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India Flood Inventory: Creation of a multi-source national geospatial database to facilitate comprehensive flood research

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Abstract:

Floods are one of the most devastating natural hazards across the world, with India being one of the worst affected countries in terms of fatalities and economic damage. In-depth research is required in order to understand the complex hydrometeorological and geomorphic factors at play and design solutions to minimize the impact of floods. But the existence of a historical inventory of floods is imperative to promote such research endeavors. Though, a few global inventories exist, they lack the spatio-temporal fidelity necessary to make them useful for computational research due to reasons such as concentrating exclusively on large floods, limited temporal scope, non-standard data formats etc. Therefore, there is an urgent need for developing a new database that combines data from global and hitherto-underutilized local datasets using an extensible and common schema. This paper describes the ongoing effort of building the India Flood Inventory (IFI), which is the first freely-available, analysis-ready geospatial dataset over the region with detailed qualitative and quantitative information regarding floods, including spatial extents. The paper outlines the methodology that has been adopted as well as some preliminary findings using the data contained in this inventory. This dataset is expected to advance the understanding of flood processes in the worst affected region of the world.

Key words: Flood database, hazard assessment, impact assessment, hydrological modeling

1. Introduction

Floods continue to be one of the most devastating natural disasters across the world, accounting for one-third of all global geophysical hazards (Smith and Ward, 1998). In India alone, between 2010-2016, more than 10,000 people lost their lives and total damages of around 16,500 crores were caused by floods, according to the Central Water Commission (CWC, 2018). According to an Asian Development Bank report, floods have caused $50 Billion of economic damage since 1990 (Patankar, 2019).

The existence of a comprehensive historical database of floods with adequate spatio-temporal information is a key building block towards facilitating research into the causative factors and impacts of floods. Several databases exist globally, such as the International Disaster Database (EM-DAT), Relief Web (by United Nations), the International Flood Network (IFNET), Global Active Archive of Large Flood Events by Dartmouth Flood Observatory (DFO). The Global Flood Inventory (GFI) was one of the earliest efforts to synthesize information from multiple sources and databases to create a continuous flooding record (Adhikari et al. 2010). However, there are several limitations to GFI such as limited time span from 1998-2008 as well as point locational information on floods with acknowledged uncertainty. The global databases were also found to be of limited fidelity when it comes to describing spatial extents of flooding impact as well as temporal coverage. The bigger motivation behind the compilation of the India Flood Inventory (IFI) is the availability of large amounts of valuable information currently stuck in printed documents published by various government departments in India which have never found usage in furthering research due to not being available as an easily accessible database. This data is ground-validated and can be ascribed higher trustworthiness in terms of ascertaining damages, fatalities, as well as spatial extents.

The IFI has been designed ground-up with careful consideration put into keeping it open, standardized, and, extensible, with data recorded in a way that could be useful for quantitative disaster modeling and analysis. The paper describes in detail the spatial and temporal coverage of the India Flood Inventory, the augmentations made to existing datasets, incorporation of new sources of information, and a summary of preliminary insights gained from this new dataset.

2. Existing flood databases and their biases

Several multi-hazard databases catalogue flooding events with varying scope and intended function. Two existing such databases are ReliefWeb (http://www.reliefweb.int/) maintained by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and the International Flood Network (IFNET, http://www.internationalfloodnetwork.org/) . ReliefWeb is more geared towards long-form information about real-time events as they unfold and don't provide a historical database. While the IFNET doesn't provide enough useful information over a long enough period to be useful as a historical dataset. As such, both these databases were ignored during the creation of the IFI.

A more widely-used international database is the The Emergency Disasters Database (EM-DAT, http://www.emdat.be/) which is administered by the Center for Research on the Epidemiology of Disasters (CRED) that collates natural and man-made disasters from 1900 to present. The criteria for an event to be included is when 10+ people are killed, 100+ people are affected, a state of emergency was declared, or a call for international assistance. This is the longest readily available database available of disasters internationally. However, since the inclusion criteria is impact-based, the data may be biased towards population centers like urban areas.

The Dartmouth Flood Observatory (DFO, http://floodobservatory.colorado.edu/) is a more comprehensive database exclusively focused on floods from 1985 to present. It's a simple excel sheet titled Global Archive of Large Flood Events, where the data is sourced from news, government sources, and satellite imagery. Though the data is richer than EM-DAT due to the availability of flood start and end dates, country, details of affected locations, flooded river, number of fatalities and damages, and spatial extent of flooding. The database also provides both static images and analysis-ready imagery showing the flood-affected regions. Though it has fairly good global coverage and higher data fidelity than EM-DAT, the database has lower temporal coverage compared to other databases. The georeferenced record of flood event locations is also only since 2006, limiting its viability in verification of long-term hydrologic simulations, which is our primary objective behind creation of IFI.

