REMOTE SENSING AIDED QUANTITATIVE ANALYS IS OF FRESHWATER FLUME OF FILYOS RIVER IN THE BLACK SEA

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ABSTRACT

An integrated research has been conducted in this study on a river to better understand the fundamental theoretical properties of turbulent mixtures aided by RS technology. The pilot region selected for this study is the Filyos River that ends in the Black Sea, Turkey. It is accepted that the disperse distribution of the turbid freshwater flume at the river month where it opens to sea presents a Gaussian behaviour. Previous spatial data on the region gathered by Istanbul Technical University, ITU, and the field data collected during these studies have been used together with Landsat images belonging to years 1992 and 1999. During the studies, it is revealed that the distribution of turbid freshwater demonstrates Gaussian dispersion by analysing the reflection data, and is observed that it completely reflects concentration distribution. It is then that the dispersion coefficients, time of dispersion, variance and average flow rate have been calculated. This study forms an example showing the utility RS technology that presents quantitative data and better defines the hydraulic behaviour of a river with high turbidity.

Keywords: Freshwater Flume ; Filyos River; Quantitative Analysis; Remote Sensing.

INTRODUCTION

One of the most striking examples of fluid mechanics influencing the natural balance is the complicated movement of the fresh water in the sea, occurring at the mouths and deltas, where rivers reach the sea. Under such circumstances that produces a horizontal plume or jet, a lot of interrelated events occur, natural ecologic and morphologic characteristics of the coast come into existence and/or directly influenced. It is known that rivers carry into the sea not only freshwater flow but also a considerable amount of suspended material. The main source of these natural materials is erosion occurring on the bed of the rivers which are the main feeding sources of the shore morphology. Substances containing debris also accumulate because of discharges to the rivers. This is why it is extremely important to investigate freshwater plumes and identify their characteristics as a means to ensure the continued existence of nature.

Identifying the areas where the suspended substances carried by the freshwater cloud reach the shores and obtaining vital information in terms of the morphological and ecological aspects can aid to take precautions to protect the beaches by determining whether the quality of the sea water has deteriorated. It is widely known that there is a chronic beach erosion problem in most of the beaches. The main cause of this problem is the remarkable reduction in the amount of transported material carried by the rivers because of their retention in the dam basin. Contrary to what is expected, erosion occurs in long beaches instead of just the beaches next to the river mouths makes the coastal scientists and river basin planners to propose opposing solutions. Polluting materials carried to marine environment especially during heavy run-off periods lead to deterioration of coastal zones starting from the month of the river towards the sea in a dispersed manner. It is of utmost importance to monitor run-off and overflows in rivers and to put forth their impact regarding planning and sustainable management. The application of conventional monitoring techniques cause certain troubles thus, modern and new technologies like remote sensing (RS) that is based on optical determination appear to be the most appropriate method in monitoring studies. It provides better identification and understanding the movement of turbidity transported through overflows through synoptic view of the terrestrial landscape and is used to inventor, monitor and to change detection analysis of environmental and natural resources. Although remotely sensed images seldom replace the usual sources of information concerning water resources, they can provide valuable supplements to field data by revealing broad scale patterns not recognizable at the surface, recording changes over time, and providing data for inaccessible regions. Hydrological models and remote sensing techniques are advanced tools that are better suited to estimate hydrological processes at a regional scale by means of supplying up to date data on activities. It sets forth problems in an objective manner; swiftly transfers satellite data to user, and ensure the monitoring of temporal changes introduced by the solution applied. Using remote sensing data and GIS help to find solutions to the potential hydrological and environmental problems on time. Furthermore, accurate, fast and low cost data/information can be obtained in the studies. Remotely sensed data may provide an easy access for monitoring the spatial separation and obtaining the hydrodynamic characteristics of the turbid freshwater plume created by river flow in the marine environment.

