remote sensing

Review

Open-Source Data Alternatives and Models for Flood Risk Management in Nepal

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Abstract: Availability and applications of open-source data for disaster risk reductions are increasing. Flood hazards are a constant threat to local communities and infrastructures (e.g., built-up environment and agricultural areas) in Nepal. Due to its negative consequences on societies and economic aspects, it is critical to monitor and map those risks. This study presents the open access earth observation (EO) data, geospatial products, and different analytical models available for flood risk assessment (FRA) and monitoring in Nepal. The status of flood risk knowledge and open-source data was reviewed through a systematic literature review. Multispectral optical data are widely used, but use of microwave data is extremely low. With the recent developments in this field, especially optical and microwave data, the monitoring, mapping, and modeling of flood hazards and risk have been more rapid and precise and are published in several scientific articles. This study shows that the choice of appropriate measurements and data for a flood risk assessment and management involves an understanding of the flood risk mechanism, flood plain dynamics, and primary parameter that should be addressed in order to minimize the risk. At the catchments, floodplains, and basin level, a variety of open data sources and models may be used under different socioeconomic and environmental limitations. If combined and analyzed further, multi-source data from different models and platforms could produce a new result to better understand the risks and mitigation measures related to various disasters. The finding of this study helps to select and apply appropriate data and models for flood risk assessment and management in the countries like Nepal where the proprietary data and models are not easily accessible.

Keywords: open access data; disaster risk reduction; geospatial data; remote sensing; modelling

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1. Introduction

Evidence-based decision-making on flood hazards and risk management is possible through factual data and detailed assessment [1–3]. The lack of adequate data affects the ability to model, predict, and plan for hazards and risk, which can have obvious negative consequences on human health and socio-economic aspects [4,5]. Natural phenomena become hazards when they have the potential of inflicting damage on people's lives along with causing economic and social losses [6,7]. All such disasters are challenging to eliminate, but with advancements in science and technology, the hazards' frequency and intensity can be estimated [5,8,9]. These estimations are backed by data and scientific evidence, which can significantly help alleviate the negative consequences of employing effective risk assessment measures [10–12]. The nature and extent of any risk can be determined by evaluating the existing vulnerability conditions that could potentially harm the people at risk, their livelihoods, and the environment [13,14].

Nepal is highly prone to various natural disasters due to its diverse and rugged topography coupled with active tectonic plates [15]. The country's typical north-south extension is about 140 km, while its east-west extent is around 800 km, nearly parallel to the Himalayan axis. The elevation varies across this short span from 60 m in Terai to 8848.5 m in the High Himalaya, with five separate physiographic zones (Terai, Siwalik, Middle Mountain, High Mountain, and High Himalaya). It is highly flood-prone (mainly Terai) and ranks 20th worldwide in terms of flood-affected populations. For example, in August 2017, floods triggered by heavy rainfall affected up to 1.7 million people across 35 of 75 districts of Nepal [16]. The flooding and inundation displaced approximately 461,000 people and destroyed 65,000 houses. In 2012, 40 people were killed and 32 went missing when water surged down the Seti River due to a landslide [15]. In addition to the natural factors, Nepal's disaster-induced damages increase due to human activities, such as deforestation, unplanned settlements, and inadequate proactive legislation. Common types of floods in Nepal includes fluvial/inland, flash floods, dam burst floods, and urban floods.

Data deficiencies on disaster risk assessment and planning leads to a massive loss of human lives and economic assets [17–19]. The Government of Nepal has been trying its best to strengthen the institutional setup and improve the data system, data availability, and accessibility in its federal structure [20]. A responsible national authority has recently been established to look after overall Disaster Risk Reduction (DRR) measures and management-related issues in Nepal [21]. At provincial and local levels, disaster management committees are responsible for working on these issues. Moreover, these authorities are mandated to continuously work in a complete disaster management cycle to prepare and act in case of any natural disaster; however, these authorities are having difficulty making proper decisions due to the constant lack of evidence and reliable data.

Many studies are available in Nepal on the study of floods using high-resolution remote sensing imagery, Google Earth, and Digital Elevation Model (DEM) to identify the flood susceptible area. For this, hydraulic and hydrological modelling are commonly used approaches. Sharma and others [22] summarized the basin-wide flood hazard studies in Nepal and discussed the remote sensing approaches. Further, they indicated that both the commercial and open data are used but did not extensively consider the potential and extent of the open data and analytical tools.

Open data are unrestricted, freely available data that anyone can access, use, and redistribute, and exist in digital, machine-readable format [23,24]. Such data are accessed by users usually through web-based interfaces called open data portals. For example, (a) USGS provides open access earth observation mission products such as Landsat, Sentinel, and DEMs from different sources; (b) web-portal hosted by the government and international organizations provides disaster incident and magnitude data; and (c) open-source analytical models and tools such as HECRAS, GIS, Integrated Flood Analysis System (IFAS), and machine learning algorithms facilitate the assessment and management of flood risk. The demand for open data is increasing rapidly in developing countries, such as Nepal, where there is a critical knowledge gap regarding the use, potential and challenges associated with the use of data [25]. Open data helps increase data accessibility, enhances community involvement, promotes transparency of research results, increases effectiveness, decreases costs of data, and promotes advancement and innovation [26]. The use of these available data could provide an efficient, cost-effective, and timely assessment of the risk and support in taking preparedness actions. Analytical models are mathematical models with a closed form solution, meaning that a mathematical analytic function may be utilized to define the solution to the equations used to describe changes in a system. Using such models, the mechanisms underlying complex physical processes can be simulated, elucidated, and predictions can be made. These models have been used mainly for predicting system behavior and understanding various hydrological and hydrodynamics processes in terms of assessing floods and landslides.

Studies that examine flood risk analysis and assessment evaluations often focus on methodological and scale-related difficulties, uncertainty, mapping, or economic damage issues; however, the majority of these studies offer a glimpse of the scientific state of the art for risk assessment that is just a partial overview, centered on a small proportion of chosen data sources and methodologies. A comprehensive literature analysis to assess the application of data and models for flood risk assessment and management is lacking in Nepal.

This study aims to exploit recent advances in Earth Observation (EO), open-source data from various sources, and high-performance analytical models to innovate an approach for flood risk and impact assessment through a systematic literature review and analysis. This study also aims at setting a recommendation to develop a risk assessment platform that could be significantly helpful for the Disaster Risk Assessment (DRA) and preparedness strategies at the local government units in Nepal.

2. Materials and Methods

2.1. Data Collection

The existing literature was reviewed for the available open data sources, analytical models, and computational resources including an open-source web-based risk assessment platform, which can be potentially used for flood hazards and risk mapping and assessment, and modelling. The data and information available at different spatial scales (global, regional, federal, and local) were considered for the review with a specific focus on the Nepalese context.

A systematic literature review [27–29] was used following the PRISMA Protocol [30] for this study. In this process, the review was completed in two phases. The first phase includes: (a) definition of the scope of the analysis to draw the boundary of the study; (b) locating studies by keywords, time, type of documents, and language; and (c) selection and evaluation of relevant papers. The second phase constitutes the extraction and presentation of relevant information from the screened and selected studies in the first phase. The conceptual framework of the study is presented in Figure 1. As shown in Figure 1, vulnerability to flood hazard is the function of exposure to hazards, sensitivity, and adaptive capacity. Whether it be identifying risk and vulnerabilities or planning for resilience, all require hazard mapping and modeling. Open data alternatives and models would help to perform such tasks with greater efficiency and transparency.

