Hydrologic application comparison among typical open global DEM data based on remote sensing images
——taking Fenhe River Basin of China as an example

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Abstract—**As the data source in digital topographic analysis, digital elevation model (DEM) data plays an important role in many fields, and hydrologic application is an important one among them. The successive release of open global DEM datasets provides multi choices for these applications, but also brings puzzles in DEM data selection. Taking Fenhe River Basin of China as the study area, this research compared the hydrologic networks extracted by typical global DEM data using matching difference (MD), correctness (C) and figure of merit (FM) indexes. Firstly, four DEM-derived hydrologic networks (DHNs) were acquired through topographic analysis using four typical global DEM datasets, including Shuttle Radar Terrain Mission (SRTM) data with 1 arc second resolution (SRTM1), SRTM data with 3 arc second resolution (SRTM3), ASTER global DEM data in the second version (GDEM-v2) and ALOS world 3D-30m (AW3D30) data. Then, the reference hydrologic network (RHN) was interpreted based on remote sensing images. Finally, the DHNs were evaluated and compared by referencing the RHN using different indexes. Research results show: (1) four DHNs have similar distribution in mountain regions but much different performance in flat regions; (2) all the indexes (including MD, C and FM) indicate that about the quality of the DHNs, the best is the AW3D30 data, then the SRTM1 data, the next is the SRTM3 data, and the GDEM-v2 data has the worst quality; (3) through analyzing the MD distribution in different slope classes for the four global DEM datasets, the MD mainly distributes in flat region, and then sloping region, but seldom in steep region. Overall, AW3D30 has the best quality, a little better than SRTM1 and much better than SRTM3 and GDEM-v2; SRTM3 and GDEM-v2 data have much worse quality, and GDEM-v2 data is the worst in the four global DEM datasets. Considering that the AW3D30 data is originated from the DEM dataset with 5m resolution, it may exerts more effect in future digital topographic analysis.**

Keywords: **hydrologic application comparison; matching difference; correctness; figure of merit; typical open global DEM data; remote sensing images; Fenhe River Basin**

I. INTRODUCTION

Digital Elevation model (DEM) data can provide significant information for many research activities. Hydrological process, especially hydrologic network mapping or watershed delineation is an important one. Successive release of global DEM datasets provide many choices for hydrologic applications, but brings selection puzzles simultaneously [1].

Taking Fenhe River Basin of China as the study area, this research aims to compare the hydrologic applications among typical open global DEM datasets using different indexes, including matching difference (MD), correctness (C) and figure of merit (FM) indexes. Through hydrologic application comparison, this research provides reference for open global DEM datasets selection, especially in hydrologic applications.

II. STUDY AREA AND DATA SOURCES

A. *Study Area*

Located in northern and middle part of China, Fenhe River Basin distributes between the latitudes of 35ºN and 39ºN and longitudes of 110ºE and 114ºE (Fig. 1). The elevation decreases from north to south and is high in two sides. With a drainage area of about 3.97×10^4 km^2, Fenhe River Basin refers to the region controlled by Fenhe River and its tributaries. Across two important cities of Taiyuan and Linfen, the mainstream of Fenhe River flows from north to south in the middle section of Fenhe River Basin. Fenhe River has a length of about 695 km and (Sun et al., 2013), which is the biggest river in Shanxi Province and the second largest tributary of Yellow River (the mother river of China).