In this study, Filyos river mouth located at the Black Sea coast of Turkey is the study area and flow properties in particularly horizontal dispersion coefficient has been calculated by using Landsat satellite images taken in two different times. Additionally, the effects of the plume on the morphology of neighbouring beaches have also been examined. The parameters like structure of the mouth of the freshwater flow, density of seawater, and current and wave conditions near the shore are required to discuss the movement of turbid freshwater in the sea so as to reflect the most characteristic features of the mixture in a turbulent environment in terms of hydrodynamics. The concentration of the solid substances carried with freshwater gets reduced via horizontal and vertical dispersion. It becomes sparse compared to the initial C_0 concentration at the mouth and becomes close to the concentration of the sea environment at the end of the cloud. Although it is known that in its movement, the freshwater cloud according to the depth comes into existence in the vertical mixture, it is at a negligible level (Fisher et al, 1979). The most general approach which expresses the change in the cloud environment of a high concentration cloud, which becomes sparse via diffusion and dispersion, is to write the distribution of the concentrations in the horizontal way in a receiving environment with the Gaussian Formula. According to this, the lateral distribution of the cloud concentration starting from the mouth to an x distance, which starts from the opposite y-axis, can be shown as follows;

$$s^2 = \left\{ \int_{-\infty}^{\infty} y^2 C(y).dy \right\} / \int_{-\infty}^{\infty} C(y).dy \quad (1)$$

Here s^2 shows the variance of the distribution. The coefficient of horizontal dispersion, D_y for any discharge time t, can be calculated as

$$D = s^2 / 2t \quad (2)$$

The value of the mixture in the area can be obtained by means of examining the movement of the fresh water cloud in the sea via classic or modern methods.

$$C(X,t) = C_0 .\exp(x^2 / 2s^2) \quad (3)$$

In the above equation, the distribution turns to a normal distribution if the mass is a unit. The relations between the momentums of this distribution can be used in solving diffusion. The variance of the distribution can be written as equation (1) and is accepted as a measure of the intensity of the distribution of the cloud (Schroeder, 1976). Standard deviation s, which is the square root of the variance, is a measure of the extension of the distribution dimensions. Gaussian distribution shows that 95% of the concentration is within $4s$. This is why the width of the cloud is calculated as $4s$ or $4\sqrt{2Dt}$ in most practical problems. Accordingly, the diffusion coefficient is obtained as $2D = ds^2 / dt$ or as $D = s^2 / 2t$ regarding the integration in a t discharge time. In these equations, it is seen that s^2 is related to the time and the formula below is written for two consecutive times of t_1 and t_2 (Schroeder, 1976).

$$s_2^2 = s_1^2 + 2D(t_2 - t_1) \quad (4)$$

If X_1 and X_2 are the distances from the discharge point on the cloud, then according to the speed at these points, the average speeds are $t_1 = X_1 / U_1$ and $t_2 = X_2 / U_2$. Therefore, the variance can also be written as $s^2 = 2D.(X / U)$.

As the traditional measuring system is very expensive and time consuming in examining the freshwater clouds of the rivers, using remote sensing methods has become a must. With such a technique, considering the fact that the reflection coefficients in various layers of the cloud are related to the concentration, distribution concentration is obtained as the reflection coefficient and it is proven that it is in line with the Gauss distribution, as expected. Related to this, s^2 values in various cloud layers are also obtained. In addition, Filyos River's solid item load and its current are known. So, it seems possible to obtain information about other features of the cloud through using such an approach. If it is accepted with reasonable approximation that the maximum concentration of fresh water cloud in the sea in the axis moving with the exit speed until the point where it is firstly spread is equal to the initial concentration, s_1^2 value at this point can be determined by means of remote sensing and can be calculated with the dispersion coefficient by equation 2.

In this study, the features of beaches adjacent to the river mouth, which can be under the influence of solid substances spread via the fresh water cloud, are analysed through of the remote sensing technique and limited local data.

DESCRIPTION OF THE STUDY AREA

The Filyos Stream located at the Western part of the Black Sea with a 13 300 km^2 drainage area is within the West Black Sea basin that covers 46 % of all the basins in the Black Sea. It is 215 km in length in the Southwest to Northeast direction, and 120 km in length in the North to South direction. The basin of the Filyos Stream is surrounded by the Black Sea and Bartýn River basin in the north, Guluc and Buyukmelen streams basins in the west, Yukari Sakarya basin in the south, Devrek Stream basin in the southeast, Gokirmak basin and Devrekani Stream basin in the northeast. This area consists mostly of mountains and plateaus and there are many small, medium and high mountainous areas starting from the coast leading south. This study has been conducted on only a part of the river basin, 30 km from the point where the Filyos River joins the Black Sea. At this region, the Filyos River is in a large meandering valley and the width reaches up to 1 km in certain places. The slope of the river, which lies on a flat plain, is 0.07 % (SHW, 1998). The intensity of erosion can vary from one area to another and the amount of sediment carried can change from one river to another depending on precipitation, vegetation, geological and morphological structure and land-use. Because there is a multiplicity of reasons, along this plain, except for the flat or slightly sloped agricultural area existing on both sides, on the sloped agricultural fields, there is low intensity surface erosion. In forest areas between agricultural areas, erosion is expected. However, the amount of erosion is below the average for the whole country as the area consists of high quality forests and pastures. The main reason of erosion is the uncontrolled farming on steeply sloped fields. The Caycuma plain in the study area is Figure1: Study Area is approximately 190 km^2 and its height is between 10-100m. Study area is shown in Figure 1. The average annual precipitation in the area is 608.4 mm.