The data for this study were collected from the Web of Science and Scopus database using keywords. In addition, the data for this study were included published official reports of the government and non-government organizations and other documentation. The date range for the selected literature was from 1 January 1983 to 31 December 2021. The review first focused on risk assessment, then narrowed down to open data and most importantly on methods in analyzing the available data in producing meaningful information. The keywords and the number of articles selected for this study are presented in Table 1. Both the citation and keyword network analyses were performed. For example, the number of articles listed using the keywords on the Web of Science was 4948 during the first phase. A total of 2403 relevant articles were identified among which 256 were from Nepal and 2147 from various parts of the globe as illustrated in Figure 2.

2.2. Data Analysis and Validation

The data are presented in graphical and tabular formats. Both descriptive and quantitative analyses were used. Strengths, weaknesses, and future scope of open-source data and analytical models for flood hazards and risk assessments are discussed.

The review was further refined and validated through an online expert consultation meeting, organized in Kathmandu, Nepal. The participants in the meeting were experts, researchers, practitioners, and planners from various research fields in the DRRM sector. Based on the result of primary review, the participants were consulted on the available data types, data sources, data collection methods, and analytical models and their usefulness and applicability in the context of Nepal.

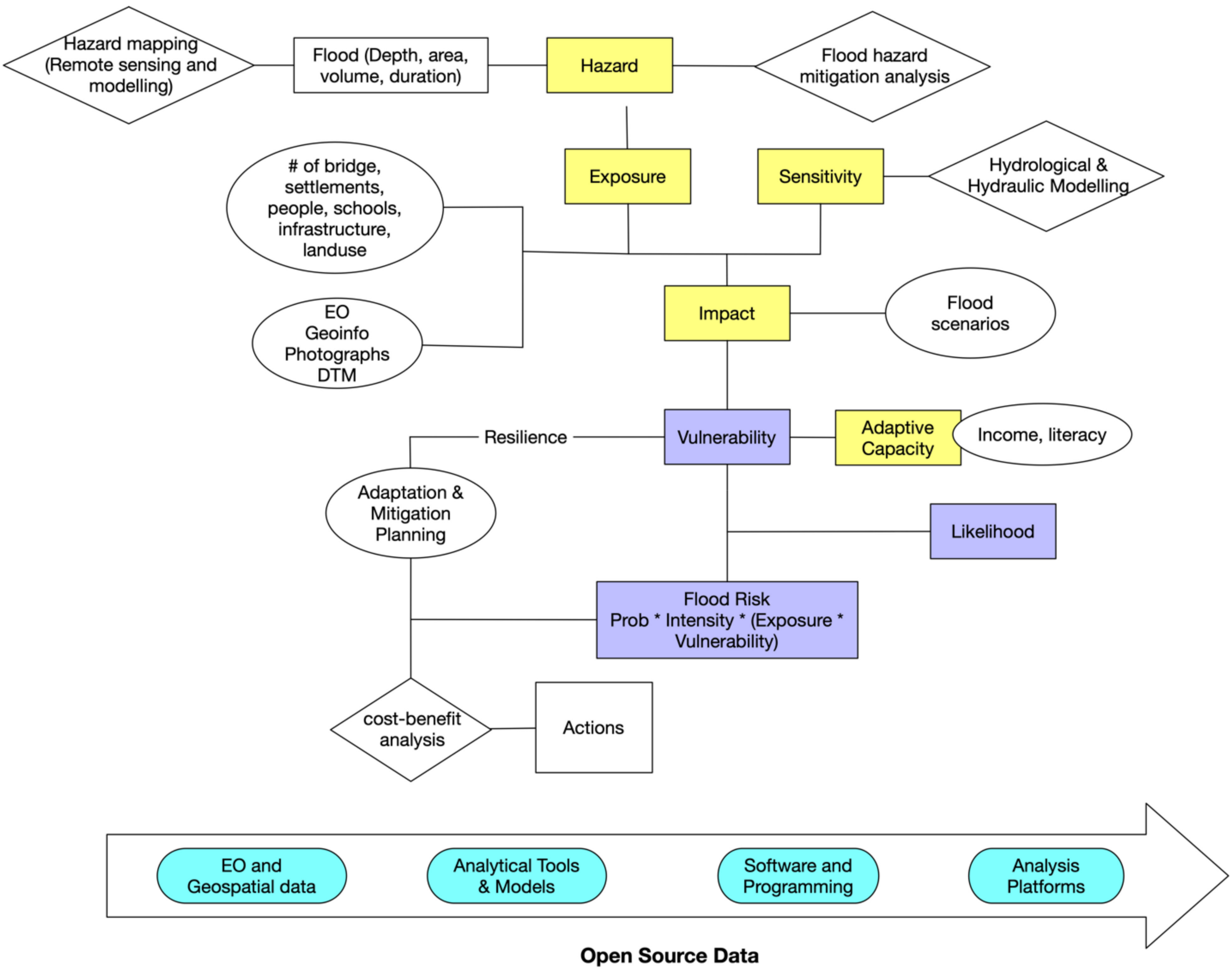

Figure 1. Flood risk assessment methods and conceptual framework of the study.

Table 1. Details of the key words and articles screened for the analysis.

Topic	Keywords/Search Strings Used	Percentage (%) of Articles
Flood	Flood Nepal, flood hazards, flood risk, flood vulnerability, hazards Nepal	15
Open data	Earth observation flood, free open data flood, open data flood risks, flood mapping, flood disasters, open GIS data Nepal, flood web-portal, Open data disasters Nepal	32
Analytical tools used in Nepal	flood analytical tools, open flood risk models, flood risk assessment, flood risk assessment model, flood modelling, flood hazard models, flood data analysis	25
Open computing resources	Open GIS software, Open computing source disaster, Open computing source flood, online platform, cloud computing, open computing in disaster, open-source software in disasters	28
Total		100

