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SNOW COVER MONITORING BY REMOTE SENSING AND SNOWMELT RUNOFF CALCULATION IN THE UPPER HUANGHE RIVER BASIN

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ABSTRACT: The upper Huanghe (Yellow) River basin is situated in the northeast of the Qinghai-Xizang (Tibet) Plateau of China. The melt-water from the snow-cover is main water supply for the rivers in the region during springtime and other arid regions of the northwestern China, and the hydrological conditions of the rivers are directly controlled by the snowmelt water in spring. So snowmelt runoff forecast has importance for hydropower, flood prevention and water resources utilization. The application of remote sensing and Geographic Information System (GIS) techniques in snow cover monitoring and snowmelt runoff calculation in the upper Huanghe River basin are introduced amply in this paper. The key parameter—snow cover area can be computed by satellite images from multi-platform, multi-temporal and multi-spectral. A cluster of snow-cover data can be yielded by means of the classification filter method. Meanwhile GIS will provide relevant information for obtaining the parameters and also for zoning. According to the typical samples extracting snow covered mountainous region, the snowmelt runoff calculation models in the upper Huanghe River basin are presented and they are mentioned in detail also. The runoff snowmelt models based on the snow-cover data from NOAA images and observation data of runoff, precipitation and air temperature have been satisfactorily used for predicting the inflow to the Longyangxia Reservoir, which is located at lower end of snow cover region and is one of the largest reservoirs on the upper Huanghe River, during late March to early June. The result shows that remote sensing techniques combined with the ground meteorological and hydrological observation is of great potential in snowmelt runoff forecasting for a large river basin. With the development of remote sensing technique and the progress of the interpretation method, the forecast accuracy of snowmelt runoff will be improved in the near future. Large scale extent and few stations are two objective reality situations in China, so they should be considered in simulation and forecast. Apart from dividing, the derivation of snow cover area from satellite images would decide the results of calculating runoff. Field investigation for selection of the learning samples of different snow patterns is basis for the classification.

KEY WORDS: upper Huanghe River; snowmelt runoff; remote sensing and GIS; snow cover area

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1 INTRODUCTION

There are $3451.8\times10^8m^3$ of the mean annual snowfall and $535.6\times10^8m^3$ of the snow water storage in the arid regions of the northwestern China in winter (LI, 1987; LI, 1989). The water equivalent in seasonal snow cover reaches to $10^{12}m^3$ (LAN, 1991; LAN, 1999). The Longyangxia Reservoir in the upper Huanghe River basin is able to hold $27.4\times10^9m^3$ of water, and over 80% of its inflow comes from the drainage basin above the Tangnag Hydrometric Station (YANG and MA, 1984). Elevation of the station is over 3000m a. s. l. and the total area is 121 972km^2, where climate is very cold, and there is plenty of snow cover in the mountainous region over 4000m a. s. l. from October to June. Only a few hydro-meteorological and meteorological stations are situated in the surroundings of snow-covered areas, providing a little

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precipitation for studying dynamic variation on snow cover. Fortunately, snow cover information in the drainage basin can be obtained from the AVHRR images of the NOAA meteorological satellite in recent years. These images can provide sufficient information on snow cover at different periods, which is quite important for studying the dynamic variation of the special extent of snow cover, snow volume, water equivalent, and their changing trend.

2 CALCULATION PRINCIPLES

2.1 Calculation Principles, Technology and Methods

For snowmelt runoff modeling, more commonly simulating construction is to select temperature (T), precipitation (P) and snow cover area (S) as factors of models with a period from end of March to early June. The formula is mentioned as like this:

$$Q = f(T, P, S) + \mu$$

where μ represents remaining parameters computed and obtained by investigating and testing, e.g., time lag, runoff coefficients, recession coefficient and cover degree of snow and glacier. Because of the great scale basins of the western China, the zoning and dividing based on properties of partial geomorphology and climate has great utility value. It is better for each sub-basin (the basic unit for simulation), that not less than one observation station would be used for runoff processing. For raising the accuracy of forecasting, four technological steps have often been used to overcome the shortcomings mentioned above. The first is to establish GIS in order to understand the environment conditions and terrain factors. The second is to divide the basin into sub-basins using Digital Terrain Analysis (DTA). The third is to use data sets from nearby stations outside to substitute as control station based on correlative analysis. The fourth is to reform models in order to satisfy requirement of obtaining real-time update.

