CO-023

MAPPING THE TURBIDITY CONCENTRATION IN THE WATER OF THE ITUPARARANGA/SP/BR RESERVOIR ESTIMATED THROUGH MULTISPECTRAL IKONOS IMAGERY

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ABSTRACT

Scientific researches about water quality use inference models of water component, copied from other ones observed on field, enabling a better spatial representation of the variants, besides the cost reduction. The turbidity is one of the physical parameters observed in the analysis of water bodies quality, which beyond being a physical feature of easy obtainment on field, it represents a correlation with the superficial electromagnetic radiation of the water body, enabling its assessment by multispectral images taken by sensors from orbiting platforms. The purpose of this research was to perform the mapping of water turbidity concentration in the Itupararanga (SP/Br) Reservoir, using a multispectral IKONOS imagery, at the bands 1 (450 – 520 nm); 2 (520 – 600 nm); 3 (630 – 690 nm); and 4 (760 – 900 nm) and turbidity data obtained “in situ”. For such, it was created an inference model of turbidity, after some adjustments and processing, and an analysis of the correlation between the available data. Such model, along the variant measured “in situ” at specific sampling sites, allowed us to estimate and map the concentration of turbidity in the reservoir water, providing in this way information for the environmental specialists. The conclusion was also that the concerned Reservoir presents a low concentration of solids in suspension. Generally the research was considered economically viable.

1 BACKGROUND AND OBJECTIVES

Scientific researches related to water quality make use, among other available methods for environmental analysis, the analysis of correlation between the concentration of the optically active components and spectral information of water bodies obtained from orbital data (Dekker, 1993; Ritchie & Cooper, 1998; Giardino et al., 2001; Ekercin, 2007; Galvão et al., 2003; Novo et al., 2006). The construction of empiric models for estimating some of the components, from other observed on fields, enables a greater spatial representation of the variant and reduces the costs of field work, mostly of with the reduction of the lab analysis.

The water quality, represented by parameters that translate its main physical, chemical and biological features (Von Sperling, 1996; Braga, 1998; Di Bernardo, 2002) is closely related to springs contamination, which restrains its use for human purveyance, aggravating even more the problem of this resource’s shortage, so discussed nowadays.

The turbidity is one of the physical parameters observed in the analysis of quality of water bodies, defined as the degree of reduction or interference that the light suffers by crossing the water, giving it a turbid aspect. For Von Sperling (1996) it is generated by solids in suspension of rock, argil and silt particles, beside algae and other microorganisms. Beyond being a physical feature of easy obtainment on field, it presents a correlation with the superficial electromagnetic radiation of the water body, which can be evaluated by the multispectral imagery taken by the sensors set on the orbiting platforms. Despite the remote sensing technology have nowadays real application and potential to evaluate aquatic resources and monitor the water quality, limitations of the spatial and spectral resolutions of the orbital sensor systems have restrained the utilization of satellite images in applications directly related to the monitor of water quality (Ritchie et al., 2003). However, with the availability of orbital images caught by high spatial resolution sensors, as well as the increasing using of multispectral cameras set in aircrafts, the matter of spectral resolution of the images still remains a huge restrain for its use, so that the majority of the studies about water quality, using remote monitor, has been limited by the detection of particles in suspension (Novo et al., 1989) and of the aquatic vegetation in big reservoirs (Galo et al., 2002; Galo et al., 2004).

Before what was exposed, the current research main purpose is to map the concentration of water turbidity in the Itupararanga/SP/Br Reservoir, making use of multispectral imagery of high resolution and data from the physical parameter turbidity collected “in situ”. As specific objective, it is pretended to generate a turbidity inference model, from the available research data, applied on the studied Reservoir.

2 APPROACH & METHODS

For the research development, a multispectral image of high spatial resolution from the IKONOS II Satellite (spectral bands 1, 2, 3 and 4, corresponding respectively on the intervals of wavelength between 450 and 520 nm; 520 and 600 nm; 630 and 690 nm; 760 and 900 nm) was obtained simultaneously to the performance of a field survey, in which was measured the parameter of turbidity.