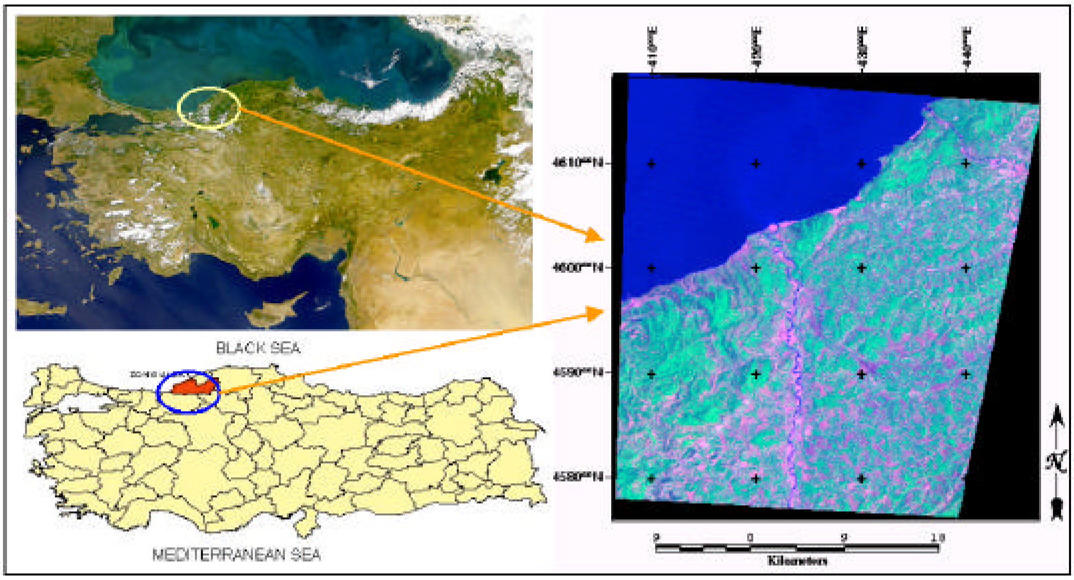

Figure 1. *The study area*

The Filyos River discharges during the flood observed are given in Table 1. Wind strength on the day the satellite passed over the area is given in Table 2. In the area, bathymetric conditions at the mouth of the river as in Figure 2 and the extension of the river into the sea can be clearly seen. During May, the average wind speed is determined as 37 knots in a NNW direction. On the coasts where the mouth of Filyos River is, the wave value given by the satellite is calculated as 0.7 m high in a WNW direction. This value was calculated using the CERC method and the data in Table 1. Solid substances, existing as a result of corrosion of the land surface and creek beds due to water, wind and ice movements, are carried by rivers. These sediments that partly accumulate in beds, in the natural or artificial reserves while reach the sea or lakes can be divided into two, suspended and bed load. The most valid method in determining the amount of the suspended load is to measure the sediment through an adequate number of observations. The bed load, which cannot be determined by means of measurement, is generally calculated as a certain percentage of the suspended load. According to the measurements undertaken by the flow observation station on the Filyos, the amount of sediment in the suspended load is determined as 237 tons/year/ km^2. When the bed load is also added, the amount becomes 296 tons/year/ km^2. According to these values, it can be argued that the Filyos River basin is subject to medium intensity erosion. The annual suspended sediment load of the river is 2.100.400 m^3/year.

DATA GATHERED AND METHODOLOGY APPLIED

In the measurements of the sediment cloud, Landsat satellite images data from 1992 and 1999 are utilized. The 1992 image was taken on 19 May 1992 when the amount of sediment the Filyos River carried was at the maximum. Taking the first channel of this image and by means of the density slicing method, the route of the sediment carried by the Filyos River towards in the sea and its direction are determined. This is given in Figure 2. The features of the satellite images used in this study are presented in Table 3.