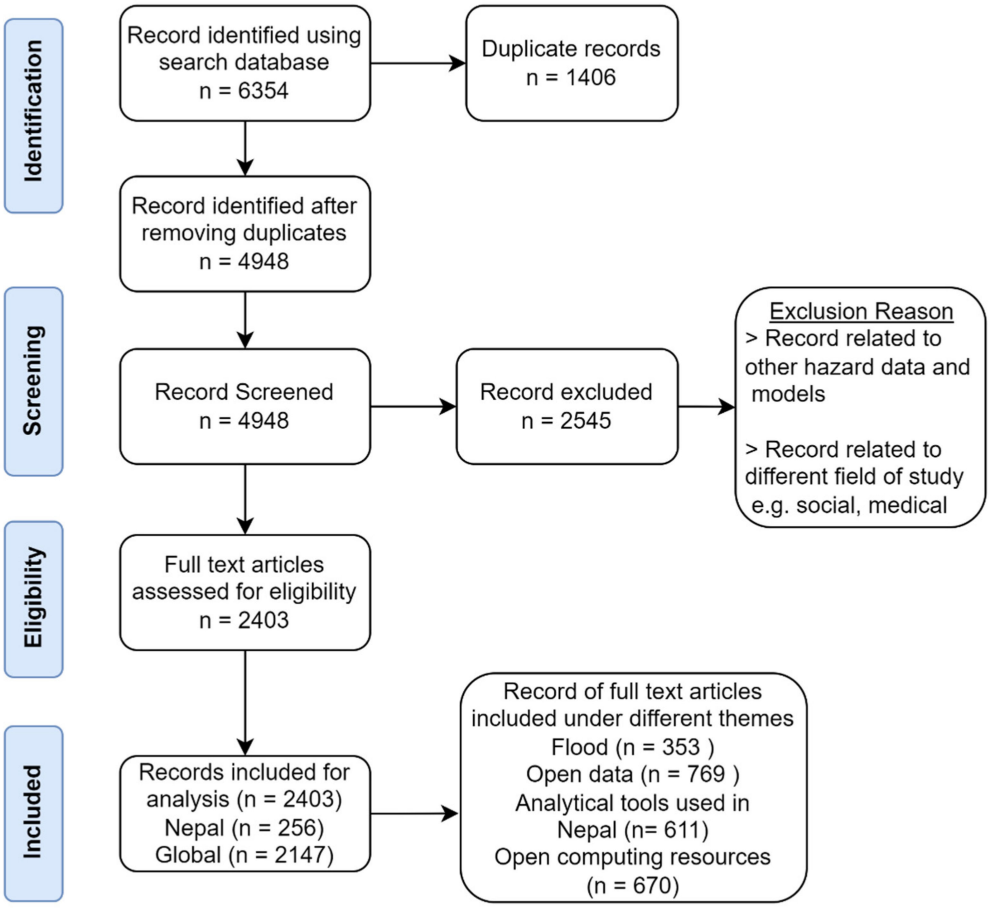

Figure 2. PRISMA flow diagram of the study.

3. Results and Discussion

3.1. Earth Observation Data

Satellite products are invaluable for flood hazards and risk analysis as they provide the basis for the extraction of different earth feature data [31]. Different GIS layers can be derived from Earth observation data (Optical, LiDAR, and microwave radar data) for a large-scale flood-related functional evaluation [32,33]. These include maps of hydrogeomorphic units, ditches, vegetation, biomass, and wetland boundaries. Mapping of different impacts and functions over large areas can serve as an efficient tool for policymakers and other stakeholders [33]. Specifically, this earth observation satellite has the potential for mapping of flood hazards and their impacts. The open-source satellite products are presented in Table 2.

Table 2. Some open access earth observation mission and products.

Satellite/Mission	Sensor	Sensor Type	Resolution (m)	Description	Reference(s)
Corona	KH-1, KH-2, KH-3, KH-4A/4B	Optical	High (~2)	Declassified; 1959 to 1972	[34,35]
Argon	KH-5	Optical	High (~2)	1962 to 1964	[36]
LANYARD	KH-6	Optical	High (~2)	1963	[37]
GAMBIT 1	KH-7	Optical	High (~2)	1963 to 1967	[38]
GAMBIT 2	KH-8	Optical	High (~2)	1966 to 1984	[39]

Table 2. *Cont.*

Satellite/Mission	Sensor	Sensor Type	Resolution (m)	Description	Reference(s)
Hexagon	KH-9	Optical	High (~2)	1971 to 1984	[39]
Landsat	MSS, TM, ETM+, OLI	Optical	15–60	From 23 July 1972; 16 days	[1,10,40]
Sentinel	2A, 2B	Optical	10	5 days	[41]
Sentinel	1A, 1B	Microwave (Synthetic Aperture Radar-SAR)	5 × 20	ESA	[42]
Terra	ASTER	Optical	15	Launched in 1999; On demand	[4]
Terra, Aqua	MODIS	Optical	250–1000	1–2/day	[42,43]

Landsat imagery archive, ESA Sentinel data, and ASTER in 2015 are open access EO products. Declassified historic satellite imagery since the 1960s can provide high-resolution information related to the earth's surface [44]. Landsat mission began in the early 1970s and it provided its data openly in January 2008 [45]. It now has the longest time-series data on earth observation [46]. Copernicus Sentinel mission was another EO mission to provide high-resolution data open access [47]. Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) was initially a commercial product, but in 2015, made all their data publicly available [48]. Unlike, Landsat, data of ASTER are not acquired at a regular time interval for the same location. Data are acquired as per the demand of the authorized personnel. Similarly, data of Corona, Argon and Lanyard were declassified in 1995, and Gambit and Hexagon satellite imagery in 2002. Some of these data sources are older and may not be available for future use, yet they are important to generate and reconstruct historical hazards and disaster events.

Currently, the DEMs that have nearly global coverage and free access are SRTM and ASTER GDEM [49]. In addition, recently, ALOS PALSAR L-band SAR based DEM of 12.5 m resolution was released (Table 3). Various flood and other hazard risk applications have already been implemented using these products [50,51].

Table 3. List of open Digital Elevation Models (DEMs).

DEM Name	Sensor	Resolution (m)	Data Source	Reference
SRTM (Shuttle Radar Topography Mission)	Released in 2003	30 (1 arc-second); 90 (3 arc-second)	USGS portal (NASA and NGA) www.earthexplorer.usgs.gov (accessed on 16 October 2021)	[22,52–54]
ASTER GDEM	Released in June 2009	30	A product of NASA and METI (http://gdem.ersdac.jspacesystems.or.jp (accessed on 16 October 2021))	[43,49]
ALOS PALSAR	ASF Data Search Vertex. PALSAR is the L-band SAR	12.5	ASF website (as of 18 September 2020) From 2006 to 2011	[55]
The High Mountain Asia (HMA) DEMs (https://nsidc.org/data/highmountainasia (accessed on 16 October 2021)	Derived using stereo imagery from DigitalGlobe's satellite constellation collected from 28 January 2002 to 24 November 2016	8 m (High Mountain Asia)	NSIDC DAAC 28 January 2002 to 24 November 2016	[56]

Open-source multi-resolution data from the latest EO technologies (Figure 3) is used for flood risk assessment and simulation of flood hydrodynamics to provide spatial and temporal flood characteristics [57]. A study on flood early warning system in the Karnali shows that the benefit-cost ratio is between 24 and 73% [58]. The benefit-cost ratio of the flood Early Warning System (EWS) can be increased by using open-source data and tools. Microwave data, such as Sentinel-1 SAR, can be very useful data for monitoring the floodwaters [59,60]. These data have a certain benefit over the optical data [61]. Precipitation is one of the key data required for flood hazards assessment. Sun and others [62] reviewed 30 different global precipitation products including regular gridded station-based, satellite-based, and reanalysis precipitation data. Some satellite-derived precipitation products are now available, including the Tropical Rainfall Measuring Mission (TRMM) [63], the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) [64], and the Climate Prediction Center (CPC) morphing technique (CMORPH) [65] products. These are widely used in flood simulation and forecasting. An example of flood extent mapping using open-source data (Sentinel) is given in Figure 4.