It was performed an analysis of the correlation between the turbidity and the spectral image. Methods of classic linear regression were applied in order to create a turbidity inference model, estimating in this way, the spatial distribution of this variant in the reservoir. The Figure 1 presents the research study area, that was the Itupararanga/SP/Br Reservoir, belonging to the Sorocaba River Watershed, for it is one of the largest springs of drinking water of Sorocaba region, supplying the cities of Votorantim, Mairinque, Alumínio, Ibiúna and São Roque, in one amount of approximately 800.000 inhabitants, and considered of good water, by the official bureaus.

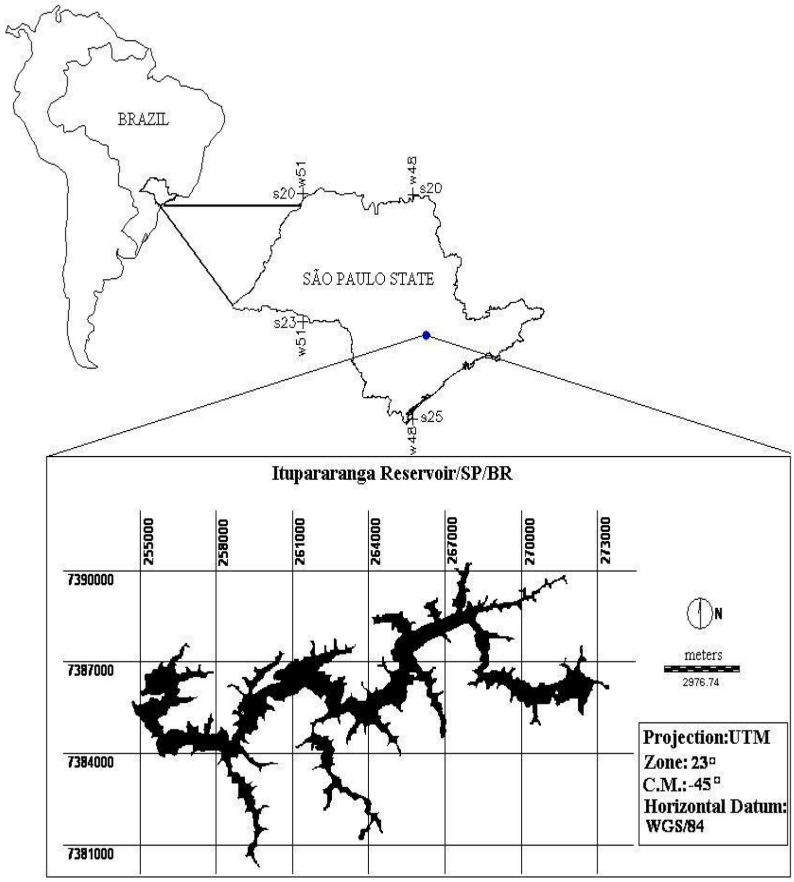

Figure 1 – Itupararanga Reservoir localization in São Paulo State, Brazil

The collection of turbidity "in situ" was based on a sample scheme pre- defined for the distribution of the sampling elements. Such scheme considered a number of sites that enabled the samples optimization and granted, at the same time, the spatial representativeness of the parameter collected for the water quality analysis. For such, it was based on the spectral variability of the water body during the time and in the entrance of the main affluents into the Reservoir (Pereira et al., 2007). In total, it was defined 72 sampling sites spread throughout the Itupararanga/SP/Br Reservoir, and in the entrance of the tributaries, as shown by the Figure 2.