Remote sensing is the most useful data on the study of snow hydrology since it can survey snow covered area and snow melting procedures. As the spectral and spatial resolution of available sensors much improved, three platforms now have been extensively employed in China: Landsat, NOAA/TIROS satellites and airscape. In general, the MSS, TM, AVHRR are more current and useful data sets. As a new geographical analysis method, Geographic Information System (GIS) is applied for study the environmental subjects because it is able to provide some parameters related to the features of terrain. In experience, DTM with terrain factors, land cover including snow cover and vegetation cover, coordinating system, radiation index and model parameters could be acquired. It's an important tool to understand the environment features.

2.2 Snowmelt Runoff Models

There are four types of snowmelt runoff models, such as improved snowmelt runoff model (RANGO and MARTINEC, 1995), model based on glaciology principals, model based on energy balance and statistics model. In these models, the same characteristics are that snow cover area, temperature and precipitation have been input as the dominant parameters. The succeed models which have been checked out by forecasting for hydrological stations and water resources units are shown as follows: 1) Improved SRM Model in Heihe Basin(ZHANG, 1988); 2) Zoning Snowmelt Runoff Model in Qu'ngoin Valley, a branch of the upper reaches of the Huanghe River (WANG, 1988); 3) Gray Model for snowmelt runoff in the upper reaches of the Huanghe River (LAN and KANG, 1997); and 4) Statistics Model for Snowmelt Runoff in the upper reaches of the Huanghe River (LAN, 1991).

2.3 Calculation Procedure

Before doing inside analysis, ground truth investigation are very important and can't be replaced in any other ways. It is best if ground truth coincides with satellite passes over the area of investigation. The context of an investigation includes 1) records on number of normal black and white photographs for recognizing snow cover distribution and for training sites of image processing; 2) snow properties surveys such as snow depth, snow density, snow metamorphism and intensity of snowmelt runoff; 3) replenishment of basic data for some watersheds with insufficient hydro-meteorological data and more a temporary thermometer screen need to be equipped for this object.

2.3.1 Digital terrain analysis and zoning

In order to manage systematically and control efficiently ice and snow water resources information and environmental elements, in sample basin, Ice and Snow Water Resources Information System (ISWRIS) is established at first, which can provide relative information including Digital Terrain Model (DTM), administration traffic, statistics data sets, hydro-meteorological data and so on (WANG, 1988). Normally, there are four approaches for zoning, they are: 1) administration units with their boundaries; 2) control area of observation station; 3) terrain factors including elevation, slope, aspect; 4) geographical nature elevation. Distribution of snow cover is very regular in the dividing elevation zones and the connecting control areas of station have usually been used to complete division in many watersheds in western China. A sample about the Qu'ngoin River Basin of western China, a first-order branch of the upper Huanghe River, and snowcover map of the basin and its three sub-basins and their characteristics are illustrated respectively in Fig. 1 and Fig. 2.