The mainstay of IFI is the hitherto under-explored "Disastrous Weather Events" (DWE) database compiled by the Indian Meteorological Department (IMD). This is a printed publication that has been published by IMD since 1979 till date and is extremely hard to access due to not being available online readily. The publication covers a wide gamut of natural hazards such as snowfall, cold wave, heat wave, squall, gale, dust storm, lightning, thunderstorm, hailstorm, floods and heavy rains, and cyclonic storm. The database has been used very few times in scientific research. For example, De et al. (2005) has used a small subset of this archive along with other databases to provide broad highlights of extreme weather events in India over 100 years (1901-2004). In another study, a more focused study on floods was performed with data from 1978-2006 highlighting the flood events, fatalities, and damages (2013). But the data currently remains underutilized as it is not available publicly in a geospatial-analysis ready format.. The effort involves tremendous amounts of manual and automation work as well as careful verification, which the present study has sought to embark upon, the details of which are explained in the next section. While designing the IFI, we have been motivated by our desire to create a schema and database that is suitable for use in big data modeling studies in the future.

3. Compilation of the Flood Inventory

3.1 Sources of Information

The IFI currently incorporates information from the following sources, which then undergoes multiple levels of augmentation:

a. An annual printed publication named "Disastrous Weather Events" (DWE) by the Indian Meteorological Department from 1979 till date. The database covers a wide number of geophysical hazards, of which only floods were digitized for IFI
b. Dartmouth Flood Observatory (DFO)
c. Emergency Events Database (EM-DAT)

3.2 Description

The flood inventory has been structured into 2 parts: textual attributes and a spatial database. In order to capture the qualitative and quantitative aspects of floods, we have defined several terms for the database:

a. Unique Event Identifier (UEI)

Each flood event is assigned a unique identifier in an extensible format such as UEI-IMD-FL-2015-0001, where IMD is the source dataset name, FL is for flood, 2015 is for year, and 0001 is for the serial event number of that year. This schema is flexible enough for us to incorporate different disaster database within a common framework. It will also facilitate incorporation of other geospatial disasters in the future and maintain interoperability, which may facilitate research into compound disasters such as floods and landslides.

b. Start date

This is the start date of the flooding event. The IMD DWE contains more granular information about the start and end of the event while databases EM-DAT often only indicate the months.

Often, the times provided are generic such as 3rd week of the month, which were transformed to exact calendar dates. In order to maintain interoperability between various formats, all dates conform to ISO 8601 (YYYY-MM-DD), which is the international standard for the representation of dates and times.

c. End date

This is the end date of the flooding event which also conforms to ISO 8601 standards.

d. Duration

The number of days that have elapsed between the estimated start and end date of the event.

e. Main Cause

The primary cause of the flooding event, as recorded in the databases.

f. Location

This is only available for information incorporated from IMD. It indicates the names of districts, states, and regions.

g. Districts

This information had to undergo lots of standardization and quality control as many district names are wrongly entered in the original databases.

h. State

Substantial amount of data did not come with state information and only with region or district information. These had to entered manually after consulting national geospatial databases. A few states have undergone changes in their official names, which have also been corrected. They conform to

i. Latitude and Longitude

A major lacuna of the existing databases is the non-availability of latitude and longitude of the events, which is required for computational studies. For data sourced from DFO, the coordinates were recorded as available. For IMD, based on the district and state information provided, shapefiles were generated for the thousands of events, the centroid for which was recorded in the database.

j. Severity

Only events sourced from DFO contains severity information.

k. Area affected

Only events sourced from DFO contains area affected information.

l. Human fatality, injured, and/or displaced

While DFO contained human fatalities and displaced for certain locations, IMD DWE contains far more granular information regarding these. However, they were available in a verbose textual style, which have now been recorded separately in the database.

m. Animal fatality

IMD DWE also contains information on animal casualties which are not unavailable in global databases.

n. Description of casualties

IMD DWE contains textual description of causalities which have been kept in their original format to provide more context.

o. Extent of damage

IMD DWE contains granular information on how the flood damage happened (E.g. Houses and bridges collapsed, low lying areas flooded etc.). This is expected to provide more contextual information to individual events.

p. Event Source ID

Wherever available, the original source IDs have been preserved in IFI in order to facilitate cross-checking.

3.3 Methodology

A systematic methodology was adopted to build the India Flood Inventory with the goal of conforming to modern interoperable standards and promoting computational hydrology research and applications. Different challenges were encountered with different datasets.

EM-DAT and DFO were the two global datasets that were incorporated. DFO was a simple excel sheet and the attribute names were standardized for our dataset and provided the Unique Event Identifiers (UEI). For EM-DAT, the same operation was performed after accessing the global database.

However, majority of the work required the digitizing and processing of the IMD Disastrous Weather Events that are available only as paper publications. The IMD DWE dataset is the most detailed official dataset of flooding in India, but records are available in a format not readily amenable for computational work and a geospatial database (See, Figure 1). The dates were conformed to ISO 8601 standards and the human and animal casualties/injury numbers were extracted into separate columns. The most valuable part of this dataset was the information regarding districts that were affected. In order to generate GIS-friendly spatial extents of flood-affected areas, these district names were reverse-matched with a national district shapefile database (http://projects.datameet.org/maps/districts/) and a consolidated shapefile was generated for each event. Based on this event-based shapefile. the centroid of latitude and longitude was extracted and recorded. Each event was assigned a unique identifier like the global databases.