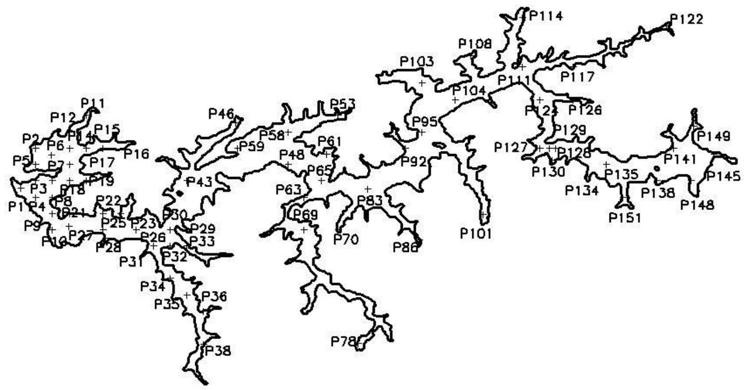

Figure 2 – Itupararanga Reservoir and the position of 72 points defined from sample scheme for turbidity survey "in situ"

The turbidity survey "in situ" took place on February 07 and 08/2007, in a way that the illumination conditions (nebulosity) and wind (waves on water surface) were noticed on field spreadsheets. At the first day on the field were performed measurements in 31 sampling elements, with the presence of sun, clouds and winds. At the second day, with the occurrence of torrential rains and some moments of drought with clouds, were evaluated only four sampling elements, totalizing 35 sampling sites.

Simultaneously to the turbidity survey on the field, it was obtained a multispectral image of high spatial resolution by the satellite Ikonos II, from the study area, corresponding to the bands B1 (spectral range of 450 – 520 nm); B2 (spectral range of 520 – 600 nm); B3 (spectral range of 630 – 690 nm) and B4 (spectral range of 760 – 900 nm). Such images can be programmed for the period wished by the user, however without the specific definition of the days they were taken. Besides, due to the need of synchronism between the obtainment of the turbidity parameter and the obtainment of the image, the definition of a better date for the collection can be just approximated. Therefore, it was planned the survey "in situ" and the obtainment of the image for the week of February 05 to 09, with the image taken by the Ikonos II Satellite in February 05, thus, lagged in 2 or 3 days from the obtainment of the scene. The image obtained was considering covered by clouds in great part of the concerned sites of the research.

2.1 Collection of the turbidity parameter "in situ"

Due to the fact that the image is covered by clouds over part of the sampling sites and yet, the heterogeneity of weather conditions on the two days of field works, there was a need to classify the sample following the meteorology conditions, at the moment of its obtainment, in four groups, as shown at Table 1.

TABLE 1 – Classification of sample points according to meteorological conditions during the survey "in situ" and clouds in Ikonos imagery

	Group 1	Group 2	Group 3	Group 4
Samples	03	10	12	10
Points	P30,P32, P36	P22,P23, P25,P26, P27,P28, P29,P33, P34,P35	P2,P5,P6, P7,P8,P9, P10,P12, P15,P16, P19,P31	P1,P3, P14,P17, P18,P21, P104,P111 P117,P129
Sky	Clear	Clear	Cloudy	Cloudy
Wind	Light	Average	Light	Strong
Wave	wavelet	wavelet/ medium	wavelet	Medium/High
Hour	14:51 to 15:32	14:03 to 16:06	11:32 to 15:12	10:58 to 14:10
Localization	Western sector	Western sector	Extreme western sector (dam)	Western and eastern sectors
Average Turbidity (NTU)	1,20	0,76	0,84	1,73

The collection of the turbidity parameter "in situ" was made in the fathom of Secchi disc, keeping the water samples for posterior lab analysis, in the sites previously defined (Figure 2). The collection was made with collectors of continuous flow, where the water was suctioned through a hose of 30m length, marked in each meter, and released into plastic bottles for water sampling. The analysis were made with a turbidimeter, as said (Cavenaghi, 2003).

2.2 High Resolution Multispectral Image

The multispectral image from the Ikonos II, corresponding to bands B1, B2, B3 and B4, respectively spectral intervals 450-520 nm, 520-600 nm, 630-690 nm and 760-900 nm, was submitted to treatments in order to make it spatially and radiometrically compatible with the turbidity parameter obtained "in situ". Such treatments were: georeferencing of the scenes, clipping mask of the water body and radiometric and atmospheric corrections.

The georeferencing of the image was made in the program SPRING-INPE/BR (Georeferenced Information Processing System - National Institute for Space Research, Brazil), using the Affine Transformation on the scheme and 12 control points. The residue of the geometric transformation was 1 pixel, considered acceptable for the work.

