研究快报

高浑浊内河悬沙浓度的遥感估测：以中国云南金沙江下游支流为例

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山区土地利用和土地覆盖变化对水文过程的影响是人们关注的热点，因为它与洪水或干旱等严重的自然灾害有密切关系。一般认为，森林的清除会引起一个地区水沙量的明显增加。但是，要通过在地面进行观测来测算大河流域泥沙流量是十分困难的，特别在山区和人烟稀少地区更是如此。遥感手段为在这些地区收集相关资料和数据提供了一个有效的途径。在这个研究项目中，我们开发出了基于测量在可见光、近红外光波段的遥感反射系数的高浑浊内陆河流悬沙浓度(SSC)预测方法，并采用了中国云南金沙江下游河流 SSC 的地面观测值和河水反射光谱的数据进行了校准和检验。

我们在2002年6月龙川江的流量和输沙量比较高的时候开展了野外调查，使用了GER－1500手持光谱仪测量河水的反射光谱。SSC的地面观测值采用标准水样过滤法获取。结果表明，地面观测得到的SSC的变化范围为16～13 000 g/m^3，其中间值和平均值分别为800 g/m^{3}和1 900 g/m^3。光谱仪测得的在800 nm和550 nm波段的反射率的比值(R800/R550)与上述SSC在0～250 g/m^{3}的范围内有很好的相关关系；两者的关系可以用

$$r = r_0(1 + S/a)/(1 + S/b)$$

的关系式表示。

式中，r是河水在800 nm和550 nm波段的反射率之比(R800/R550)，S是河流悬沙浓度(SSC)，r_0、a、b是相关参数。该公式通过变换后即可通过河水在绿色和近红外波段测得的反射率计算求取SSC的量值。但是当SSC值非常高时该关系式不能使用，因为800 nm和550 nm的反射率在高SSC时呈现大致恒定的量值，而我们大多数的野外观测点的值都高于250 g/m^3。

另外一种算法是依据河水的反射光谱构建一个水体反射光学模型，将悬沙颗粒在550 nm处的逆向散射系数(X550)和溶解有机质在440 nm (G440)的吸收系数作为两个相关参数代入模型。在此换算中，首先从光谱拟合模型所得到的反射光谱中提取X550，然后利用SSC和X550之间的关系计算SSC的量值。结果发现，悬沙的逆向散射系数X550与SSC在整个地面测得的SSC值范围(0～13 000 g/m^3)内有非常好的线性关系，相关系数高达0.97，即R^2= 0.97。

第一种算法仅使用了两个波段的反射光谱，因此适合用来估算基于具有绿色和近红外波段的LANDSAT或SPOT卫星信息的SSC。第二种算法需要更多可见光和近红外区的波段，以实现光谱拟合。不过，由于只需要两个参数(X550和G440)，有可能从一个有限数量的波段提取这些参数，比如LANDSAT或SPOT卫星传感器所具有的那些波段。

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Remote Sensing Estimation of Suspended Sediment Concentrations in Highly Turbid Inland River Waters: An Example from the Lower Jinsha Tributary, Yunnan, China

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Abstract: The impact of land use and land cover change in mountain areas on hydrological processes is a major concern, as it potentially can result in catastrophic events such as floods and droughts. It has been suggested that forest removal causes increased water and sediment yield. However, it is difficult to quantify the sediment fluxes of large river basins by ground measurements, especially in mountainous and less accessible areas. Remote sensing provides a viable option for obtaining data on the sediment loads of rivers in these areas. In this study, we developed algorithms for estimating suspended sediment concentrations (SSC) in highly turbid inland river waters from remote sensing reflectance measurements in the visible and near-infrared wavelength bands. The algorithms were calibrated using ground measurements of SSC and water reflectance spectra at tributaries of the Lower Jinsha River in Yunnan, China. The field trip was conducted in June 2002, a season of high water discharge and high sediment yield. A GER 1500 handheld spectrometer was used to acquire the reflectance spectra. Suspended sediment concentrations were measured using the standard method of water filtration. The SSC values spanned a wide range from 16 g/m^3 to 13 000 g/m^3. The median and average concentrations were about 800 and 1900 g/m^3 respectively. The ratio of the reflectance at 800 nm and 550 nm (R800/R550) was to correlate well with SSC up to approximately 250 g/m^3. The ratio R800/R550 could be fitted to the equation

$$r = r_0(1 + S/a)/(1 + S/b)$$

where r = R800/R550, S is the suspended sediment concentration and and r_0, a, b are the fitting parameters. This equation could be inverted to obtain the SSC value from the measured reflectance in the green and the near-infrared bands. This inversion algorithm could not be used for waters with very high SSC, as the ratio R800/R550 remained approximately constant at high SSC. More than half of our sampling points fell into this category. In this case, we fitted the water reflectance spectra to an optical model of water reflectance with the backscattering coefficient of sediment particles at 550 nm (X550) and the absorption coefficient of dissolved organic matter at 440 nm (G440) as the fitting parameters. The suspended sediment backscattering coefficient X550 was found to vary linearly with SSC for the whole range of measured SSC values (up to 13 000 g/m^3), with a high correlation coefficient (R-squared) of 0.97. In the second inversion algorithm, X550 was first retrieved from a reflectance spectrum using the spectral fitting method. The SSC value was then calculated using the relation between SSC and X550. The first algorithm used only the reflectance at two bands and hence would be suitable for use in estimating SSC from LANDSAT or SPOT satellites with green and near-infrared bands. The second algorithm would require more spectral bands in the visible and near-infrared region in order to perform spectral fitting. However, since only two parameters (X550 and G440) were needed, it might be possible to retrieve these parameters from a limited number of bands, such as those present in LANDSAT or SPOT satellite sensors.