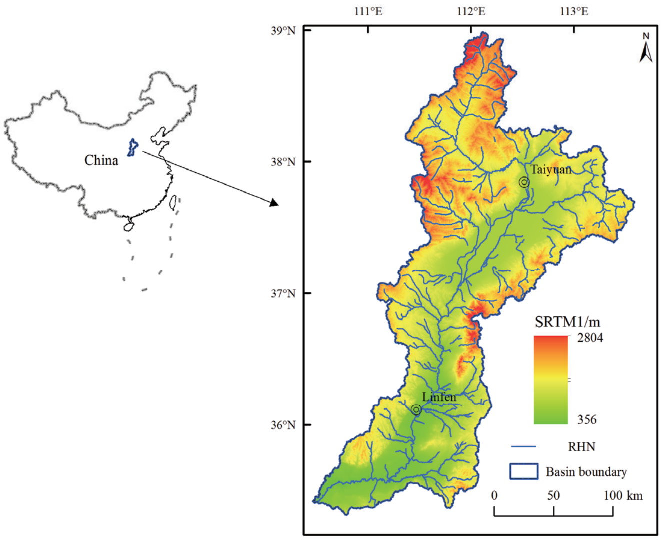

Figure 1. Location and geomorphic units in the study area

B. Data Sources

The main data sources in this research include remote sensing images and the typical open global DEM dataset which refers to Shuttle Radar Topography Mission (SRTM) data with 1 arc second resolution (SRTM1), SRTM data with 3 arc second resolution (SRTM3), ASTER global DEM data in the second version (GDEM-v2) and ALOS world 3D-30m (AW3D30) data.

Remote sensing images were downloaded from Geospatial Data Cloud (http://www.gscloud.cn/). The downloaded images include Landsat 8 products in 2015 and Landsat global composite products (1999-2003). Landsat global composite products adopt 7, 4 and 2 bands with false natural colour. To keep band spectrum consistency, Landsat 8 products adopt 7, 5 and 3 bands. With spatial resolution of 15m, remote sensing images at two phases can provide comparison and verification in interpreting hydrologic networks.

Collected over 11 days in February 2000, SRTM data covers the land between 60ºN and 56ºS, about 80% of global land. SRTM1 data was released from NASA's Earth Observing System Data and Information System (EOSDIS) website (http://reverb.echo.nasa.gov/) in 2015. Fortunately, there were no holes for SRTM1 in the study area (Fig.1). SRTM3 data was processed and downloaded from the CGIAR-CSI (http://srtm.csi.cgiar.org/). It is the 4th version, so it is also called for SRTM3 V4 DEM data. SRTM3 data is a homogeneous-quality elevation data around the world, so it achieves great success after its release.

Acquired by global ASTER stereo images, GDEM-v2 data has higher spatial resolution (1 arc second) and wider coverage (83^{o} N-83^{o} S) than SRTM3. Released in October 2011, GDEM-v2 data can be downloaded from USGS Global Data Explorer. GDEM-v2 is an upgraded version of GDEM-v1, which is developed using an advanced algorithm and more data sources. GDEM-v2 may replace GDEM-v1 in the future.

Released in March 2017, AW3D30 data covers similar coverage to SRTM data. Meanwhile, all the holes are filled by existing DEM datasets. Using both mean and median values, AW3D30 data was resampled from the "World 3D Topographic Data" with 5m spatial resolution, so AW3D30 data is regarded as the most precise global DEM dataset at 30m resolution level [2]. The "World 3D Topographic Data" with 5m spatial resolution may be freely released in the future, so it is much significant to estimate the performance of AW3D data in advance.

III. METHODOLOGY

The workflow of this reserach is: DEM-derived hydrologic networks (DHNs) were firstly extracted from typical global DEM datasets using digital topographic analysis methods; then, reference hydrologic network (RHN) was visually interpreted from remote sensing images; then, finally, key indexes such as C, FM and MD were computed to compare RHN and DHNs. Especially, MD were computed in the slope distribution at different classes.

A. DHNs Acquistion

DHNs were computed based on all the four global DEM datasets using Hydrology Tools in ArcGIS 10.2 software. Firstly, all the sinks were filled using "Fill" function; based on the filled DEM data, flow direction from each cell to its steepest downslope neighbor was computed; then, using "Flow Accumulation" function, the number of accumulated upstream cells can be computed for each cell; finally, DHNs were acquired for the four global DEMs using "stream definition" function based on a threshold value of contributing area.

The threshold value of contributing area has close relation to the level of details of the streams. A higher value corresponds to sparse hydrologic network, while lower value may create small stream features that do not actually exist. Through experiment, the threshold value in this research was determined as 64.8 km^2.

Finally, significant rivers were selected through stream classification. In this research, streams were left at third-order to present main hydrologic networks in the study area. All other small streams were removed from the DHNs.

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B. RHN Acquistion

RHN was used to compare and evaluate the DHNs. According to the order and length of the extracted DHNs, RHN was visually interpreted based on remote sensing images and basic geographic database in ArcMap software.

