weights showed a significant agreement with CONAMA Resolution 357/2005, and consequently, they are suitable for the reality of the Hydrographical Basin of Pardo River.
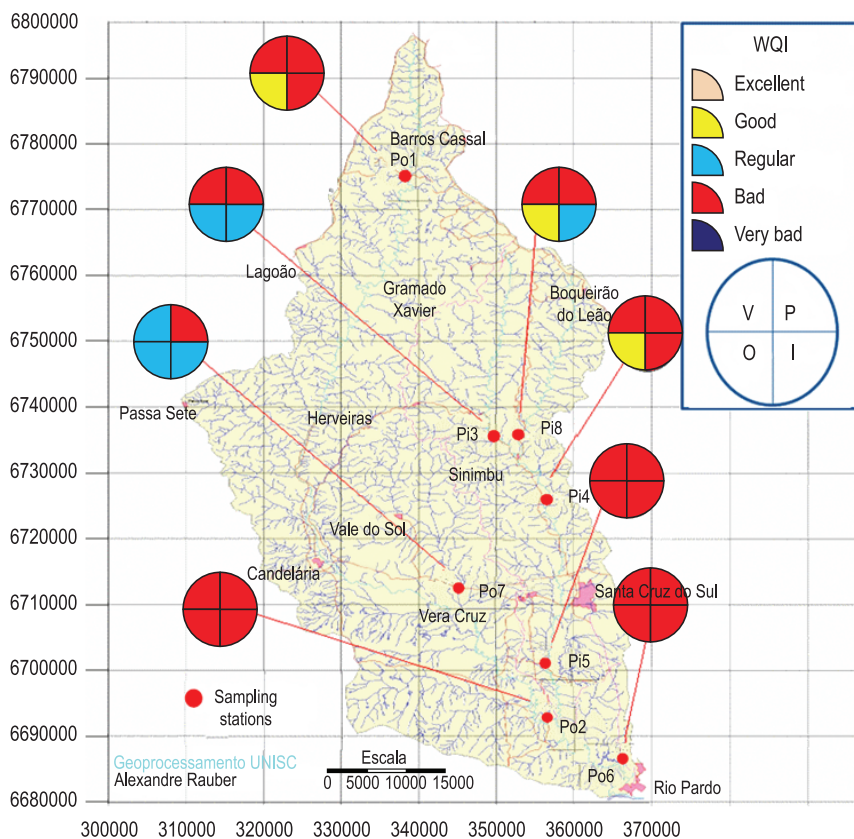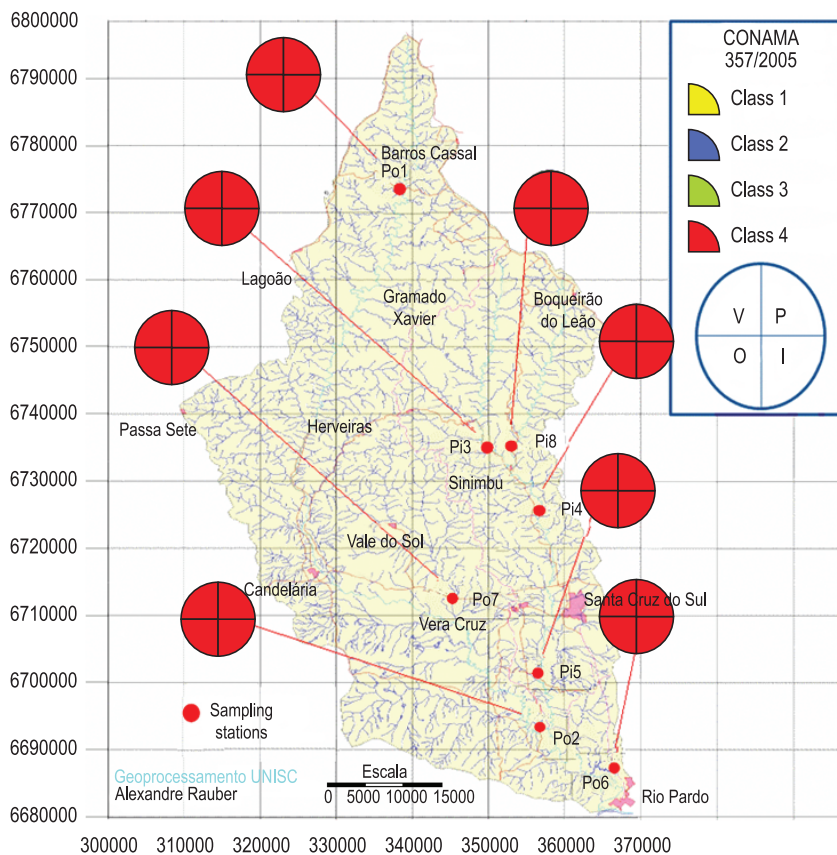
Figure 5. Comparative Maps of water quality on the eight sampling stations of the Hydrographic Basin of Pardo River, according to CONAMA Resolution and calibrated WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) of 2007.