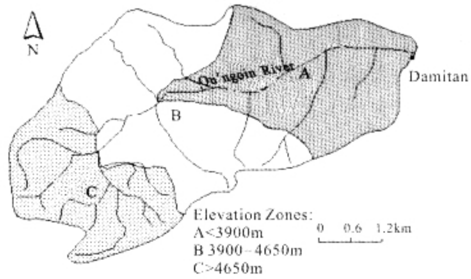

Fig. 1 The Qu'ngoin River basin of western China, its three sub-basins and their characteristics

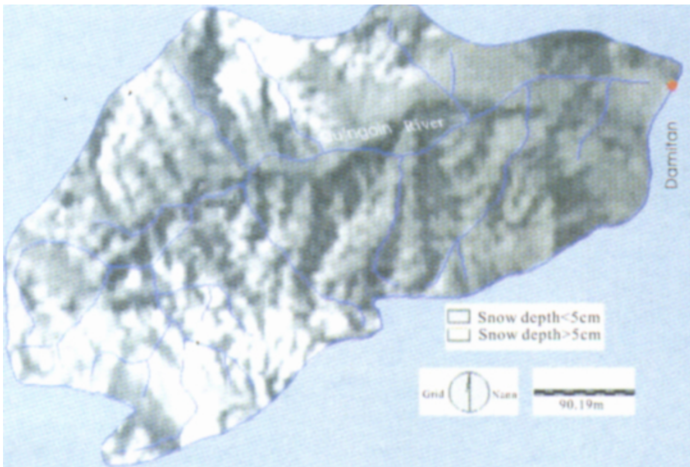

Fig. 2 Snow cover of the Qu'ngoin Basin

2. 3. 2 Snow surveys

(1) Data set sources. Recently, Landsat MSS, TM and NOAA/AVHRR have been utilized extensively to make snow map (Landsat MSS, TM to be obtained from Beijing Chinese Satellite Services Station, NOAA/AVHRR from LIGG Data Center). For monitoring and forecasting in real-time, the NOAA/AVHRR is a best choice for its guaranteed access to remote sensing data in spatial and temporal. The topographic and line data and their attributes were managed by ARC/INFO. The point data sets (observation data from stations and investigations) were also input and established database. All of information in no-image relative test area could be loaded and applied from database.

(2) Image processing. In view of higher abedlo, it is not difficulty to extract snow indices from other categories. However, the regions in western China are seldom cloud free at one time. Therefore, regional mosaic techniques must be used for the images in a period. Apart from the difference of index thresholds between snow and cloud, by comparing and analyzing alternatively between the continual images in difference days, snow could be mapped from a mixed situation.

Most commonly, the classification method is applied by supervised learning samples for snow cover phenomenon in mountainous regions. Best results were obtained by classifying AVHRR band 1 and 2 using the minimum distance classifier (BAUMGARTNER and RANGO, 1995). Fig. 3 shows a processing to get snow cover extent by image reclassification and image filter in the Qu'ngoin basin ($5286km^2$), on 16 Dec., 1989.

3 SNOWMELT RUNOFF CALCULATION AND FORECAST

Snowmelt runoff Model (SRM) (MARTINEC and RANGO, 1987) based the degree day method and calculated the snowmelt runoff on a daily basic is effectively used with extensive testing. The results show the accuracy of SRM (BAUMGARTNER and RANGO, 1995). In the other sides, the model based on fully distributed energy balance has also been studied within sample regions(CAZORZI and FONTANA, 1996). But, because of the requirement of many input

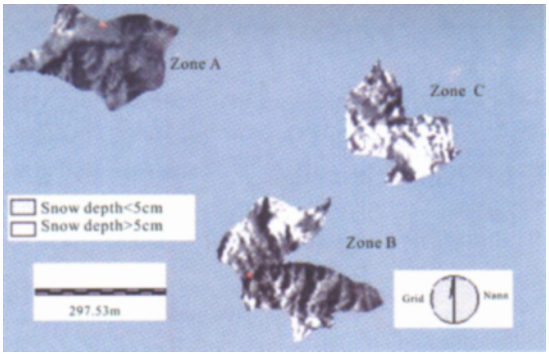

Fig. 3 Snow covers extent for each zone in the Qu′ngoin River Basin on 16 Dec. 1989

variables and data sources, it is indeed difficult to utilize SRM for forecasting in real-time for larger basins. Authors consider that snowmelt modeling by combining air temperature and a distributed radiation index (CAZORZI and FONTANA, 1996) has been in some degree likely to a most responsible simulating model for real forecast. Connection with guarantee of input variables and limit of large scale in western China, some simple, but available methods have been applied to build the snowmelt runoff forecast models in medium and longer period for many basins of western China.