3.2. Geospatial Data

Many open data repositories at different scales are available that provide different geographic data, statistics including socio-economic and scientific data, that can potentially be used for understanding the disaster risks in Nepal (Table 4). Detailed information on communities and infrastructure systems can be collected and processed from multiple sources including OpenStreetMap, Google Earth, and global data products to support impact analysis. Usually, the data generated and shared by the public organizations are considered as open-source. Data sharing policy and copyright information does not exist in the data generated by the national institutions/organization; however, over the past five years, there has been progressing in sharing of the government data online [66]. Apart from the national institutions and private sectors, international organizations provide information on different development indicators.

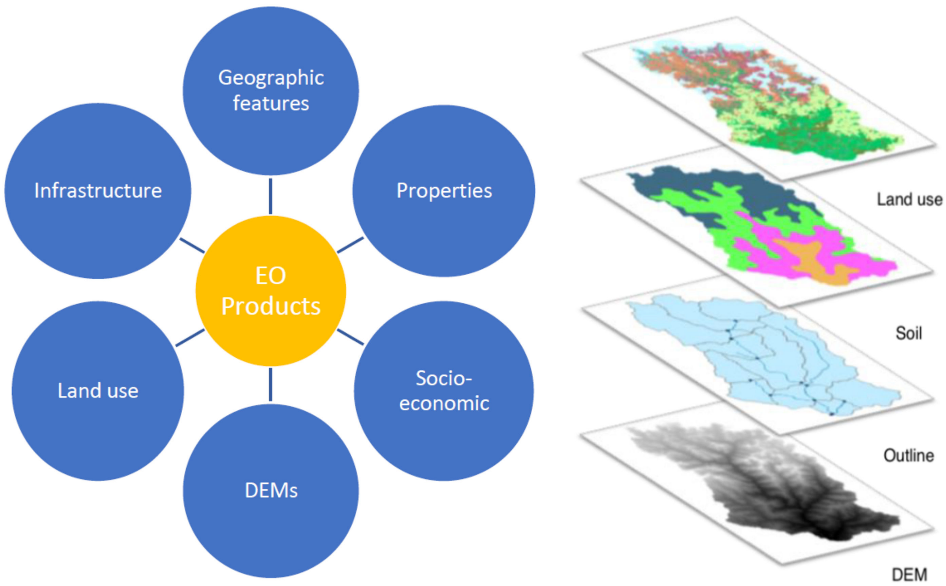

Figure 3. Different remote sensing data necessary for risk assessment (**left**) and thematic layers used to store the specific spatial information in the GIS database (e.g., Dudh Koshi River basin in Nepal) (**right**).

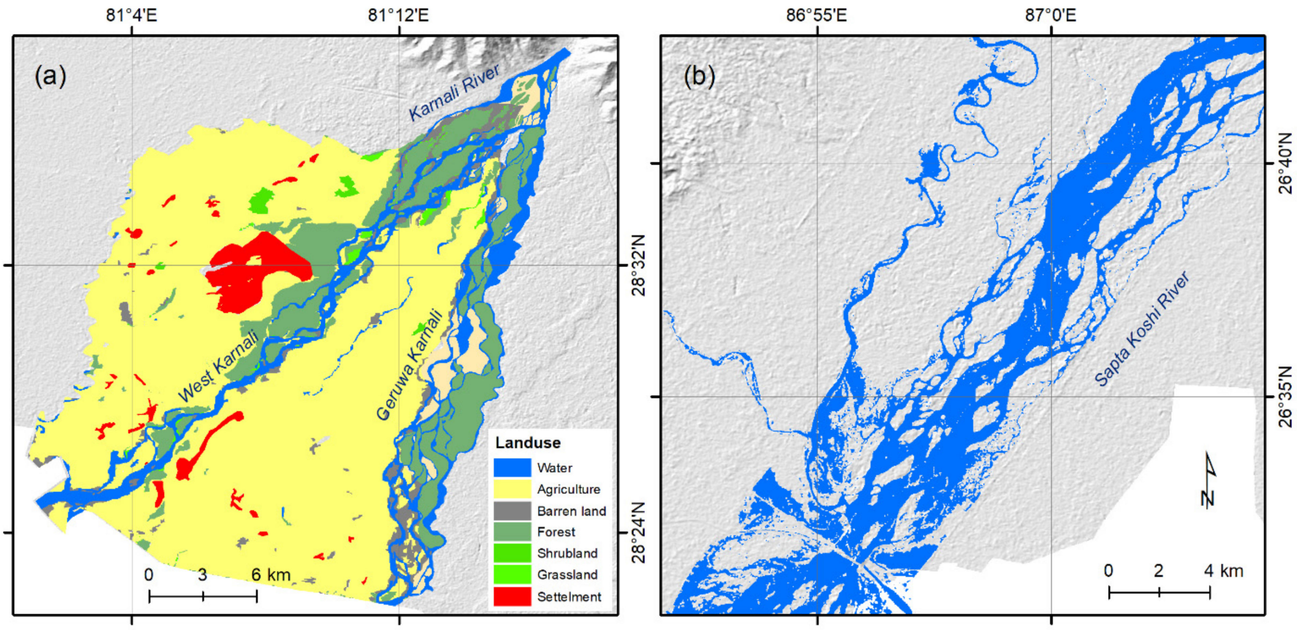

Figure 4. Mapping of flood extent using open source Optical and Radar data, prepared by Authors as examples in this study: (**a**) Flood extent and land use mapping of the lower Karnali River using Optical imagery of Sentinel 2A of 12 October 2019 and (**b**) Flood mapping of the Koshi River of Nepal using Sentinel-1 SAR data of 12 July 2020 (summer monsoon) as an example. Background represents the hillshade from the ASTER GDEM. The optical data during the monsoon are rarely usable as they are affected by the cloud cover; the SAR data can be the best choice to overcome such issues.

Table 4. Geographic open and public data sources in Nepal and their characteristics.