Taking some cross-sections from the same image, which shows spectral reflection values, it has been investigated whether or not they are in coherence with the Gauss curve. In the study, Erdas Imagine 8.2 has been used as an image processing method. The cross-sections taken from the image and their places are shown in Figure 3 where it has subsequently been moved into the CAD environment and the crosscuts have been manually quantified on the monitor and the values on each fracture point obtained as point pairs.

Table 1. Filyos River Discharges During thee Flood (March-May) (SHW, 1998)

Day	*Month*	*Discharge (m^3 / s)*	*Day*	*Month*	*Discharge (m^3 / s)*	*Day*	*Month*	*Discharge (m^3 / s)*
21	*March*	*259.0*	*12*	*April*	*533.0*	*4*	*May*	*174.0*
22	*March*	*244.0*	*13*	*April*	*518.0*	*5*	*May*	*165.0*
23	*March*	*247.0*	*14*	*April*	*435.0*	*6*	*May*	*156.0*
24	*March*	*253.0*	*15*	*April*	*386.0*	*7*	*May*	*149.0*
25	*March*	*242.0*	*16*	*April*	*335.0*	*8*	*May*	*145.0*
26	*March*	*307.0*	*17*	*April*	*266.0*	*9*	*May*	*145.0*
27	*March*	*503.0*	*18*	*April*	*259.0*	*10*	*May*	*142.0*
28	*March*	*745.0*	*19*	*April*	*247.0*	*11*	*May*	*123.0*
29	*March*	*956.0*	*20*	*April*	*275.0*	*12*	*May*	*112.0*
30	*March*	*813.0*	*21*	*April*	*359.0*	*13*	*May*	*109.0*
31	*March*	*509.0*	*22*	*April*	*401.0*	*14*	*May*	*101.0*
1	*April*	*416.0*	*23*	*April*	*381.0*	*15*	*May*	*95.0*
2	*April*	*429.0*	*24*	*April*	*268.0*	*16*	*May*	*89.3*
3	*April*	*440.0*	*25*	*April*	*234.0*	*17*	*May*	*88.0*
4	*April*	*435.0*	*26*	*April*	*238.0*	*18*	*May*	*85.3*
5	*April*	*468.0*	*27*	*April*	*230.0*	*19*	*May*	*82.6*
6	*April*	*443.0*	*28*	*April*	*228.0*	*20*	*May*	*78.5*
7	*April*	*473.0*	*29*	*April*	*213.0*	*21*	*May*	*74.9*
8	*April*	*558.0*	*30*	*April*	*223.0*	*22*	*May*	*72.5*
9	*April*	*654.0*	*1*	*May*	*211.0*	*23*	*May*	*70.1*
10	*April*	*570.0*	*2*	*May*	*195.0*	*24*	*May*	*67.7*
11	*April*	*485.0*	*3*	*May*	*182.0*	*25*	*May*	*64.3*

Table 2. Wind data on the day the satellite passed over the area

Hour	*Direction*	*Velocity*	*Hour*	*Direction*	*Velocity*	*Hour*	*Direction*	*Velocity*
01	*SSE*	*14*	*09*	*NNW*	*21*	*17*	*NNW*	*23*
02	*SSE*	*7*	*10*	*NW*	*21*	*18*	*NNW*	*17*
03	*SE*	*16*	*11*	*NNW*	*29*	*19*	*NNW*	*13*
04	*SE*	*17*	*12*	*NNW*	*27*	*20*	*NNW*	*11*
05	*SSE*	*12*	*13*	*NNW*	*22*	*21*	*NNW*	*10*
06	*ESE*	*9*	*14*	*NNW*	*26*	*22*	*NNW*	*10*
07	*SSE*	*9*	*15*	*NNW*	*31*	*23*	*SSE*	*11*
08	*WNW*	*12*	*16*	*NNW*	*26*	*24*	*SSE*	*17*

Table 3. Information about satellite images used in this study

Image Date Landsat	*Spatial resolution (m)*	*Number of bands*
19 May 1992	*30, 120*	*7*
19 August 1999	*30, 60, 15*	*8+1*