S.N.	*Date / Period*	*Area affected*	*Intensity [River(s)]*	*Casualties*	*Extent of damage*
9	17 & 18 Aug.	Shimla, Sirmaur, Solan, Una	Heavy rains	2 persons died & 5 others injured as wall collapsed.	iii) Vehicular traffic disrupted due to damage of roads.

Figure 1: Example of how IMD Disastrous Weather Events records information

3.4 Uncertainty and limitations of the database

Compiling a hazard database of this nature is crucial for developing future hydrologic studies but requires painstaking work that is both scientifically and logistically challenging. The data itself is inconsistent as different agencies record it in different ways, but without the data in a common usable format, it remains a source of information rather than promoting further research. The obvious bias in the global databases such as EM-DAT and DFO is concentrating on only events with large impacts and covered by international media, while smaller events and more granular information is better recorded in local databases such as IMD DWE. There are several uncertainties inherent in the IMD DWE database which may be noted. Firstly, administrative factors that may impact the information in these databases, for example over-reporting when flood assistance from federal government is tied to damage reported by local disaster management offices. Secondly, under-reporting of events may happen for locations that have experienced fewer damages or casualties or located in more geographically distant locations instead of the bigger cities. Reporting bias is especially true in developing countries such as India where data collection is constrained due to budgetary reasons. This bias can be reasonably expected to have reduced over the years and hence an obvious increase in the number of flooding events may simply be due to better observational capabilities.

Finally, the other main source of uncertainty is the locational information. For example, the IMD DWE dataset is often inconsistent in what it is recording as the location, using districts, states, and regions interchangeably. The geographic centroid has been painstakingly recorded by building shapefiles for every event but is likely being biased due to insufficient granularity in the original database. But since no dataset is currently available for India, such information is expected to provide a certain bound in terms of understanding these natural hazards.

4 Preliminary analysis of hazards, fatalities, and damages

4.1 National and regional patterns

After the digitization, standardization, and augmentation, the India Flood Inventory was analyzed for spatio-temporal patterns to understand the frequency and severity of the events, the human and animal fatalities caused, and the causative factors. The IMD DWE dataset yielded the largest number of events (4176) with the highest spatio-temporal data fidelity. Collected manually from government records, it can also be regarded as the best available lower-bound of ground reality. EM-DAT contains 276 events but since the criteria for inclusion in the dataset is 10 or more fatalities and 100 or more injuries, it is inherently biased towards larger flood events. Additionally, DFO contained 262 events, but for a much shorter period. The summary of these databases is provided in Table 1 with the global databases, EM-DAT and DFO, contributing 6% and 5% to the IFI respectively, while the national database of IMD DWE is contributing 89%, which substantially increases the sample size and consequentially the robustness of studies based on this dataset. For the common period of 1985-2016 between the three databases, the number of recorded events is 206 for EM-DAT, 235 for DFO, and 3487 for IMD DWE.

Table 1: Summary of databases incorporated into the India Flood Inventory

Summary of information	Global		National
	EM-DAT	DFO	IMD DWE
Date	1926-2019	1985-2019	1967-2016
Number of records	276	262	4176
Percentage of India Flood Inventory	6%	5%	89%
Number of records (1985-2016)	206	235	3487

Figure 2 shows the evolution of the number of floods events in India for different time periods since 1926, as available in the 3 data sources. The increasing trend is clearly visible in all three, though some of it may be attributed to better data collection over the years as well.

With a slope of -2.45, the IMD data shows the sharpest trend, followed by EM-DAT with a slope of -0.16, and DFO with a slope of -0.13.