SN	Data Source	Description	Data Types	Scale	Coverage	References
1	Nepal Disaster Risk Reduction Portal (http://drrportal.gov.np/ (accessed on 19 October 2021))	National disaster management information system managed by Ministry of Home Affairs. Provides spatial data and information on all types of disaster all over Nepal with regular updates.	Disaster incident data from 2011 to present	National	Municipality	[67,68]
2	Central Bureau of Statistics (https://cbs.gov.np/home/ (accessed on 19 October 2021))	Established in 1959 under the National Planning Commission Secretariat of Nepal. Generates socio-economic statistics through census and surveys.	Census data on population, social, cultural, economic, environment	National	Municipality	[4,69]
3	Department of Hydrology and Meteorology (https://www.dhm.gov.np/ (accessed on 19 October 2021))	Established in 1988. Collects hydrological and meteorological data from all over Nepal.	Hydrological and meteorological data	Local	Station	[1,40,70]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
4	Ministry of Home Affairs Nepal Government GEO-PORTAL (http://drm.moha.gov.no/ (accessed on 19 October 2021))	Developed by Survey Department, Geographic Information Infrastructure Division (NGIID), GoN. Facilitates finding geospatial data and sharing in the country.	Raster and vector maps on disaster, elevation, administrative boundaries, drought, etc.	Local	Municipality	[21,71]
5	National Emergency Operation Center–SAHANA Disaster Management System (http://sahana.neoc.gov.np/sahana/default/index (accessed on 19 October 2021))	Data management system under MoHA. The Emergency Operation Centers at district level and government authorities collect and send them information on disaster incidents, facilities available, and response.	Disaster incident data, facilities, and response data	National	Municipality	[72,73]
6	Nepal Agriculture Management Information System (NAMIS) (http://www.namis.gov.np/ (accessed on 19 October 2021))	A project implemented by Ministry of Agriculture and Livestock Development under the component of building resilience to climate-related hazards. Focuses on obtaining agricultural data and timely delivery of agro climatic and weather information under early warning systems to farming communities.	Agricultural statistics on production, area, and yield. Weather and flood forecast data. Livestock population and products data from 2000 to 2014	National	District	[74,75]
7	Open Data Nepal (http://opendatanepal.com/ (accessed on 19 October 2021))	An initiative to make Nepal's data accessible online and use, reuse, or redistribute as well as publish, explore, download, and utilize data making own visualizations. Consists of 627 datasets from 46 sources under various categories	Administrative boundaries shapefiles, rainfall and temperature data of 2014, agricultural statistics till 2016 and other livestock data, education, finance, geospatial, health, census, energy data, etc.	Local	Municipality	[40,66]
8	Nepal Map (http://nepalmap.org/ (accessed on 19 October 2021))	A project of Code for Nepal which works to increase the use of open data in Nepal, providing easy access to data. It uses the National Data Profile, created by CBS and other official sources, to create user-friendly data visualizations on key demographic issues.	Demographics, agriculture, educational and household data	National	District	[66]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
9	Nepal in Data (http://nepalindata.com/data/ (accessed on 25 July 2021))	An open data portal, aimed to make development data and statistics on Nepal from 1950 to present available and accessible. Provides more than 4000 indicators divided over 12 sections covering various sectors including agriculture and land; energy and environment; economy, market, and finance; infrastructure, communication, and technology; state and politics; the sustainable development goals; etc.	Crop and livestock data, climate, disaster, energy, wildlife data, etc.	National	District	[66]
10	Open Nepal (http://opennepal.net/ (accessed on 20 October 2020))	A knowledge hub to produce, share and use data and information for development. Consists of 311 datasets related to 19 sectors including agriculture, climate change, education, energy, geography, finance, etc.	Agriculture data on crops, fertilizers, seeds, etc.; demography data of 2011; rainfall data (2001–2012); disaster and loss data; land use pattern data for 2001; forest area cover percent from 1978 to 2005, etc.	National	District	[66]
11	Open earthquake data portal (http://eq2015.npc.gov.np/#/ (accessed on 25 July 2021))	Developed by Kathmandu Living Labs with guidance from CBS and National Planning Commission. Consists of data on household survey between Jan 2016 to May 2016 in the 11 earthquake-affected districts.	CSV datasets on demographics, building structure, etc.	National	District	[76]
12	DesInventer (https://online.desinventer.org/desinventer/#NPL-DISASTER (accessed on 25 July 2021))	Disaster Information Management System Project initiated by LA RED and hosted by UNDRR. It is a tool for generation of National Disaster Inventories and construction of databases of the effects of disaster.	Historic disasters data since 1971	Local	Municipality	[21,77]
13	Open Street Map (https://www.openstreetmap.org (accessed on 20 October 2021))	Built by a community of mappers that contribute and maintain data about roads, trails, buildings, etc. emphasizing local knowledge.	Datasets on building footprints and spatial layers of geographical objects, i.e., roads, rivers, health facilities, educational institutions, etc.	Local	Wards	[40,78]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
14	World Bank (http://data.worldbank.org/ (accessed on 20 October 2021))	Provides free and open access to global development data on 20 different indicators	Agriculture and rural development, climate change, education, health, environment, gender etc.	Regional	Country	[58,79]
15	UN Digital Repository (https://data.unorg/en/index.html (accessed on 20 October 2020))	Launched in 2005. Maintained within Statistics Division of the Department of Economic and Social Affairs (UN DESA) of the UN Secretariat. Provides web-based data services to search and download varieties of statistical resources under themes including education, health, finance, agriculture, environment, etc.	Agriculture, education, energy, environment, finance, gender, health, population and migration, etc.	Global	Country	[80]
16	USGS Earth Explorer (https://earthexplorer.usgs.gov/ (accessed on 19 October 2021))	USGS Earth Explorer is an online search, discovery, and ordering tool developed by the United States Geological Survey (USGS). The tool provides users the ability to query, search, and order raster images and cartographic products from several sources.	Satellite images aerial photographs, digital elevation model, land cover data, etc.	Global	Country	[4,10,20]
17	CGIAR-CSIGEOPORTAL (http://srtm.csi.cgiar.org/srtmdata/ (accessed on 19 October 2021))	CGIAR Consortium for Spatial Information (CGIAR-CSI) is the geospatial science Community of Practice supported by the CGIAR Platform for Big Data in Agriculture that facilitates CGIAR's use of geospatial data and analysis in research.	Digital Elevation Model	Global	Country	[81–83]
18	Global Risk Data Platform (https://preview.grid.unep.ch/index.php?preview=extract&cat=2&lang=eng (accessed on 20 October 2020))	Developed as a support to the Global Risk Assessment Report on Disaster Risk Reduction (GAR). It shares spatial data information on global risk from natural hazards, which could include past hazardous events (human and economical hazard exposure, risk).	Data on tropical cyclones and related storm surges, drought, earthquakes, biomass, fires, floods, landslides, tsunamis, and volcanic eruptions.	Global	Country	[84,85]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
19	World Pop (https://www.worldpop.org/geodata/summary?id=6314 (accessed on 20 October 2020))	Produces different types of gridded population count databases with 100 m resolution from 2000 to 2020 allowing regional and national scales.	Geotiff data for Nepal population 2020.	Global	Country	[86]
20	Our World in Data (https://ourworldindata.org/country/nepal (accessed on 20 October 2020))	Provides research and data on the world's largest problems, such as poverty, disease, hunger, climate change etc. to make the knowledge of big problems accessible and understandable.	Demography, agriculture, natural disasters	Global	Country	[87]
21	Humanitarian Data Exchange (https://data.humdata.org/dataset/ (accessed on 20 October 2020))	Repository maintained by UNOCHA, launched in 2014. Provides an open platform for sharing humanitarian data and use it for analysis.	Disasters and other humanitarian crisis data through raster data, shape files, and CSV datasets on earthquake.	Global	Country	[88,89]
22	BIPAD (https://bipad.gov.np (accessed on 20 October 2020))	BIPAD is a comprehensive Disaster Information Management System (DIMS) initiative led by the Government of Nepal (GoN), Ministry of Home Affairs (MoHA), National Emergency Operation Centre (NEOC) with the technical support from Youth Innovation Lab.	Disaster incident data, disaster loss and damage data, real time data on rainfall, river water level, air quality, etc.	National	Municipality	[90]
23	ICIMOD Regional Database System (http://rds.icimod.org/Home/Data?any=nepal&Category=datasets&&page=2&&themekey=Nepal (accessed on 20 October 2020))	Portal for data curation and dissemination providing easy access and download of curated datasets to the users. Consists various datasets for different thematic areas in the Hindu Kush Himalayan (HKH) region.	Landslides, floods, fire, incidents, glaciers, land cover, hazards, vulnerability, and risk indicator datasets	Local	District	[10,20]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
24	Global Forest Watch Fires (https://fires.globalforestwatch.org/map/#activeLayers=viirsFires%2CactiveBasemap=topo&activeImagery=&planetCategory=PLANET-MONTHLY&planetPeriod=null&x=860154785&y=27.286056&z=7 (accessed on 20 October 2020))	Online platform for monitoring forest and land fires using near real-time information through high resolution satellite imagery, detailed maps of land cover and other various data to track fire activity and related impacts.	Time series data of fire with forest loss and tree cover loss or gain data from 2001 to present.	Country and regional	Country	[91,92]
25	EMDAT- The international disaster database (http://www.emdat.be/ (accessed on 20 October 2020))	Emergency events database maintained by Centre for Research on the Epidemiology of Disasters (CRED). Contains database compiled from various sources including UN agencies, NGOs, research institutes etc. on the occurrence and effects of over 18,000 mass disasters in the world from 1900 to present.	Disaster data with human, economic, sectorial, and infrastructural impact	Global	National and international	[15,61,93]
26	Global Land Cover Characteristics Database-USGS (http://glcfapp.glcf.umd.edu/data/landcover/ (accessed on 20 October 2020))	A global land-cover characteristics database developed by the U.S. Geological Survey and available since mid-1997. Generates a 1-km resolution global land cover characteristics data for use in a wide range of environmental research and modeling applications.	Land cover classification datasets	Global	Wards	[70,94,95]
27	Center for Hydrometeorology and Remote Sensing, University of California (http://chrsdata.eng.uci.edu/ (accessed on 20 October 2020))	The Center aims to advance the knowledge of the water and energy cycles at scales ranging from local watersheds to continental basins. Contains open-source software, real time monitoring tools, hydrologic models, mesoscale models, and data, etc.	PERSIANN global satellite precipitation data from 2000 to present	Regional, National and Global	District	[4,64,96]