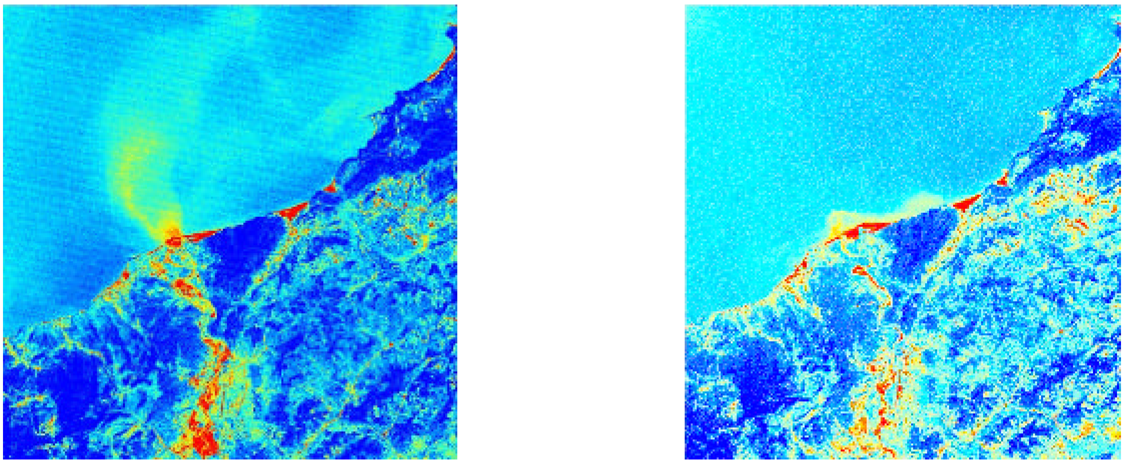

Figure 2. *Images of Filyos River where it joins the sea showing its progression*

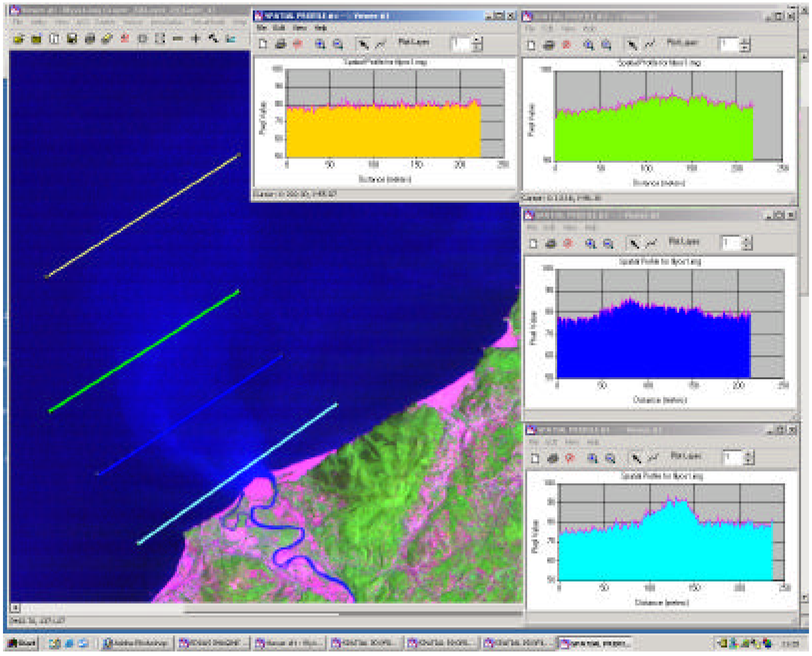

Figure 3. The sediment cloud's distributional spectral reflection cross-sections

The values have been turned into a data file and whether they are in coherence with the Gauss curve or not have been investigated. The cross sections obtained from 1992 images have been determined to be in line with the normal distribution from the statistical tests conducted. A similar procedure has been carried out on two crossections from the 1999 image. However, it has been observed that while the one, which was very close to the coast, is in correlation with the normal distribution, the one, which was far from the coast, is not. This is an output as on 19 August when the satellite image was taken sediment and water amount decreased to a minimum. Test results for the year of 1992 are given in Table 4.

Kolmogorov-Smirnov test is used to compare the values in the data vector X with a standard normal distribution (that is, a normal distribution having mean 0 and variance 1). The null hypothesis for the Kolmogorov-Smirnov test is that X has a standard normal distribution. The alternative hypothesis is that X does not have that distribution. The result H is 1 if one can reject the hypothesis that X has a standard normal distribution or 0 if one cannot reject that hypothesis. One rejects the hypothesis if the test is significant at the 5% level. H=Lillie test(X) performs the Lilliefors test on the input data vector X and returns H, the result of the hypothesis test. The result H is 1 if one can reject the hypothesis that X has a normal distribution or 0 if one cannot reject that hypothesis. The hypothesis is rejected if the test is significant at the 5% level. The Lilliefors test evaluates the hypothesis that X has a normal distribution with unspecified mean and variance, against the alternative that X does not have a normal distribution. This test compares the empirical distribution of X with a normal distribution having the same mean and variance as X. It is similar to the Kolmogorov-Smirnov test, but it adjusts for the fact that the parameters of the normal distribution are estimated from X rather than specified in advance.