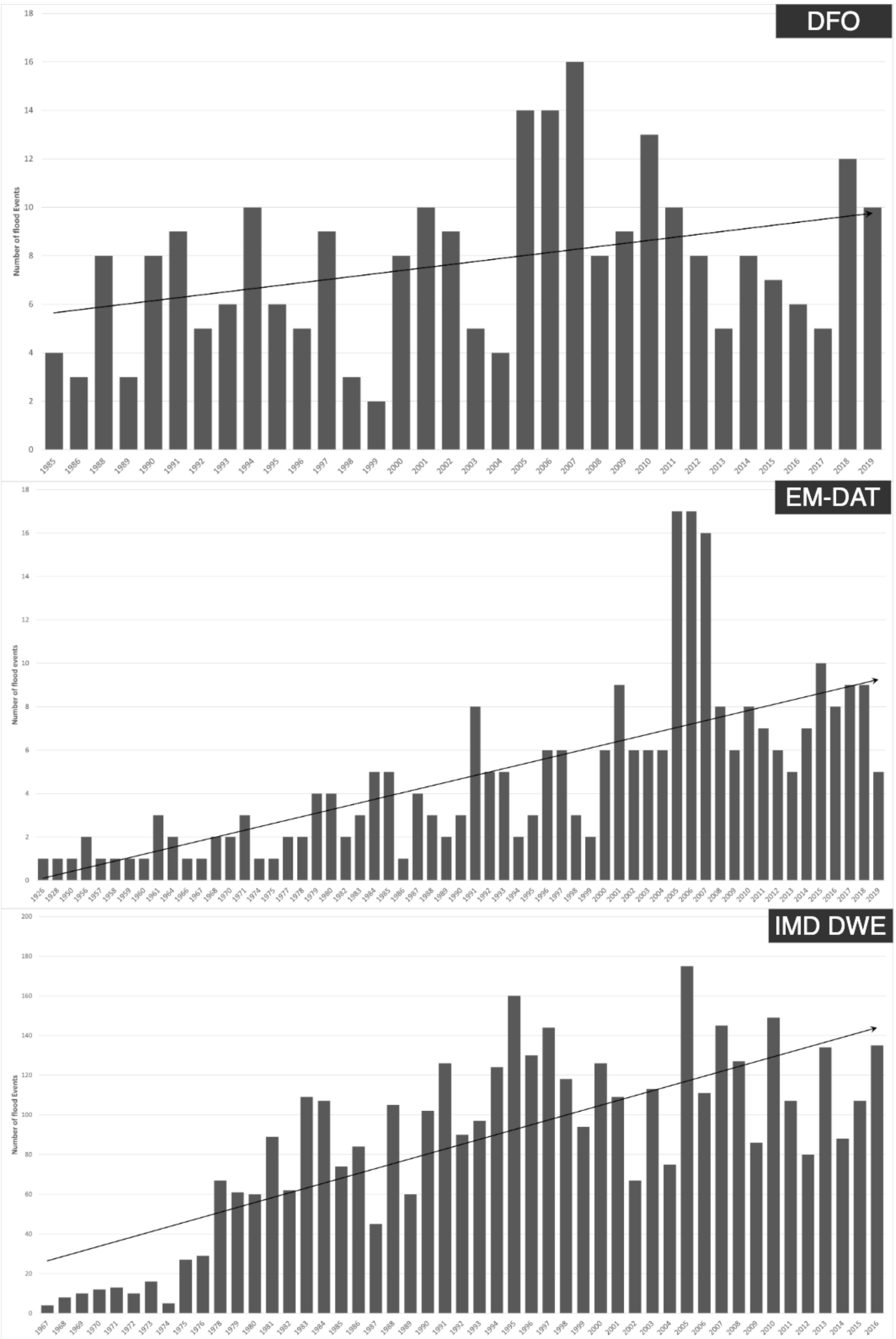

Figure 2: Temporal evolution of the number of floods at national scale

Figure 3 shows the temporal evolution of the number of flood fatalities over India since the 1970s. The number of fatalities per year vary widely, with the lowest being 67 in 1974, highest being 5473 in 2013, and an average of 1387 fatalities per year in the IMD DWE. The single worst [Database code: UEI-IMD-FL-2013-0131/UEI-DFO-FL-2013-0001] event in terms of fatalities is the 2013 June 14-18 cloudburst-induced heavy rainfall and flash flood event in Uttarakhand that caused more than 5000 human fatalities. Multiple landslides and avalanches were reported at several locations with 12 out of the 13 districts badly affected, with the worst affected being Chamoli, Pithoragarh, Rudraprayag, and Uttarkashi districts. Similarly, events with extraordinarily large number of fatalities were also observed in 1979, 1980, and 2000. In a well-known event known as Machchhu dam failure of Morbi disaster, the dam breach inundated the town of Morbi killing approximately 1500 people according to official estimates. In 1980, around 1300 people perished due to severe flooding and ensuing drowning, house collapses, landslides, and boat tragedies in large swathes of Uttar Pradesh. Overall, there is a definite increasing trend in flood fatalities across India.

