

## **Description of Additional Supplementary Files**

File Name: Supplementary Data 1

Description: Metadata and detailed information for all river samples used in this study.

File Name: Supplementary Data 2

Description: Basic information of viral operational taxonomic units (vOTUs).

File Name: Supplementary Data 3

Description: Virus–host linkages identified in this study.

File Name: Supplementary Data 4

Description: Kofamscan results for auxiliary metabolic genes (AMGs) involved in Methane, Nitrogen, Sulfur and Phosphorus metabolism.

File Name: Supplementary Data 5

Description: Anti-defense systems identified in vOTUs.

File Name: Supplementary Data 6

Description: Identification of specialists and generalists using the Shannon, Levins, and occurrence methods.

File Name: Supplementary Data 7

Description: The number of antibiotic resistance genes (ARGs) and virulence factor genes (VFGs) for each MAGs.

File Name: Supplementary Data 8

Description: The results of gene-sharing networks using vConTACT2 with vOTUs in this study and refseq.

File Name: Supplementary Data 9

Description: The summary statistics of environmental variables and surface energy flux parameters for sampling sites.

File Name: Supplementary Data 10

Description: Functional profiling of auxiliary metabolic genes (AMGs) of viruses in GtRVC.

File Name: Supplementary Data 11

Description: Viral identification tools used in this study, including their descriptions and source URLs.