The delimitation of the Reservoir was made on SPRING, from choosing a segmentation by region growth using similarity parameters equal to 20 and an area of 200 pixels, after tests with other values, due to the fact that it is the most appropriate for delimiting the contours of the dam, comparing to the other ones. We applied the unsupervised classification technique Isoseg to group the defined regions in the segmentation with a threshold value equal to 90%. The mapping of the thematic classes was performed and the manual edition of the contour. The generated mask was used for the cutting of the Information Plans regarding to the four bands of the multi-spectral image. The radiometric calibration was performed with the objective of converting the DN's (digital numbers) from the original image into spectral radiance. For this, the spectral radiance or radiance in the sensor was calculated from mathematical equations presented by Soudani et al. (2006) for Ikonos images, and the calibration factor used for the bands obtained from the Ikonos Soudani et al. (2006) and Goward et al. (2003).

The atmospheric correction, that aims the conversion of DN's (digital numbers) or brightness values of original image in apparent reflectance was performed based on the empirical method of Chavez (1989), called DOS - Dark Object Subtraction, using for this the Application IDRISI Andes (Clark University). Among the parameters needed to implement the method in Idrisi, we got the value of Dn haze (digital number of the darkest pixel), which was obtained from the observation of the frequencies histograms to the original band that was being corrected. It was stipulated that the value of Dn haze would be one of the DL previous to the frequency change more abrupt observed in the histograms. However, were observed occurrences of pixels with brightness values or frequencies already in DN = 1 for all bands of Ikonos images. Therefore, the value of Dn haze adopted was zero.

The resulting image from the georeferencing, from radiometric calibration and atmospheric correction was then submitted to a softening from the application of filters of simple moving average in order to reduce the possible presence of noise and radiometric oscillations (Tsai & Philpot, 1998). This process was carried out in IDRISI Andes application, with different sizes of windows and observed that the results of correlation with higher values (greater than 0,6) at a significance level of 5% took place into the filter window 3x3 pixels. Performed the pre-processing operations of the image, it was applied the band ratio to the values extracted at the points of concern, for the intervals and combinations indicated by Kirk (1994), Barbosa (2005); Rundquist (1996), Hoge et al. (1987), Gitelson (1992), implicating the four Ikonos bands:

(B3/B2) (1)

(B2/B3) (2)

[(B2–B3)/(B2+B3)] (3)

[(B2-B4)/(B2+B4)] (4)

(B4/B3) (5)

(B3/B1) (6)

(B4/B1) (7)

(B3/B4) (8)

(B1/B2) (9)

(B1/B4) (10)

2.3 Correlation Analysis

The correlation analysis were performed between the image bands and turbidity limnological variant. It was tried to analyze the correlations considering the four data groups in which the sample was divided, according to weather conditions previously discussed, however, not all points could be read on multi-spectral imagery of February, due the presence of clouds.

Thus, the group 1, with 3 points (P30, P32 and P36) and group 2 with 10 points (P22, P23, P25, P26, P27, P28, P29, P33, P34 and P35) were not included in the analysis for their points were under the clouds. The group 2 presented two spots whose reflectance values could be read (P34 and P35) which were used as reference, due the impossibility of applying correlation and tendency on them (n = 2 suggests non normality of data). Therefore, the analysis were conducted by making use of the group 3, with n = 11 points (P02, P05, P06, P07, P08, P09, P10, P12, P15, P16 and P19), and point-31 dropped for being under the clouds, and the group 4 with 10 points (P01, P03, P14, P17, P18, P21, P104, P111, P117 and P129).

The correlation coefficients obtained from the Ikonos multi-spectral imagery bands and the variant turbidity are presented for the group 3 (Figure 3) and for the group 4 (Figure 4).