The interpreted RHN was shown in Fig. 1, which presented main stream distribution in the study area.

C. C and FM Acquistion

C and FM are mainly used to evaluate the similarity between RHN and DHNs. C refers to the correct portions of RHN represented by the DHNs. FM refers to the degree of RHN represented by the DHNs [3]. To acquire C and FM, the RHN and DHNs were firstly transformed from vector (line) to raster type. The formulas of C and FM were the following:

$$C = \frac{N_{R \cap D}}{N_R} \times 100\% \quad (1)$$

$$FM = \frac{N_{R \cap D}}{N_{R \cup D}} \times 100\% \quad (2)$$

In the equations (1) and (2), R refers to raster type of RHN; D refers to raster type of DHNs; $N_{R \cap D}$ refers to the pixel number of RHN intersecting DHNs; $N_{R \cup D}$ refers to the pixel number of RHN merging DHNs [3].

Considering the spatial resolution of remote sensing images and typical open global DEM datasets, the pixel size for C and FM computation was determined as 100m.

D. MD Acquistion in Different Slope Classes

Through superimposing RHN and DHNs, some small polygons may create due to the mismatch between RHN and DHNs. MD refers to the ratio between the area of these small polygons and the total area of the drainage [4], the formula of which was the following:

$$MD = \frac{\sum A_i}{A_D} \times 100\% \quad (3)$$

where A_i refers to the area of the small polygons due to mismatch between RHN and DHNs; A_D refers to the total area of the drainage, that is, the area of the study area in this research.

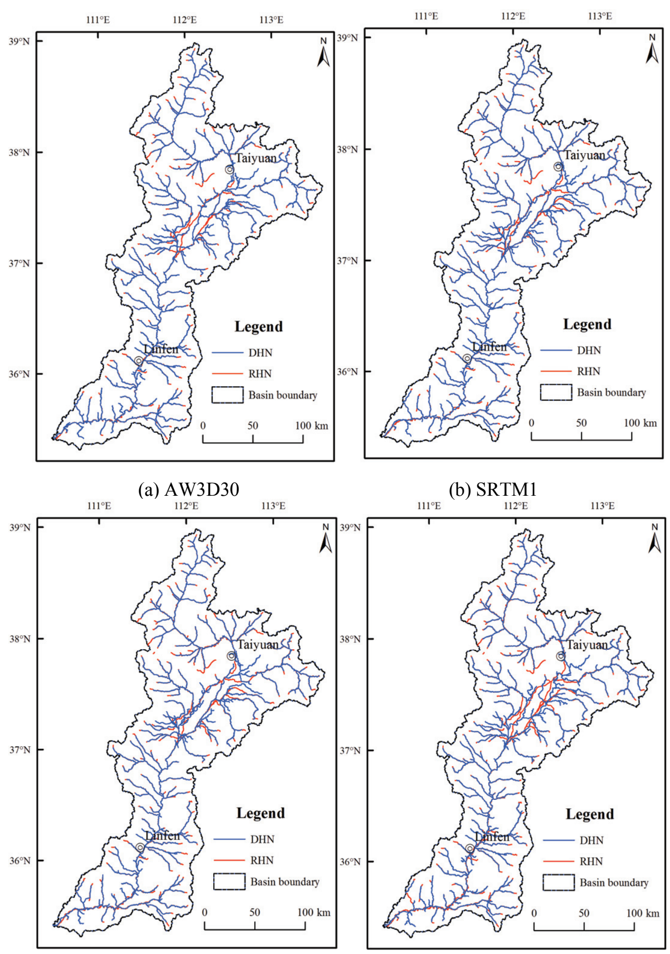
MD represents the coincidence degree between two hydrologic networks, they are, RHN and each DHN in this research. So it is an important index to evaluate the accuracy of the DHNs. Moreover, the MD index is analyzed in different slope classes in the study area in this research.

IV. Results

Firstly, RHN and DHNs were compared in both flat and steep regions; then, C and FM indexes were evaluated among typical global DEM datasets; finally, MD were analyzed in different slope classes in the study area.