3.1 Zoning Snowmelt Runoff Model in the Qu′ngoin River Basin, a branch of the Upper Huanghe River

Supported by remote sensing data and database, snow covered area can be calculated and a representative station for each zone has been extracted using components analysis. The three variables, snow cover area, temperature and precipitation are chief input variables. The covered glaciers in c zone (altitude over 4650m) possesses an importance in snowmelt runoff calculating, which would delay the melting period with a higher runoff coefficient almost to 20% than snow covered zones according to field investigation. Snowmelt runoff calculating equations during the period from the end of March to the early of June are as follows:

$$Q_a = C_s(-4.96 + 0.345 P_a + 1.214 S_a + 0.56 T_a)$$
$$Q_b = C_s(-1.72 + 0.3 P_b + 0.72 S_b + 0.412 T_b)$$
$$Q_c = C_g(-13.6 - 12.98 P_c + 0.5 S_c + 0.751 T_c)$$
$$Q = C_s(1 - K)(Q_a + Q_b + Q_c)$$

Snowmelt runoff calculating equations in April are as follows:

$$Q_a = C_s 16.65 + 0.3 P_a - 0.47 S_a + 0.162 T_a)$$
$$Q_b = C_s(15.87 + 0.13 P_b - 0.31 S_b - 0.2 T_b)$$
$$Q_c = C_g(16.05 - 0.21 S_c + 0.33 T_c)$$
$$Q = C_s(1 - K)(Q_a + Q_b + Q_c)$$

where, Q : discharge (m^3/s); C: runoff coefficient; K: regression coefficient; T: air temperature; P: precipitation(mm); S: ratio of snow cover area to total area; a, b, c : symbol of zone; s, g: snow covered zones and glacier covered zone. In western China, most watersheds are larger than 5000km^2 with altitudes over 3500m. So it′s very important to divide basins into zones, or else, the bigger errors will occur in calculation. As mentioned in RANGO A and MARTINEC J (1995), the errors of no-zoning are 30% larger than those of zoning. Contrast between calculating errors of no-zoning and zoning can be seen in Table 1.

Table 1 Contrast between calculating errors of no-zoning and zoning

Periods	Measured	Calculated		Errors(%)	
		Zoning	No-zoning	Zoning	No-zoning
April in 1988	31.7	30.9	23.4	2.4	26.0
April in 1989	20.6	20.3	16.5	1.4	19.7
End of March to early June in 1988	13.9	11.2	9.7	9.7	30.6
End of March to early June in 1989	11.6	10.8	13.8	13.8	18.9

3.2 Statistics Model for Snowmelt Runoff in the Upper Reaches of the Huanghe River

The Longyangxia Reservoir situated in the northeast of Qinghai-Xizang Pleteau is one of the largest reservoir on the upper Huanghe River, and snowmelt runoff occupies over 40% in the inflow of the river during the late March to early June (LAN and KANG, 1998) . So a statistics model calculating the inflow of the river, the doubling screen and gradual regression model, was presented and it is used to forecast the inflow in spring.

Based on the snow cover data from AVHRR images and runoff data at the Tangnag Hydrometric Station(the representative observation station of the inflow into the Longyangxia Reservoir), air temperatures and precipitation data at the Golog Meteorological Station (situated in the main snow distributing region in the upper Huanghe River basin), a runoff forecast model for snowmelt period (from late March to early June) were presented and applied to predict the inflow into the Longyangxia Reservoir from late March to June.