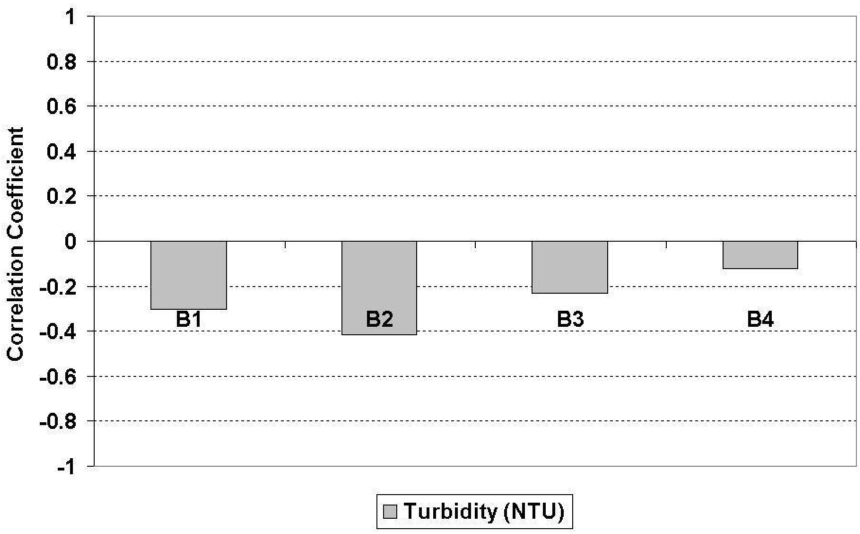

Figure 3 – Correlation coefficients between turbidity and Ikonos multispectral imagery bands for the group 3

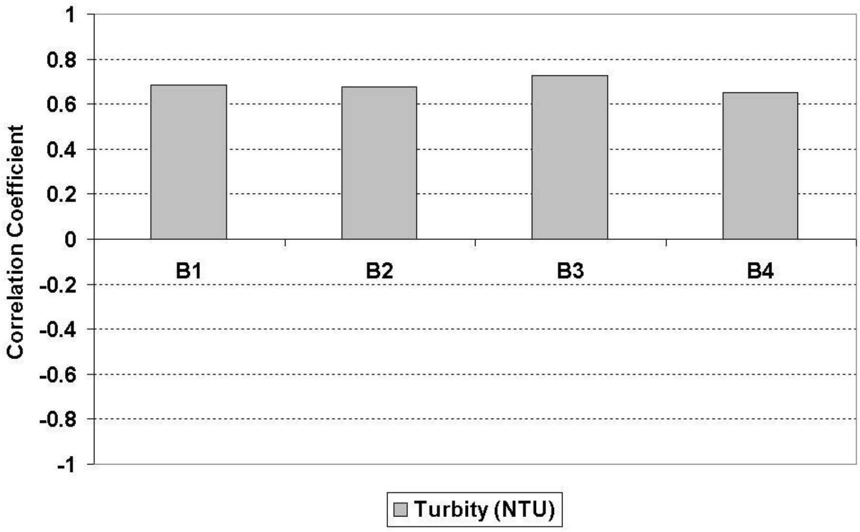

Figure 4 – Correlation coefficients between turbidity and Ikonos multispectral imagery bands for the group 4

It can be observed on the Figure 3, that it does not occur significant correlations at the significant level of 5%, while in the Figure 4 it is observed significant correlations at significant level of 5% significance between the variant turbidity and the bands:

B1 (0,685; p = 0,042) (11)

B2 (0,677; p = 0,032) (12)

B3 (0,725; p = 0,018) (13)

B4 (0,649; p =0,042) (14)

It was also performed analysis of correlations between the variant turbidity and the resulting values of the band rate of Ikonos for the groups 3 and 4 data as presented on the following Figures 5 and 6.