Table 4. *Cont.*

SN	Data Source	Description	Data Types	Scale	Coverage	References
28	Food and Agriculture Organization–Geonetwork (http://www.fao.org/geonetwork/srv/en/main.home (accessed on 20 October 2020))	Repository that provides access to interactive maps, satellite imagery, GIS datasets and related applications maintained by FAO and its partners.	Spatial datasets on agriculture, climate, topography, soil etc.	Global	Country	[70]
29	Global Data Assimilation System (GDAS) (https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-data-assimilation-system-gdas (accessed on 20 October 2020))	The system is used by the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) model to place observations into a gridded model space for the purpose of starting, or initializing, weather forecasts with observed data.	Global daily assimilation data from 2001 to present, GDAS Snow, Ice, SST, Satellite, Ship, Aircraft (GRIB) data from April 2019 to May 2020.	Global	Country	[70,97,98]
30	Nepal Climate Change & Development Portal (http://climatenepal.org.np (accessed on 20 October 2020))	Operated and maintained by NAST (Nepal Academy of Science and Technology). Contains information on six key themes: climate science, impacts, adaptation planning, adaptation policy and actions, international climate change policy, and financing and technology transfer.	Climate change bibliographies	National and local	National and local	[14]
31	Geofabrik Software Development Company, Germany (download.geofabrik.de/asia/Nepal (accessed on 20 October 2020))	Portal incorporated by two software engineers in 2007 that provides free geodata created by OpenStreetMap.	Physical infrastructure shapefiles	Local	Municipality	[1]

3.3. Analytical Models for Flood Hazard and Risk Assessment

Analytical models use advanced statistical techniques and approaches in the modeling of extreme events and making predictions about the mechanisms involved in complex physical processes. These models have mainly been used for predicting system behavior and understanding various hydrological and hydrodynamics processes in terms of assessing hazards and risk.

Hydrological models are developed and used for both river and floodplain modelling to analyze the behavior of flooding and to identify the causes and effects of flooding [99]. These models help to assess the flood frequency for the quantitative assessment of flood problems in the area and prepare flood risk, vulnerability, and hazard maps. Many models are available for flood hazard mapping and assessment and are applied in the Nepalese context [1]. Both one-dimensional (1D) and two-dimensional (2D) dynamic flood models are used [100]. A basic probabilistic model can be used to assess flood risk in addition to complex deterministic models. Depending on the context, these models have their own advantage and shortcomings [101,102]. The integrated assessment of flood hazards in flood-prone locations, the cost-benefit analysis, and the risk-based design of flood protection systems could all benefit from the adoption of such models [102]. The techniques utilized in modeling range from very simple approaches with many simplifying assumptions to quite complex applications that involve a lot of data and computation time for both the hazard and vulnerability components of the risk. Studies have shown that combinations of different models (e.g., 1D/2D) would offer optimum balance between the amount of data needed for the simulation and the accuracy of the result [103]. The detailed list of the flood analytical models with their temporal and spatial scale and outputs are given in Table 5. Some of the common models used in Nepal are described below:

3.3.1. Hydrodynamic Model

HEC-GeoRAS is used for interfacing between the HEC-RAS and GIS used for flood inundation mapping based on the flow rates for different return periods using the HEC-RAS model, and GIS for spatial data processing [104].

3.3.2. Hydraulic Models

HEC-RAS is a commonly used hydraulic modelling software in Nepal that is used for flood hazard mapping [1,105]. HEC-RAS can perform steady and unsteady flow hydraulics, sediment transport/mobile bed computations, and water temperature modelling [99].

3.3.3. Hydrological Models

To evaluate the hydrology of watersheds, spatially dispersed hydrological models are employed, including HEC-HMS [106,107], InVEST [108,109], VIC [110], and SWAT [111–113]. The SWAT has been most widely implemented in hydrological studies and is applicable under limited data availability [114,115].

Table 5. List of analytical models used for flood studies in Nepal.