Table 4. Tests applied to the cross-sections and their results

Cross-sections	*Kolmogorov-Smirnov test [H]*	*Lilliefors test [H]*
92-1	*1*	*0*
92-2	*1*	*0*
92-3	*1*	*0*
92-4	*1*	*0*

Determination of the dispersion coefficient and presentation of the results

Filyos images of August 1992 show the distribution of a flood occurred in the river basin, and in the sea. Daily average values of the flood in the Filyos River are given in Table 1 and the peak value of the flood is 1000 m^3/sec. This value expresses the flood which occurs approximately once every 8 years. The flood lasted around 60 days between 20 March and 19 May. Satellite images demonstrate the end of the flood period. At the time of the satellite passing over Filyos River, the wind speeds were recorded as given in Table 2 and the wind was blowing with a speed of 12m/sec in the WNW direction. Thus, it is expected that the plume moved to the east. It has been determined that in an average 60-day-period of time taken from the measures on the satellite image the plume went approximately10 km out to sea. So the average speed of 60 days of this occurrence can be predicted as

$$\text{"}_{mean} = 1000.00 / (60 \times 86400) = 0.19 \text{ cm/sec} \quad (5)$$

In other words, the speed of the distribution in the sea is at this rate. The s^2 values of the concentration distributions obtained are as given in Table 4. According to these values it is possible to say that the size of the concentration cloud is of $4s$ width, so the time unit the image expresses when the cross section is taken as the base is,

$$t_1 = (1260 \times 4) / 0.19 = 265263 \text{ sec} \quad (6)$$

Consequently, the image characterises a period of ~74 hours. Using equation 2, the average dispersion coefficient is calculated as follows;

$$D = (15840 \times 10^4) / (2 \times 265263) = 0.30 \times 10^3 \text{ cm}^2/\text{sec}. \quad (7)$$

Table 5 Standard deviation obtained for cross-sections

CROSS - SECTION	s	s^2
92-1	*4.1949*	*17.600*
92-2	*4.7567*	*22.630*
92-3	*4.4918*	*20.176*
92-4	*3.0381*	*9.230*

This value, based on a reader by Talbot, in Black Sea is higher than 0.75×10^3 cm^2/sec, that is the value given for continuous discharge; thus, it is possible to state that it is at an acceptable level given the fact that high turbulence characteristics during flood decrease in long term averages. This value is between the defined $(0.2 \sim 60) \times 10^3$ cm^2/sec interval for the lateral dispersion coefficient. Using equation 4, when the necessary time for the second crosscut is calculated, t_2 = 267149 sec is obtained. Using the width of $4s$ which characterises the distribution value in the second cross-sections, the average occurring speed can be calculated as (4.76 x 4 x 3000) / 267149 = 0.21 cm/sec. The fact that average occurring speeds are found to be identical same and that the results are very similar to each other in both cross-sections shows that the hypotheses were correct.

CONCLUSIONS

In this study, it has been re-shown that the observation of the spreading of the freshwater and sediment carried by rivers, in the sea can be observed in larger areas by means of remote sensing methods. In addition, the situation of sufficient local data, to reach quantitative results has been considered as an important result indicating the capacity of remote sensing methods. Particularly it has been presented that it is possible to obtain the dispersion coefficient as one of the most important hydrodynamic parameters, which characterise the spread of the turbid fresh water cloud. The fact that the hypothesis of characterising the horizontal concentration distribution, which is in coherence with the normal distribution, in the turbid fresh water used as the main starting point reaching the result, and the horizontal distribution of the reflection coefficients of the same cloud in the satellite images has been proven right should be considered a remarkable result. The sensitivity of the values obtained in the study is determined according to the presence or absence of local data of equal timing. Although the presence of the equally-timed results about the river has increased the accountability of the results, the fact that concentration and speed readers do not exist in fresh water cloud in the sea environment has prevented obtaining of better results.

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