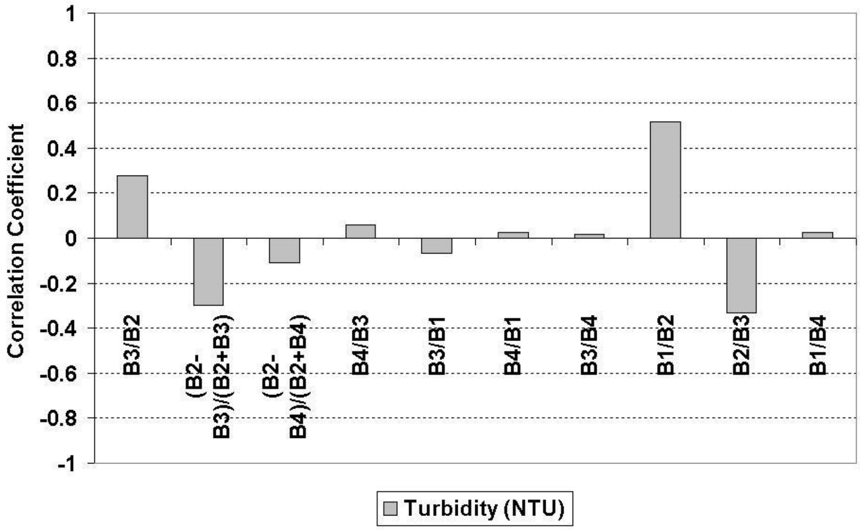

Figure 5 – Correlation coefficients between turbidity and band rate of Ikonos multispectral imagery for the group 3

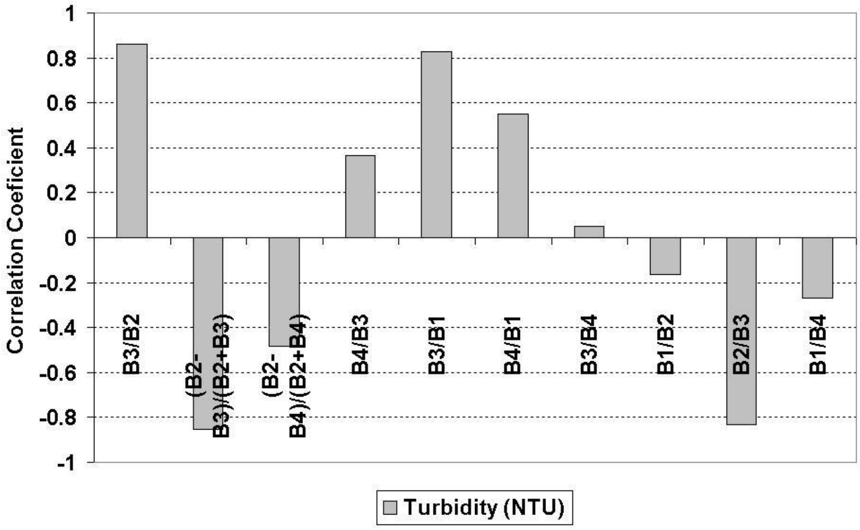

Figure 6 – Correlation coefficients between turbidity and band rate of Ikonos multispectral imagery for the group 4

On the Figure 5 it is observed that there was not a significant correlation at the level of 5% between the turbidity and the band rate studied. On the Figure 6 it presents significant values at 5% between turbidity and the band rates:

(B3/B2) (0,861; p = 0,001) (15)

(B2-B3)/(B2+B3) (-0,851; p = 0,002) (16)

(B3/B1) (0,828; p = 0,003) (17)

(B2/B3) (-0,833; p = 0,003) (18)

3 RESULTS

The analysis performed for the construction of an empiric inference model pointing to the water turbidity in the Itupararanga/SP/Br Reservoir were made for the group 4, for this was the only one that presented significant correlations at the significant level of 5%, as presented on the equations of (11) to (18).

Among the possible models the one that seemed to be more statistically adequate, as the defined criteria by Charnet et al. (1999) and Crusco et al. (2005), it was what describes the Turbidity in function of the band rates of the Ikonos equation 15: (B3/B2) with R2 adjusted explaining 70,9% of the data variability, σ2 within the average values from every models and Cp_Mallows adequated with Cp = 0,8 ~ p = 2. The formal Normality Test Anderson-Darling of the dependent variant Turbidity resulted positive for normality of (A.D. = 0,555 e p-valor = 0,113), at the significance level of 5%; beyond the p-value resulting from the analysis of the variance of regression (0,001). Then, the model got defined by the following equation:

Turbidity = -1,98 + 6,04*(B3/B2) (19)

The residue graphics from the model show their normality and a constant variance. The result of the Anderson-Darling test confirms the result of normality (A.D. = 0,271 and p-value = 0,590), being then the indicated model for turbidity inference for the group 4 data.