A. Comparison between RHN and DHNs

Making a comparsion between RHN and DHNs for different global DEM datasets, the results are shown in Fig. 2:



(a) AW3D30 (b) SRTM1

(c) SRTM3 (d) GDEM-v2

Figure 2. Comparison between RHN and different DHNs

Figure 2 shows that four DHNs have similar distribution, which have better matching degree in steep regions but worse performance in flat regions, such as Taiyuan Basin.

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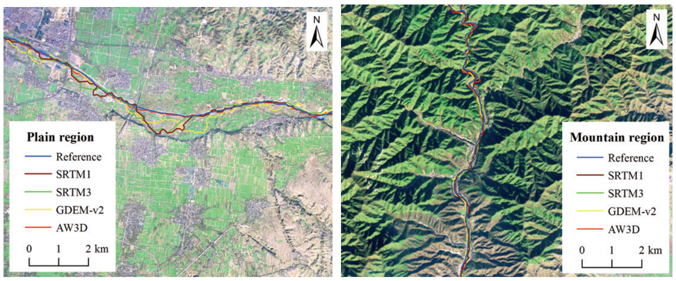
RHN and each DHN in different slope conditions are shown in Fig. 3:



(a) Plain region (b) mountain region

Figure 3. RHN and DHNs in the regions of different slope conditions

Fig.3 shows: compared to RHN, DHNs have large deviation in plain region but high coincidence in mountain region. In plain region, AW3D30 has the best coincidence; SRTM1 and SRTM3 have similar performance; GDEM-v2 has the worst coincidence.

B. C and FM Evaluation among Typical Global DEMs

Through computing C and FM for different typical global DEM datasets in the study area, the resuslt are shown in Table 1:

TABLE I. C and FM for different typical global DEM datasets

Index	***AW3D30***	***SRTM1***	***SRTM3***	***GDEM-V2***
C	0.536	0.470	0.391	0.347
FM	0.347	0.294	0.238	0.201

Table 1 shows: both C and FM reflect that AW3D30 is best, then SRTM1, the next is SRTM3, GDEM-v2 has the worst performance.

C. MD Analysis in Different Slope Classes

The computed MD represents that AW3D30 has the best match degree, then the SRTM1 data, SRTM3 data has much worse performacne than AW3D30 and SRTM1 data, but GDEM-v2 data is the worst (Table 2).

TABLE II. MD for different typical global DEM datasets (%)

Index	***AW3D30***	***SRTM1***	***SRTM3***	***GDEM-V2***
MD	1.272	1.504	2.025	2.730

The MD is analyzed in different slope classes. It is found that MD mainly distributes in flat region (0-3°) and sloping region (3-8°), especially flat region; when the slope is higher than 8°, MD becomes very low. In flat and sloping regions, MD for AW3D30 is the lowest, then SRTM1 and SRTM3, GDEM-v2 has the highest MD value.

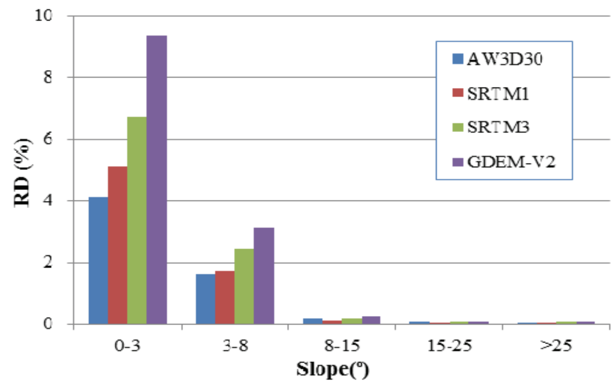


Figure 4. RHN and DHNs in the regions of different slope conditions

V. Conclusions

(1) DHNs acquired from four typical global DEM datasets have similar distribution in mountain regions but much different performance in flat regions: AW3D30 data is the best; SRTM1 and SRTM3 data are similar and a little worse; GDEM-v2 data has the worst matching degree.

(2) Through C, FM and MD indexes, AW3D30 has the best performance, then the SRTM1 data; the SRTM3 and GDEM-v2 data have worse quality, and GDEM-V2 data are much worse than other three data.

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