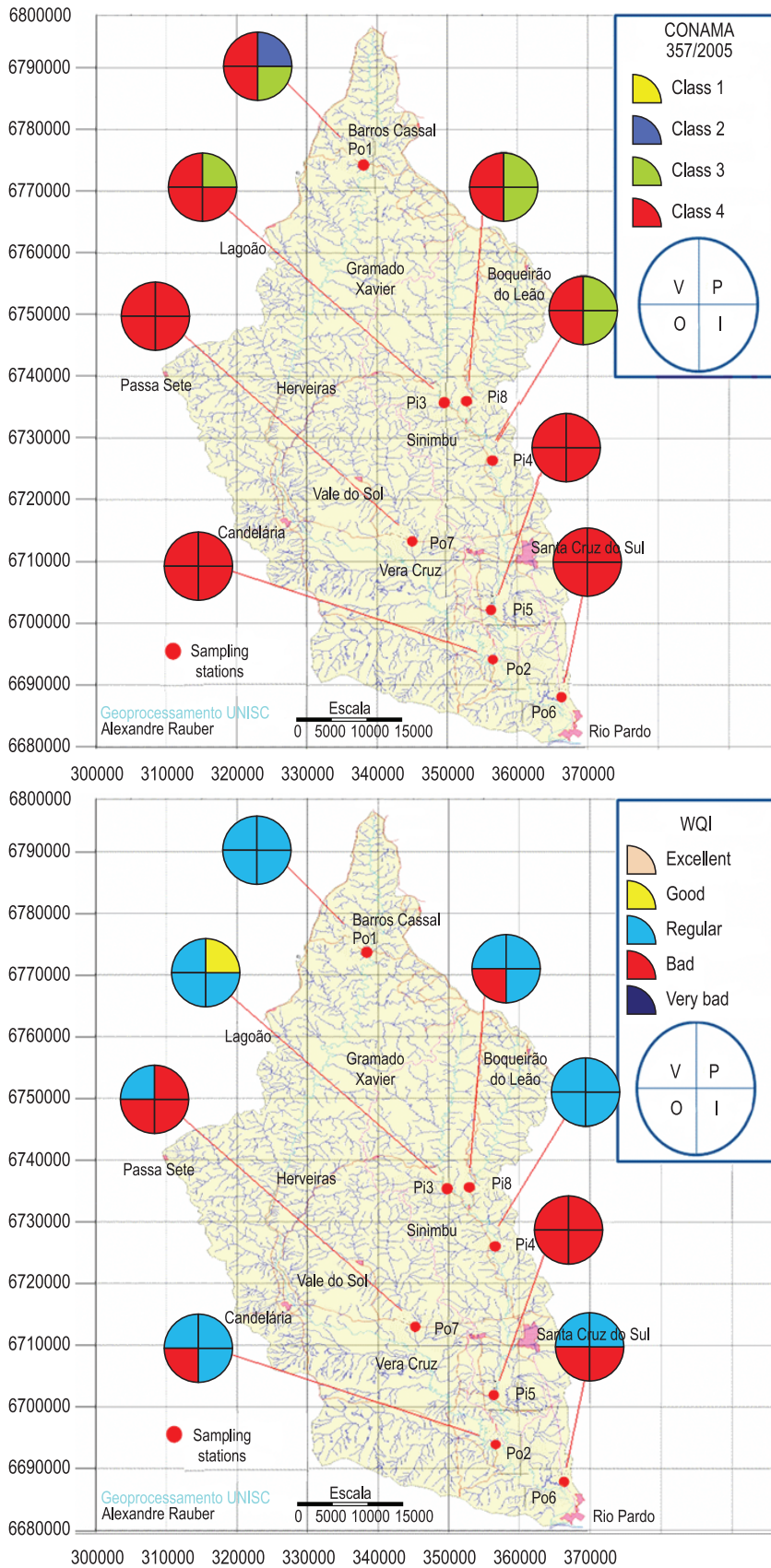
Figure 6. Comparative Maps of water quality on the eight sampling stations of the Hydrographic Basin of Pardo River, according to CONAMA Resolution and calibrated WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) of 2008.