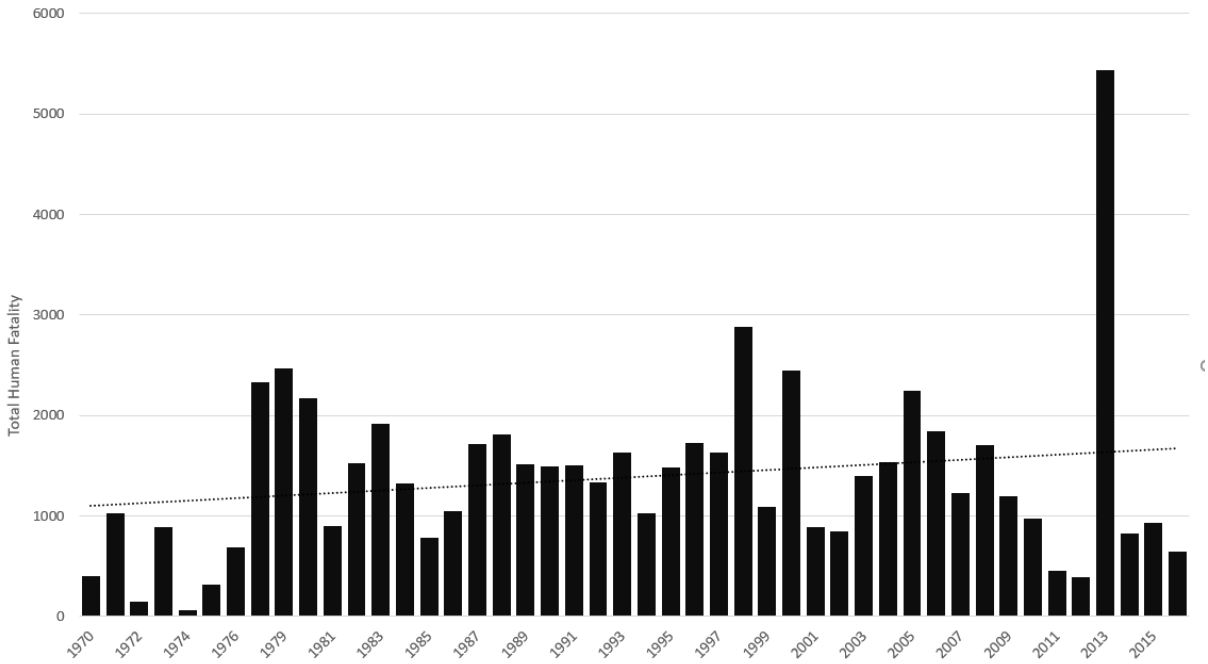

Figure 3: Temporal evolution of the number of flood fatalities at national level

This progressive increase in flood events and human fatalities in India has also been reported by other studies. Shreshtha (2008) analyzed a global dataset to conclude that there is a dramatic increase in flood disasters from 1976-2005 in South Asia. This is in line with has been observed in Europe and attributed to factors that have appeared or gained influence over the years, with higher sensitivity to smaller disasters, and a consequent increase in the reporting of such disasters (Hoyois and Guha Sapir, 2011). In a study of disasters globally, Jonkman (2005) found that Asian rivers are the most significant in terms of number of people killed and affected, with flash floods resulting in highest average mortality per event. There is a threefold rise in widespread extreme rain events over Central India (Roxy et al., 2017), increasing spatial variability in observed Indian rainfall extremes (Ghosh et al., 2012), and the increasing frequency of heavy rainfall events in peninsular, east and north east India that is correlated with flood risk (Guhathakurta et al., 2011).

India is divided into 28 states and 8 union territories, consisting of total 36 administrative entities. For the sake of simplicity, all of them have been referred to as states here. The number of flooding events for each state and database type has been shown in Figure 4. Since, DFO only records the latitude and longitude, state-wise statistics were not reported. The top 5 states have been reported in Table 2, with Assam experiencing 25% of the national totals in EM-DAT. While IMD DWE mentions Maharashtra as the highest with roughly 14% of total number of floods. Similarly, IMD DWE shows Uttar Pradesh experiencing the highest number of flood fatalities at roughly 17%. There could be several possible reasons for this difference between the two databases at the state level. Since, EM-DAT limits itself to events that have caused death of 10 or more people or affected 100 or more people, it is inherently biased towards more destructive events at a larger scale. The Brahmaputra causes longer-duration riverine floods throughout the state of Assam, causing enormous damage to life and property on a yearly basis. On the other hand, IMD has field offices across the country from where they collect the data and is also not limited by death and damage criteria like EM-DAT is. Thus, states like Maharashtra record the highest number of floods in this database, which may be due to more frequent flooding events at a shorter scale.

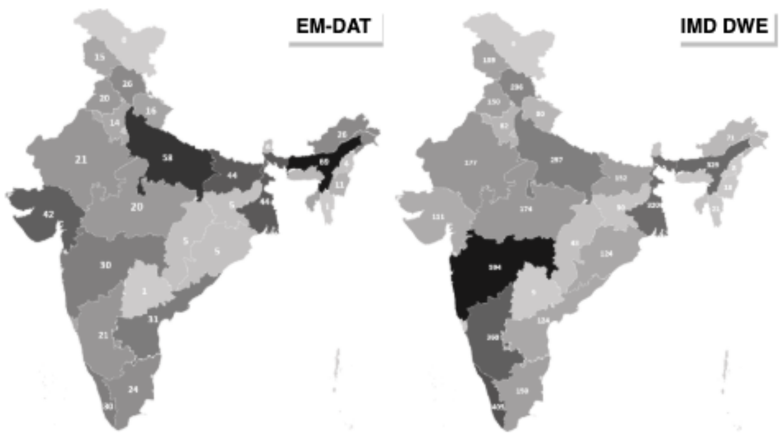

Figure 4 shows the spatial distribution of the number of flooding events in IFI from IMD DWE and EM-DAT.