Model	Description	Reference	Types	Temporal and Spatial Scale	Main Outputs
HecRAS https://www.hec.usace.army.mil/software/hec-ras/ (accessed on 18 October 2021)	Hydrologic Engineering Center's River Analysis System	[116,117]	Engineering, physically based	Minute to year; Individual to network of reaches	1D and 2D steady and unsteady analysis, sediment transport, water quality simulation, inundation areas, flood, and CC analysis
BEACH	Bridge Event and Continuous Hydrological Model	[118]	Physically based, distributed	Daily; Hillslope, small watershed	Soil moisture, ET, runoff
SWAT	Soil water assessment tool	[111–113]	Physically based, semi-distributed	Hourly, daily annual, multiyear; Large or small basins	Runoff, sediment yield, ET, percolation, transmission loss
KINEROS2 (KINEmatic Runoff and erosion model)	Hydrologic Engineering Center, US Army Corps of Engineers	[119]	Physically based, semi distributed	Event-based (a minute); Small to medium watersheds	Runoff, sediment yield, infiltration, sediment discharge

Table 5. *Cont.*

Model	Description	Reference	Types	Temporal and Spatial Scale	Main Outputs
IFAS (Integrated Flood Analysis System) http://www.icharm.pwri.go.jp/research/ifas/ (accessed on 18 October 2021)	International Center for Water Hazard (ICHARM), Public Works Research Institute (PWRI), Japan	[120]	Provides interfaces to input satellite-based and ground-based rainfall data; distributed hydrological model	Operational flood forecasting; Capable of 1D/2D simulations; Successfully used in Indonesia, The Philippines, Indus Basin Pakistan, and Malaysia	River channel network, estimate parameters of runoff analysis
Delft-FEWS (Delft Flood Early Warning System)	Deltares, The Netherlands	[121]	XML based data exchange open-source platform	Successfully applied to basins in Europe, Mozambique, Gulf of Thailand, and other parts of the world	
Anuga Hydro Model	Australian National University (ANU) and Geoscience Australia (GA), Australia	[122]	Developed in Python; Computationally intensive components are written in C routines compatible with Numpy	Capable of 2D simulation; Continuously being updated with the help of user's community; Capable of modeling highly dynamic flows	Mostly in Western Australia, UK, and Indian Ocean
SPHY (Spatial Processes in Hydrology)	FutureWater and Utrecht University, The Netherlands	[123,124]	Spatially distributed bucket-type model	Programmed in Python; GUI available for QGIS	Applied in many parts of the world, especially European region and in Nepal
HBV (Hydrologiske Byrån avdeling för Vattenbala ns)	Swedish Meteorological and Hydrological Institute	[125–127]	Lumped conceptual model	Does not have the capability of a distributed model in terms of its calculations	Applied in catchments of Brazil, China, Iran, Mozambique, Nepal, Norway, Sweden, Zimbabwe, and Nordic countries
TOPMODEL (TOPography based hydrological MODEL	TOPMODEL: Lancaster University, UK BTOPMC: University of Yamanashi, Japan	[128–130]	Written in FORTRAN77; Spatially distributed	Applicable to small to large scale catchments; Uses some distributed and some lumped parameters	River basins of Japan, China, Nepal, Sri Lanka, Indonesia, Thailand, and USA
VIC (Variable Infiltration Capacity)	University of Washington	[110,131]	Semi distributed; Surface water energy balance model for large scale application	Mostly used for long term simulations; Capability of incorporation to GCMs; Capability of integration with other models	Applied in USA and many other parts of the world

3.4. Analytical Platforms, GIS Software and Programming Languages

The integration of available data and outputs from the model is supported by a risk assessment platform which helps in interactive risk assessment and further support in decision-making [132]. Some commonly available open-source web-based flood risk assessment platforms along with their main characteristics are given in Table 6.

Table 6. Open-source online platform for the flood risk assessment.

Sn.	Platform	Major Features	References
1	Index for risk management (https://drmkc.jrc.ec.europa.eu/inform-index (accessed on 20 October 2020))	A global platform, open-source risk assessment for humanitarian crises and disasters.	[21,133,134]
2	Rapid Analysis and Spatialization of Risk (RASOR) (http://www.rasor-project.eu/rasor-platform/ (accessed on 20 October 2020))	A platform to perform multi-hazard risk analysis for the full cycle of disaster management, including targeted support to critical infrastructure monitoring.	[135–138]
3	OPENQUAKE (https://www.globalquakemodel.org/openquake/about/plat form (accessed on 20 October 2020))	A web-based platform that offers an interactive environment in which users can access, manipulate, share and add data, and explore models and tools for integrated assessment of earthquake risk; Provides tools for DRR and management.	[139–141]
4	eCapra (https://ecapra.org/ (accessed on 20 October 2020))	Probabilistic risk assessment platform. The platform consists of different modules for probabilistic risk calculations including CAPRA-GIS software module	[142–145]
5	FEMA Flood Map Service Center: Hazus (https://msc.fema.gov/portal/resources/hazus (accessed on 20 October 2020))	Models for estimating potential losses from earthquakes, floods, hurricanes, and tsunamis. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the predisaster planning process	[146–149]
6	SIDS Disaster Risk Reduction Portal (https://smallislands-riskreduction.net/ (accessed on 20 October 2020))	Hub for information concerning water disaster risk reduction management, allows searching for relevant resources of Small Islands Developing States. Enhances 'risk-reduction' and 'information and knowledge-sharing' for Small Island Developing States by providing an access point for a range of available open data, information, tools, and best practices.	[150–153]
7	Google Earth Engine (GEE) https://earthengine.google.com/datasets/ (accessed on 20 October 2020)	Established at the end of 2010; GEE provides global time-series satellite imagery and vector data, cloud-based computing, and access to software and algorithms for processing substantial amounts of such data.	[111,154–157]

Several open-source software programs provide support in modelling and analyzing hazard and risk data, and visualizing and exploring the data. Concerning disaster management applications, the most important software is the Geographic Information Systems (GIS) software, which is used to create, manage, store, analyze, and visualize geographic data. Chen and others [158] reviewed and summarized the open-source GIS software intending to apply it in water resource management. Table 7 presents open-source desktop GIS, whose functionalities are comparable to that of proprietary software.

Table 7. Open-source GIS program/software application for flood risk assessment.

Program/Software	Description	References
QGIS	QGIS supports both raster and vector layers. QGIS supports plug-in architecture. For example, InaSAFE is a multi-risk platform, developed as a QGIS plug-in that enables the assessment of several natural hazard scenarios. Similarly, FloodRisk is another QGIS plugin for flood risk analysis. The Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) analysis plugins are commonly used in Nepal for Multi-criteria Decision-Making Analysis using Geo-spatial data [4,159,160].	[157,158]
GRASS	GRASS is a cross platform system (runs in Linux, Mac, Windows). It has numerous add-ons related to landslides, floods, and other hazards. For example, http://www.slopestability.org/ is built on GRASS GIS for landslide modelling. Similarly r.hazard.flood (https://grass.osgeo.org/grass78/manuals/addons/r.hazard.flood.html (accessed on 16 October 2021)) is an implementation of a fast procedure to detect flood prone areas in GRASS GIS.	[161,162]
uDig	uDig is used as a framework for building other GIS platforms and applications. It is a full-layered open-source GIS based on Java enabled Eclipse platform	[163–165]
SAGA GIS	System for Automated Geoscientific Analyses (SAGA) provides an easy and effective implementation of spatial algorithms. Hydrological models TOPMODEL and IHACRES are implemented as module libraries in SAGA.	[166–168]
ILWIS	Integrated Land and Water Information System (ILWIS) is a geographic information system (GIS) and remote sensing software for both vector and raster processing.	[169–172]
MapWindow	GIS (mapping) application built upon Microsoft NET technology and consists of a set of programmable mapping components. MapWindow GIS can be reprogrammed to perform different or more specialized tasks.	[158,173–175]
gvSIG	gvSIG is a user-friendly desktop application for capturing, storing, handling, analyzing, and deploying any kind of referenced geographic information to solve complex management and planning problems.	[157,176–178]
OpenJump	Open Jump is a Java based open-source GIS system with an ability to work with GIS data in GML format. GML or "Geography Markup Language" is an XML (text-based) format for GIS data.	[157]
GeoDa	Supports data exploration in statistics	[145,179–181]
Whitebox GAT	Whitebox GAT (Geospatial Analysis Toolbox)	[177,182]
FalconView	Georgia Tech built this open software for displaying various types of maps and geographically referenced overlays	[183]
OrbisGIS	OrbisGIS is a cross-platform open-source GIS software designed by and for research	[183]
DivaGIS	Mapping and geographic data analysis, in particular point data	[184–186]
AkvaGIS	Free and open-source GIS-integrated hydrochemical–hydrogeological analysis tool (named AkvaGIS) for the management and interpretation of hydrogeological data	[186–188]

Programming languages are used to develop programs and models. There is an increase in the use of programming languages by scientists because of the ease with which they can derive insights from large and complex datasets [189]. The general purpose of programming languages like Python and R is for data analysis and to develop modelling applications. Table 8 explains the common and useful programming languages and notebook environments used for different computing results.