Taking the prediction of inflow into the Longyangxia Reservoir during June 1 – 10 as an example, a mid-range forecast model of the inflow can be established by means of the above double screen and gradual regression equation, and the following Hydrometric forecasters selected by the cognate degree analysis (DENG, 1986; LAN, 1993) were employed in the models: 1) the measured discharge series at the Tangnag Hydrometric Station during May 20 – 31; 2) snow-coverage series above the Tangnag Hydrometric Station in the upper Huanghe River basin from October of last year to late May extracted from NOAA images; 3) the mean air temperature and precipitation at the Golog Meteorological Station in May 20 – 31; and 4) the periodic factors series selected by defining $F_\alpha = 2.0$ whose length are 27a, 5a and 8a respectively. As a result of stepwise regression analysis, following equation with six factors composes the final forecast model:

$$Q_c = 0.90X_1 + 0.58X_2 + 0.82X_3 + 0.27X_4 - 7.6X_5 + 7.6X_6 - 164$$

where, Q_c is the predicted value of the inflow into the reservoir during June 1 – 10 (m^3/s), x_1, x_2 and x_3 are the runoff 's major cycle sequences of the 27a, 5a and 8a during June 1 – 10 for years at the Tangnag Station respectively; x_4 is the measured mean runoff series during May 20 – 31 over the years through the Tangnag Station (m^3/s); x_5 is the mean snow-cover percentage in October of last year at the Tangnag Station (%); and x_6 is the precipitation (mm) at the Golog station during May 20 – 31.

The measured and computed values of the inflow into the Longyangxia Reservoir during June 1 – 10 for years are listed in Table 1 and illustrated in Fig. 4 for comparison.

It can be seen from Table 2 or from Fig. 4 that Q_c is close to Q_m satisfactorily, and the forecast error is less than 15%. Dominant effects of the meteorological and hydrological factors and influence of the periodic variations of the runoff series both are considered in above model. Therefore, the model can represents the change processes of natural hydrological phenomena more reliably than other conventional models. As a result, the forecast error is significantly reduced.

Table 2 The calculated and measured values (Q_c and Q_m) of the inflow into the Longyangxia Reservoir during June 1 – 10 since 1976 (m^3/s)

Year	Q_m	Q_c	$(Q_m - Q_c)/Q_m$ (%)	Year	Q_m	Q_c	$(Q_m - Q_c)/Q_m$ (%)
1976	1166	1000	–14.2	1989	1167	1370	17.4
1977	688	735	6.83	1990	736	837	13.7
1978	702	660	–5.98	1991	514	465	–9.53
1979	441	400	–10.0	1992	730	660	–9.59
1980	221	297	34.4	1993	834	728	–12.7
1981	729	700	–3.98	1994	638	580	–9.09
1982	1931	1800	6.78	1995	707	650	–8.06
1983	1034	1000	–3.29	1996	862	910	5.57
1984	535	500	–7.00	1997	731	855	17.0
1985	508	560	11.4	1998	522	600	14.9
1986	809	967	19.5	1999	1520	1255	–17.4
1987	794	668	–15.9	2000	833	760	–8.76
1988	521	477	–8.44	2001	776	650	–16.2

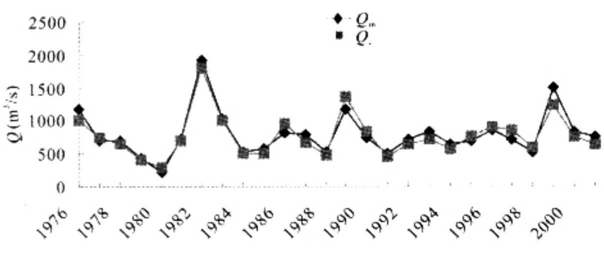

Fig. 4 The measured and calculated values (Q_m and Q_c) of the inflow into the Longyangxia Reservoir during June 1 – 10 since 1976 (Q_c after 1986 is predicted value)

4 CONCLUSIONS

The water resources originating from snowmelt (including glacier-melting) is a precious water sources in western China, especially in the spring ablation season. Accuracy of forecasting will affect management both on industry and agriculture, and on reservoir operation (Longyangxia Reservoir located at lower end of snow cover region). In China, large scale extent and few stations are two objective reality situations and should be considered in simulation and forecasting.