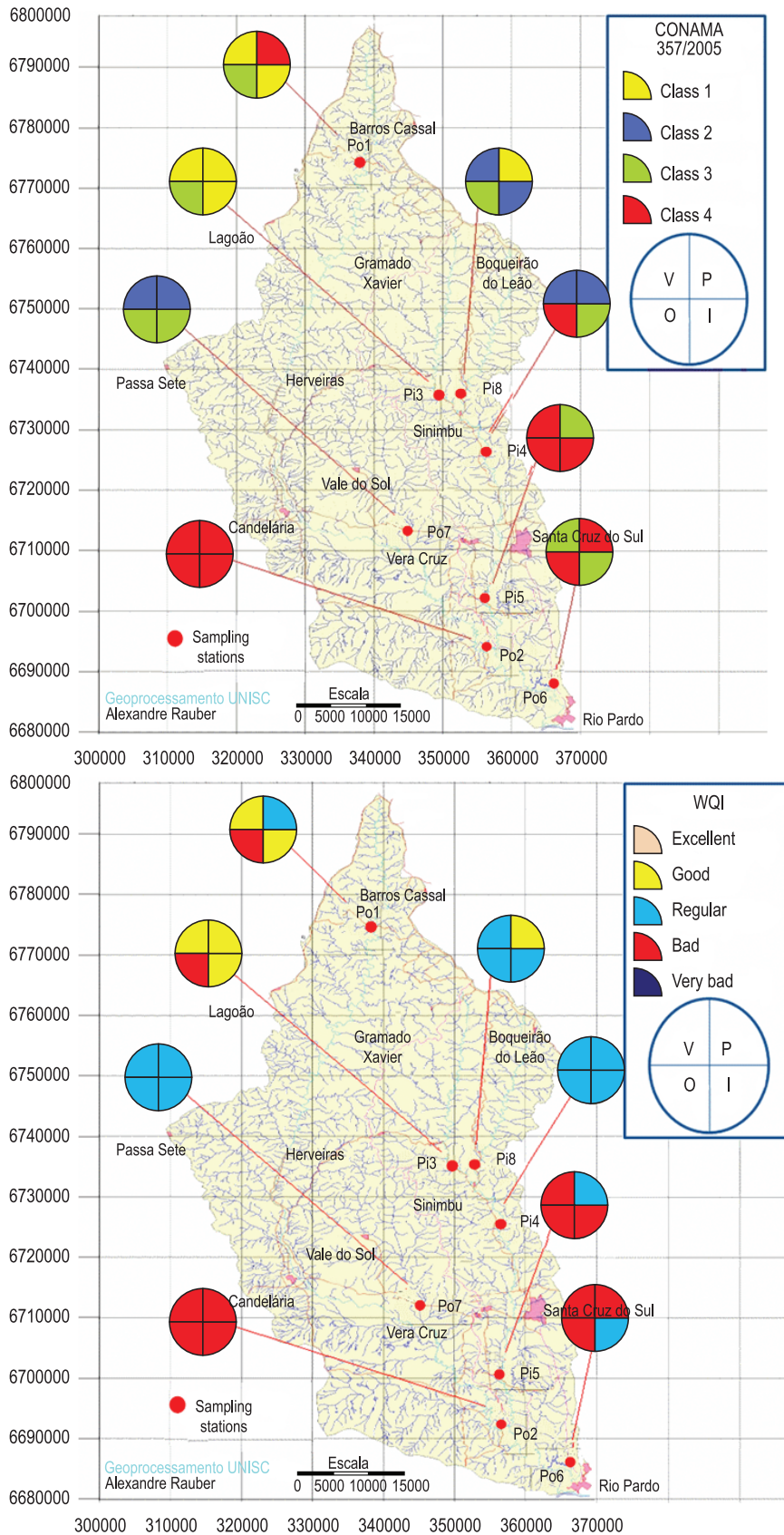
Figure 7. Comparative Maps of water quality on the eight sampling stations of the Hydrographic Basin of Pardo River, according to CONAMA Resolution and calibrated WQI during the four seasons of the year (P = spring, V = summer, O = autumn, I = winter) of 2009.

In general, the main environmental problems detected at this Basin are the process of water eutrophication, related to the concentration of nutrients and organic load originated from domestic sewage, in addition to the excess of fertilizers and agricultural inputs used in agriculture. These environmental problems characterize the great majority of the lotic systems in the Guaíba Hydrographical Region in the state of Rio Grande do Sul (Lobo et al., 2002, 2003; 2004a, b, c, 2010; Oliveira et al., 2001; Dupont et al., 2007). Still, according to Tundisi (2004), this condition characterizes the water bodies in all the south region of Brazil, according to the results obtained in the research project entitled "Waters of Brazil". In this context, the calibrated WQI, as demonstrated in this research, can be used as an efficient tool in environmental assessment programs in lotic systems belonging to Guaíba Hydrographical Basin, RS.

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