Table 2 Top 5 states with the highest number of floods and fatalities

EM-DAT			IMD DWE			IMD DWE		
States	Number of Floods	National %	States	Number of Floods	National %	States	Number of Fatalities	National %
Assam	69	25.00	Maharashtra	594	14.22%	Uttar Pradesh	12158	16.78%
Uttar Pradesh	58	21.01	Kerala	405	9.70%	Maharastra	6943	9.58%
Bihar	44	15.94	Karnataka	360	8.62%	Uttarakhand	6725	9.28%
West Bengal	44	15.94	Assam	329	7.88%	Bihar	6366	8.79%
Gujarat	42	15.22	West Bengal	320	7.66%	West Bengal	6081	8.39%

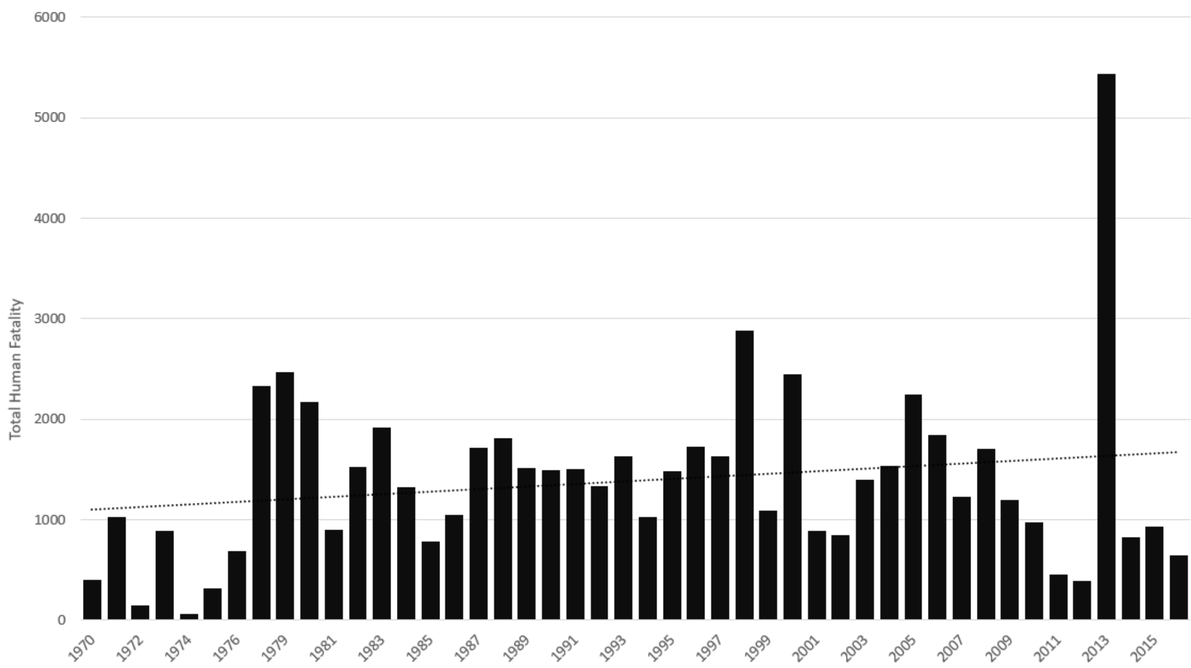

Figure 5: Temporal evolution of the number of flood fatalities at national level

Figure 6and Figure 7shows the temporal evolution of the causative factors according to DFO and IMD DWE. As expected, monsoonal rains dominate the cause behind floods in India. A substantial number of cloudbursts have been recorded in IMD DWE, which is a cause of major concern due to short but devastating nature of its impact. It is to be noted that the causative factors in IMD DWE are not encoded systematically and often don't record any causative factors. Hence, they need to be approached with caution.