Apart from dividing, the derivation of snow cover area from satellite images would decide the results of calculating runoff. Field investigation for selection of the learning samples of different snow patterns is basis for the classification.

Above runoff snowmelt models based on the snow-cover data from NOAA images and observation data of runoff, precipitation and air temperature have been satisfactorily used for predicting the inflow to the Longyangxia Reservoir during late March to early June. The result shows that remote sensing techniques combined with the ground meteorological and hydrological observation isof great potential in snowmelt runoff forecasting for a large river basin. With the development of remote sensing technique and the progress of the interpretation method, the forecast accuracy of snowmelt runoff will be improved in the near future.

REFERENCES

BAUMGARTNER M F, RANGO A, 1995. A microcomputer-based alpine snow-cover analysis system[J]. *PEER-Reviewed Article*, 36(2): 1475 – 1486.

CAZORZI F and FONTANA G Dalla, 1996. Snowmelt modeling by combining air temperature and distributed radiation index [J]. *Journal of Environmental Hazards*, 32(4): 161 – 171.

DENG Ju-long, 1986. *Grey Prediction and Decision*[M]. Wuhan: Industry Univerisity of Central China Press, 103 – 117. (in Chinese)

LAN Yong-chao, 1991. Period analysis and stepwise regression double riddling model based on satellite snow cover data for forecasting snowmelt runoff [J]. *Journal of Remote Sensing Technique and Its Application*, (Special Issue): 113 – 117. (in Chinese)

LAN Yong-chao, 1993. Application of grey cognate degree analysis in snowmelt runoff forecasting[J] . *Journal of Glaciology and Geocryology*, 15(3): 481 – 486. (in Chinese)

LAN Yong-chao, KANG Er-si, 1997. Grey Topology Forecast Method about runoff in the upper Yellow River[J]. *Journal of Glaciology and Geocryology*, 19(4): 308 – 311. (in Chinese)

LAN Yong-chao, KANG Er-si, 1998. Runoff forecast model for during spring inflow to the Longyangxia Reservoir in the upper Yellow River Basin[J]. *Journal of Glaciology and Geocryology*, 20(4): 199 – 205. (in Chinese)

LAN Yong-chao, 2000. Trend and characteristic of variation on the runoff the upper Yellow River above Tangnag[J] . *Journal of Desert Research*, 20(3): 273 – 277.

LI Pei-ji, 1987. Seasonal snow resources and their fluctuations in China[A]. *IAHS Pub*. [C], (166): 93 – 104.

LI Pei-ji, 1989. Recent treats and regional differentiation of snow variation in China[A]. *IAHS Pub*. [C] , (183): 3 – 9.

MARTINEC J, RANGO A, 1987. Interpretation and utilization of areal snow cover data from satellites[J] . *Annals of Glaciology*, 42(3): 166 – 169.

RANGO A, MARTINEC J, 1995. Degree-day method for snowmelt computation[J]. *Water Resources Bulletin* , 31(4): 657 – 669.

WANG Jian, 1988. Snow cover distribution in the Heihe Basin in the Qilian Mt. [A]. *Memoirs of Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences*[C]. (6): 55 – 63. (in Chinese)

YANG Ke-fei, MA Fu-hong, 1984. Discussion on the long-term forecast and management of runoff in April – June along the upper Yellow River[J]. *Journal of Hydropower*, 1 (1): 130 – 134. (in Chinese)

ZHANG Shun-ying, 1988. Forecasting snowmelt runoff using NOAA/TIROS satellite data for the Huanghe River and Heihe River[A]. *Memoirs of Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Science*[C], (6): 75 – 79. (in Chinese)