The validation of the regression model was accomplished by adapting the method of multiple sub-samples, known as "jackknife", which is applied to small sizes samples, for it allows the use of all observations in the estimative of parameter model (Neophytou et al., 2000).

The method consists in separating an observation from the original sample, estimate the coefficients of the model based on the rest of the sample (n-1) and estimate the restricted observation using the new equation. The procedure is repeated for all the samples so that all the observations may be estimated by models which parameters were estimated based on the other ones. The perceptual of right classifications is accumulated for all the sampling elements indicating the global precision of the model.

The Table 2 presents the Interval of Prediction (IP) in the Turbidity estimative for the validation models with the application of the adapted method "jackknife".

TABLE 2 –Interval of Prediction (IP) for Turbidity from validation models with the adapted method "jackknife"

Element sample excluded	Model Validation Turbidity = $-\beta_0 + \beta_1$ *(B3/B2)	ρ (B3/B2)	Turbidity - real (m)	Lower limit IP	Upper limit IP
1	Turbidity = -1,9872 + 6,058*(B3/B2)	0,466	0,86	-0,951	2,623
2	Turbidity = -1,9011 + 5,95*(B3/B2)	0,479	0,77	-0,816	2,713
3	Turbidity = -2,0827 + 6,179*(B3/B2)	0,467	1,04	-0,970	2,576
4	Turbidity = -2,2834 + 6,444*(B3/B2)	0,448	1,22	-1,125	2,326
5	Turbidity = -1,7501 + 5,752*(B3/B2)	0,454	0,39	-0,893	2,614
6	Turbidity = -2,2077 + 6,643*(B3/B2)	0,726	1,26	1,348	3,879
7	Turbidity = -1,9928 + 6,110*(B3/B2)	0,683	1,94	0,474	3,887
8	Turbidity = -1,6501 + 5,424*(B3/B2)	0,907	3,81	1,170	5,374
9	Turbidity = -2,0653 + 6,241*(B3/B2)	0,771	2,43	0,968	4,528
10	Turbidity = -1,7464 + 5,450*(B3/B2)	0,726	3,55	0,933	3,500

On the Table 2 it is verified that the real values of turbidity for all sampling elements are included in the Intervals of Prediction (IP) of the models. For a more robust acceptance of the original model, it was applied to the analysis of the coefficients β0 β1 of each validation model, noting that the if such coefficients belong to the confidence interval (CI) of the original model, considering α = 5%. As the confidence intervals β0 and β1 expressed by -3,8238776 < β0 < 0,1361224 and 3,127522 < β1 < 8,952478, it was verified that all coefficients β0 β1 from validation models are within the confidence interval (CI) of the original model.

Therefore, it is accepted the original model, the hypothesis of validity of the regression model generated from the ratio of Ikonos bands (B3/B2) in the inference of Turbidity is confirmed.