Notebooks are a computing environment where one can freely combine human-readable narrative with computer-readable code. In this environment, one can document the code, run it, visualize data, and see the results without leaving the environment. This makes it a useful tool for performing end to end data science workflows–data cleaning, statistical modeling, visualizing data, and many other uses.

Table 8. Programming languages used for computing.

Name	Brief Description	Capability in Data Processing and Modelling	References
Python	Python has many modules in scientific computing and machine learning, including NumPy, scikit-learn, and matplotlib. Python's extensive set of scientific libraries that make it an attractive environment for interactive development.	Python language is used in the development of models such as Anuga Hydrological Model, LISFLOOD-FP models, THRESH Landslide models. As a general-purpose language, Python can be used to build any kind of models from scratch and run on local desktop or cloud servers.	[190,191]
R	R is a free software environment for statistical computing and data analysis. It has many powerful packages that aid in processing, analyzing, and modelling data.	R has an increasing number of packages that support hydrological modelling and facilitate hydrological analyses from start to finish. R can also easily integrate GIS analyses in hazard modelling.	[190,192]
Notebook environment	Jupyter notebook is an open-source web-based computational environment that supports the creation of programming documents that combine code, text, and execution results with visualizations and all sorts of rich media [190].	Notebooks like Jupyter and Google Colab are well suited to be a platform for participatory modeling in disaster use [191].	[193–195]
	Google Colab: Google Colaboratory [196] provides a free Jupyter notebook environment that requires no setup, and runs entirely (writing, running, and sharing code) on the Cloud		

3.5. Machine Learning Models

Artificial neural networks (ANN), support vector machines (SVM), and decision trees (DT) are just a few examples of machine learning techniques that have been used to detect and analyze flood-prone zones in flood hazard assessments [160,197,198]. The machine learning models circumvent the subjective calculation of weights by learning the link between flooding incidence and the explanatory variables from the historical flooding records [199]. Global flood models frequently need many model parameters, frequent model debugging, and lengthy computation times due to the complexities of global floods. For quicker access to worldwide flood risk assessments, machine learning techniques could be a useful option [200].

EO products can be used to map and simulate the flood and provide flood characteristics; however, there is a problem of obtaining cloud-free images during the summer monsoon flooding season through the optical sensors (Sentinel 2a/2b, Landsat). Most optical imagery is full of cloud cover and cannot map the flooding. Even the microwave is absorbed by the water and thus may not be suitable for mapping the monsoon flood. To overcome this issue, the only option is to use the modelling of the flood extents or field survey using high-resolution drone mapping.

Disasters are the key barriers to achieving sustainable development targets with huge economic and societal impacts. The Sendai Framework for Disaster Risk Reduction 2015–2030 has set four main priorities for governments to focus on: (a) understanding disaster risk, (b) strengthening disaster risk governance to manage risks, (c) investing on DRR for resilience building, and (d) enhancing disaster preparedness for effective response and 'building back better' in recovery, rehabilitation, and reconstruction [201]. The developing countries are on the frontline to bear such negative impacts due to having the inadequate capacity to mitigate, adapt, and bounce back to normal condition after the crisis. Natural hazards are often hard to control, but with the proper understanding of their underlying risks and required planning to address those risks, losses could be minimized to a great extent; however, any plan for effective intervention to minimize the associated risks should be backed up by data and scientific evidence. Amongst other factors, the lack of data and reliable information sources are major hindrances in effective decision making especially in terms of a development initiative.

Previous works proposed and discussed the models for effective use of the open data [202,203]. Open data policies at various institutional and government levels are much less systematic [204]. Charalabidis and others [23] summarize the benefits of open data. Some previous documents evaluated the availability of open data in Nepal [65]. The lack of official mechanisms for the public sharing of data produced by the government is the major hindrance in open data initiatives. Despite this challenge, civil society organizations and the private sectors are taking steps to share both their data and the data from the government [65].

The review of open-access software packages by the World Bank provides a detailed evaluation of 31 models in disaster applications at the global level [12]. The report facilitates the choice of open access hazard and risk modelling tools in disaster risk management. Validation and application of the open data are undergoing with cases in different countries, e.g., flooding in Bangladesh using recent technologies, such as SAR [5], geographic data for flood disaster [22]. Previous studies also present the limitations of the remote sensing data [205].

4. Conclusions

The literature on the use of EO products, open data, and analytical models in flood hazards and risks, shows a growing interest in the field; however, the main focus of the contemporary literature is on the technology-specific applications for hazard mapping and disaster management.

Despite the availability of the open data, (a) a situation of an extremely low usage of such data are observed for most of the floods in Nepal, and (b) hazard mapping and impact evaluations in the country are limited and the capability of the available data are not explored in the country. Except for the case of study-based approaches, the disintegrated data by the local, provincial, and federal level was not found in Nepal. This might be related to the lack of efficient infrastructure (super computing device for the processing of big data), availability of human resources, and low priority of the country. Cloud computing resources, such as Google Earth Engine, can be the best alternative for filling the gap in the lack of efficient infrastructure in the country. The latest EO products and technologies, open data and analytical tools, have the potential to ensure efficient flood risk assessment, reduce the impacts of flood hazards, and flood risk reduction through the prior mitigation actions.

Producing intermediate data and indicators through the open satellite imagery, online platform (e.g., GoogleEarth Engine), and DEMs will be inputs for flood risk assessment. Multiple sources of data from different models and platforms, if combined and analyzed further, could produce a new result to better understand the risks and mitigation measures related to various kinds of disasters. Such datasets can be organized, managed, and analyzed using a digital, web-based analytical platform, which uses readily available open data sources from different flood models and produces user tailored information. Such outputs could be more understandable and guide evidence-based decision making and planning processes in the target areas.

This study documents the available open data, analytical models, and tools for flood risk assessment and underlines the potential of utilizing open data and tools for disaster risk reduction. Flood risk management requires an understanding of risk mechanism including hazard, impacts, susceptibility, and selection of management interventions. However, this study is focused mostly on the data and model for risk assessment including vulnerability and susceptibility analysis. Other models and data sources for flood control technical designs, cost–benefits analysis, and possible flood management options can be considered in similar future studies.

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