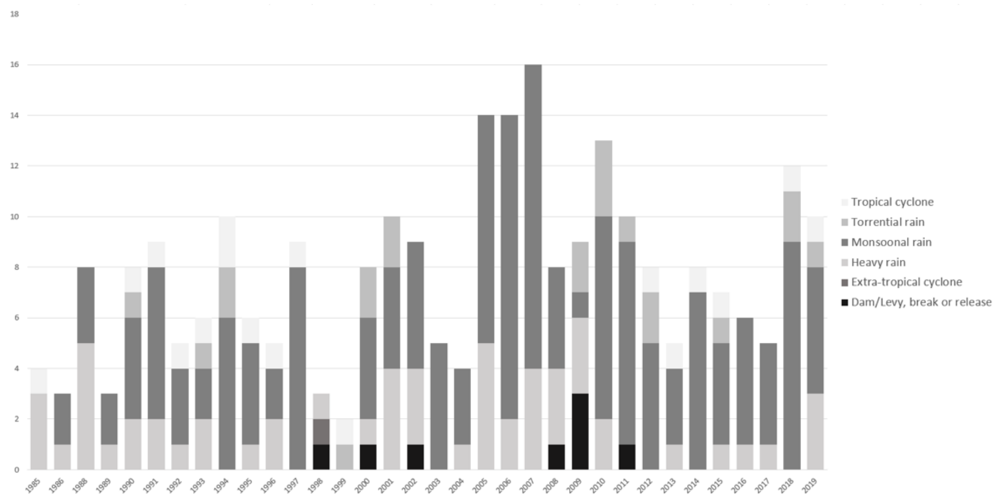

Figure 6. Temporal evolution of causative factors according to DFO

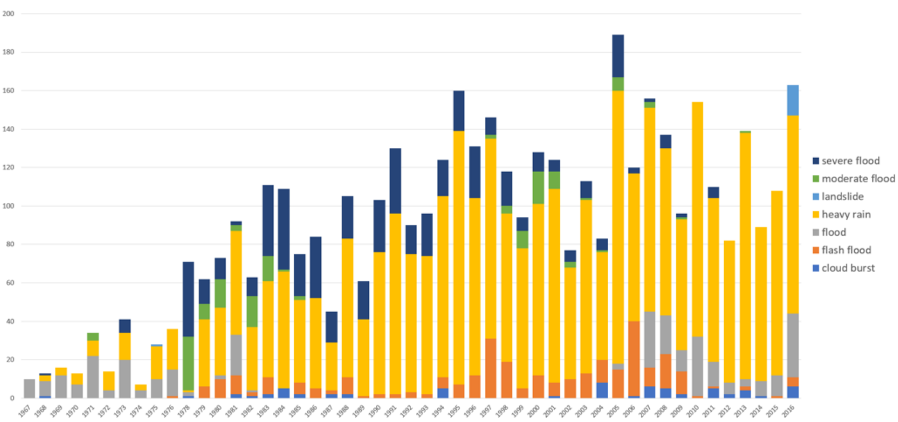

Figure 7. Temporal evolution of causative factors according to IMD DWE

4.2 Seasonal patterns of hazard and fatalities

Flooding in India varies according to monsoon activity and tropical cyclone patterns. Both the number of flooding events and human fatalities are dominated by the monsoon and post-monsoon season, which can be attributed to outbreak of monsoonal rain activity across the country. Water levels in rivers rise while reservoirs are running at capacity during this period, causing widespread floods in the country. Averaging globally, the flood season starts in May and peaks in August (Adhikari et al., 2010), but in India, it peaks in July and August as shown in Figure 8 and Figure 9. Monsoons from June to September record the majority of the flood events at 79% of the total, according to the IMD DWE. It also accounts for 83% of the total fatalities year-round. Figure 8 **shows the comparison of the number of floods per month as**

a percentage of the yearly totals. IMD and DFO records the highest number of floods in July, while EM-DAT records the highest late monsoon in August. It may be noted that EM-DAT concentrates on floods causing large number of fatalities and injuries, compared with IMD, which represents floods without regard to damage.

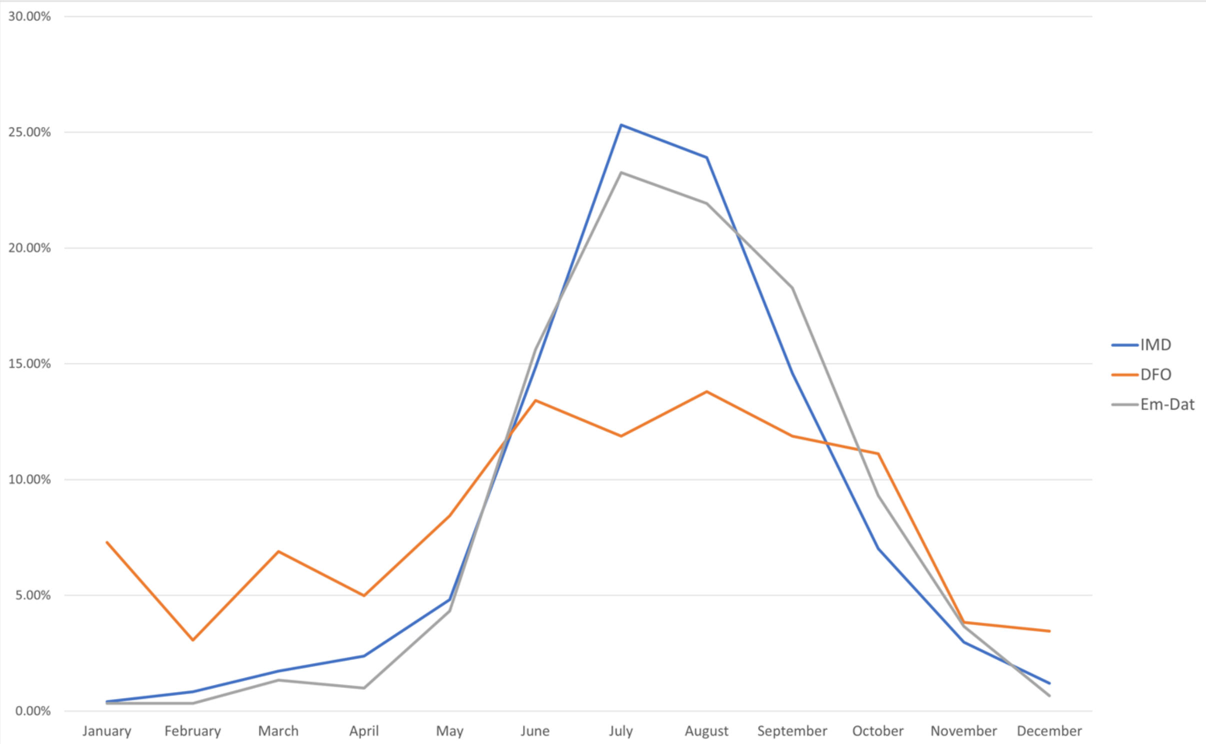

Figure 8. Monthly variation of the number of floods at national scale as a percentage of yearly totals