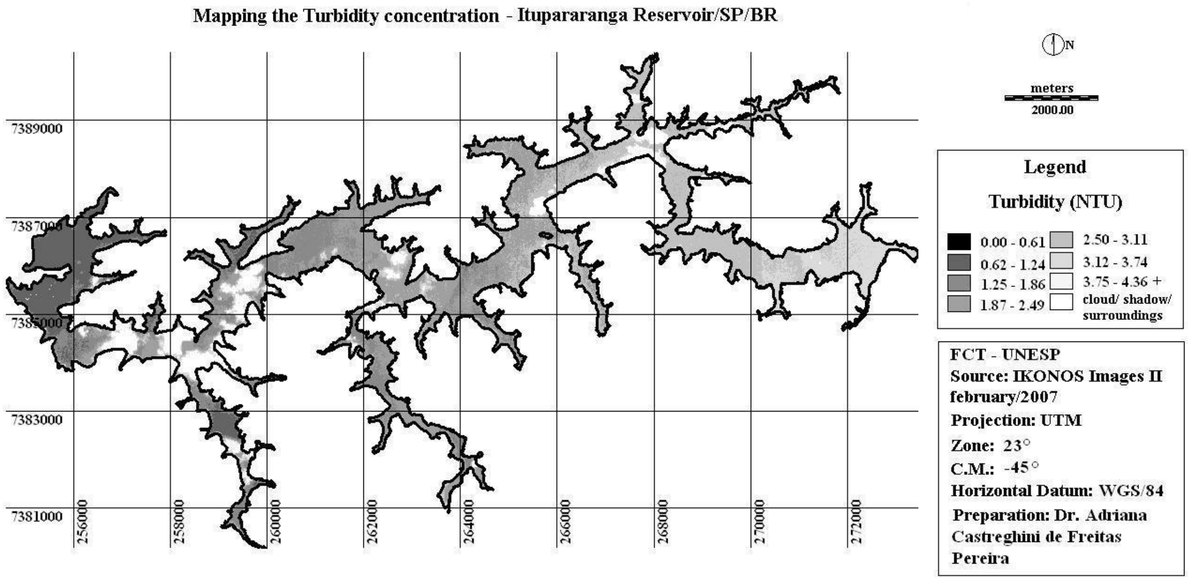

Figure 7 – Mapping the Turbidity concentration estimated from B3/B2 Ikonos images from February 2007 for Itupararanga Reservoir/SP/Br

Analyzing the mapping of turbidity, presented by Figure 7, according to its variability in concentration from the mathematical model that uses the bands B2 and B3 of Ikonos image from February 2007, one can verify that these concentrations show lower values (between 0,62 and 1,24 NTU) close to the dam (west) and between 1,25 and 1,86 NTU in central and northeast regions of the reservoir. In these regions, the soil is predominantly covered by forests in the north and forests mixed to crops, grassland and bare ground to the south, where there is an area with high-standard buildings (condominiums). The region to the east of the Reservoir close to the outfall of the Sorocaba River (upper right of image) presents higher concentrations of turbidity, between 1,87 and 3,11 NTU. The soil cover in these regions is predominantly forest to the north and agricultural crop, pasture and forest to the south. It is likely that the kind of ground cover around the reservoir of Itupararanga is contributing positively to the low concentrations of turbidity in this water body. These tests show that the result of applying the empirical model is consistent with the values of turbidity and characteristics of the water body observed on the field, concluding that the concerned reservoir presents low concentration of solids in suspension.

4 CONCLUSION

The main objective of the research was achieved, for the mapping of turbidity concentrations in the water of the Itupararanga/SP/Br Reservoir was performed, from multi-spectral imagery of high spatial resolution Ikonos and turbidity data collected “in situ”; providing useful information to environmental experts.

The specific objective, which aimed to generate inference model of turbidity from the images and sampling “in situ” was also achieved. The mathematical model generated, which used the bands B2 and B3 of Ikonos imagery showed consistent values with the actual concentrations of turbidity observed on the field, indicating that the model is suitable to represent the turbidity of the water to the Itupararanga/SP/BR Reservoir. This is reinforced in the statistical validation of the model.

Low concentrations of turbidity presented by the model (between 0,62 and 1,24 NTU for the regions close to the dam, between 1,25 and 1,86 NTU in central and northeast regions of the reservoir) support the hypothesis of low concentrations of solids in suspension in the studied reservoir.

Economically the research presented a good alternative to evaluate the water quality in reservoirs, replacing the work field and the lab analysis that, depending on the number of samples, make the research expensive and slow.

Generally was estimated that the total economic cost of research is around € 8.000, considered low cost for water quality analysis of reservoirs, which makes the research economically viable.

The greatest obstacle faced by the research was to adequate the obtainment of the Ikonos imagery to the collection of turbidity sampling in the field, which theoretically should occur on the same day. Actually, due to the conditions of Ikonos image programming, it occurred with the lag of 2 and 3 days from the field work and with considerable cloud cover, including over parts of concerned sites in the water of the Reservoir. Even then, it was possible the using of this image’s bands in the construction of the inference model of water turbidity, with good results.

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