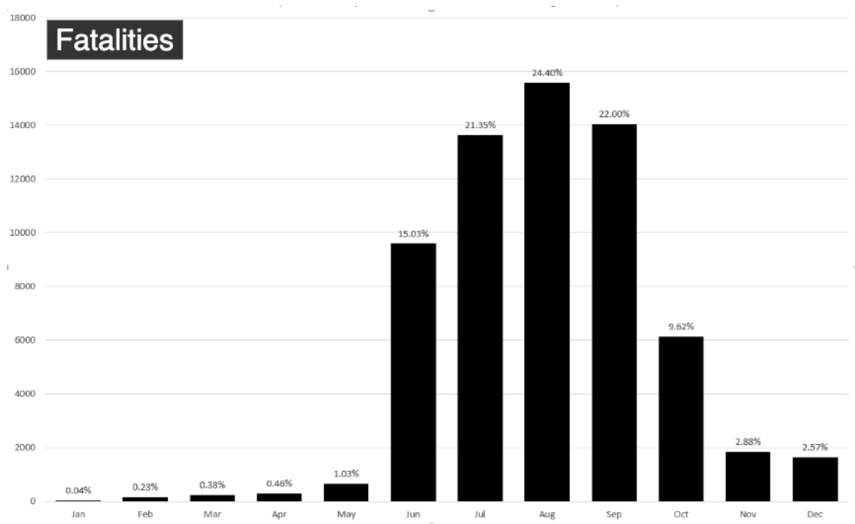

Figure 9: Monthly variation of the number of flooding fatalities according the IMD DWE

4.3 Digitization and possible Applications

Another uniqueness of this dataset is the availability of flooding extents in modern formats such as Shapefile (.shp), GeoPackage (.gpkg), and KML (.kml file). These extents have been calculated for each event by matching the district/state level information available in these datasets. Since these extents come with temporal information, remote sensing data such as Landsat/Sentinel/MODIS etc. could be used to develop inundation imagery for specific flooding events. This would be very helpful in validating hydrologic modeling simulations in various locations.

5 Conclusions and Future Work

The India Flood Inventory (IFI) is India's most comprehensive database of flooding events that is a) multi-source, b) standardized to international data specifications, and c) freely available in modern geospatial formats. Currently, IFI includes 49 years [1967-2016] of flood data digitized from the IMD Disastrous Weather Events. It also includes 34 years [1985-2019] of data from the Dartmouth Flood Observatory (DFO) and 93 years [1926-2019] of data from the International Disaster Database (EM-DAT). Best possible effort has been made to augment and standardize them to a common schema, which makes IFI an analysis-ready dataset for a wide-variety of applications related to flood hazard, risk, and exposure.

The majority of floods in the country happens in the monsoon season, which is 79% of the yearly total, with a peak in July. On the other hand, the number of flood fatalities during the same period is 83% of the yearly total, with a peak in August. The seasonality of flooding is well indicated in the country, which can guide flood management and disaster reduction efforts in the country. The large flood plains of the country such as Uttar Pradesh, Assam, Maharashtra, Bihar, and West Bengal experiences the highest number of floods and fatalities.

While, the hill states such as Uttarakhand have experienced catastrophic events, with some of the highest per capita death rates in the country.

This study has only begun a preliminary investigation into the spatio-temporal variations of flooding in India. Further investigation into the causative factors will be necessary to determine the structural and non-structural flood mitigation measures that may be necessary. This dataset is expected to contribute towards encouraging such diagnostic and prognostic efforts. One of the goals is this study was to propose a standard specification for recording natural disaster information which will aid future data collection efforts. The extensible framework proposed for India Flood Inventory can be used to integrate data from large number of disparate databases for any number of natural hazards. An on-going upgradation to the inventory is to use a cloud-based platform to derive the spatial inundation extents for the events using satellite imagery. This compilation is designed to be a massive ongoing effort going forward as we digitize and incorporate sources of information from other federal and state disaster management agencies, most of whom maintain independent datasets and are expected to be of even higher fidelity.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest.

Author Contributions

MS proposed the idea. SH and RB digitized the dataset. MS and AJ analyzed the dataset. MS and AR wrote the manuscript. SOP and DSP provided the dataset and comments on the manuscript.

Data Availability

The dataset and shapefiles are freely available from this repository: https://github.com/hydrosenselab/India-Flood-Inventory

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