Role of Flood Forecasting and Early Warning System in Flood Management: A Study of the 2010 Flood in the Swat Valley, Pakistan

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Among non-structural approaches to flood management, the Flood Forecasting and Early Warning System (FF\&EWS) plays a key role in reducing flood risks. This study focuses on the role of FF&EWS in the Swat Valley. The Swat Valley suffered from numerous floods. Among them, the 2010 flood was a disastrous one. FF&EWS is the main responsibility of the Pakistan Meteorology Department (PMD). To achieve the objectives of the study, data were collected from different sources and processed through different statistical tools. Analysis revealed that rapid change in LULC, encroachment, and deforestation were the major flood-intensifying factors. The increasing population pressure on land resources has pushed people to the flood risk areas, and as a result, people have started development in the flood-prone zone. From the analysis, it was recommended that no construction should be permitted in the vicinity of the River Swat and its tributaries. The development of settlements in vulnerable high-risk zones needs to be restricted. The existing FF&EWS and meteorological network in the Swat valley needs to be extended in order to increase the effectiveness of FF&EWS and minimize the impacts of recurrent floods. The study concludes that the effectiveness of FF and EWS in the Swat Valley can be improved by addressing the issues faced by FEWS.

Keywords: Flood Forecasting (FF), Flood Early Warning (FEW), Climate Change, Temperature, Flood Management.

Introduction:

The concept of Flood Forecasting and Early Warning System (FF&EWS) is one of the preventive measure that share flood information in flood-prone regions to minimize the impacts of floods [13]. EWS has been established by countries to share and disseminate flood information to the communities that live in flood-prone regions [1]. The FEWS relies upon forecast information to issue flood warnings [17]. FEWS helps to minimize human losses and property damage [2]. Magnitude and Intensity of flood events are increasing [3]. In flood risk planning and management, EWS serves as a key mechanism for timely response [4]. Globally, FF is an important flood monitoring mechanism to minimize floods. EWS is one of the essential components that reduces human life losses and property damage [2]. (CBEWS) is one of the key approaches that enables communities to overcome Natural hazards [5].

Many FF systems depend on rainfall inputs and the RADAR system [6]. However, the use of advanced tools and techniques in FF&EWS has minimized damage caused by floods [7]. The effectiveness of FF&EWS depends region to region because of advanced RADAR coverage. To minimize the impacts of flood damage in Pakistan, non-structural measures play a very important role [8]. In the present set-up, EWS is one of the non-structural measures implemented to reduce the flood risk. Therefore, this study aims to evaluate FF&EWS in the study area. Pakistan has experienced 23 of the worst floods that affected Pakistan on a large scale [9]. In Pakistan, flash floods mostly occur in mountainous areas, whereas riverine floods are experienced in the flood plains of Pakistan [18]. In Pakistan, the devastating floods of 2010 killed nearly two thousand people, injured over one thousand people, displaced millions of people, and destroyed livelihoods and damaged infrastructure [20]. In Pakistan, the flood of 2022 is one of the worst floods in history, which is caused by monsoon, melting of glaciers, heat waves, climate change as well as human induced factors [19]. Flood of 2022 has affected more than 33 million people and in effect only in Sindh and Baluchistan 1,355 people were died and 12,700 were injured [9]. In Pakistan, (FFD), Lahore is the main stakeholder for timely FEW to the flood prone communities [19].

This paper evaluates the role of FF& EWS in the Swat Valley. In the context, FF&EWS can help policymakers and stakeholders to identify those factors that affect the effectiveness. The role of FF& EWS in the study area is very important, due to its vulnerability to flooding. Swat Valley is one of the most flood-prone valleys due to climatic conditions and changes in rainfall patterns [20]. Ultimately, advanced and well-developed effective (FF&&EWS) can save lives and property damage in the study area. The effectiveness of FFEWS depends on the meteorological RADAR coverage and the effectiveness of the communication and dissemination process. Thus, this research paper evaluates FF&EWS in the Swat Valley. This research paper is divided into four sections. The first section gives a detailed introduction to the study. The second section deals with the methods and materials, and the third section is given to the analysis, results, and discussion. On the basis of the analysis result and discussion, this research paper is concluded, and recommendations are proposed to make FF&EWS more effective in Swat, Pakistan.

The Study Area:

Swat Valley is located from 34o34' to 35o55' N latitude and from 72o 10' to 72o50' E longitude, in KP, Pakistan (Figure 1). The elevation in the south is 500 meters to over 4,000 meters in the north [19]. The area of the Swat Valley is 5,337 km2 (Survey of Pakistan). The Swat Valley has many small and large streams and rivers. Rainwater and glaciers are the sources of streams and rivers. The river Swat and its tributaries define the Swat valley. In the Swat valley lie numerous snow-covered peaks with heights of more than 4,000 m [10]. The source of the Swat River lies in the glaciers of the northern Swat valley, and it is further fed by its main tributaries, the Gabral, Utror, and Ushu. The major tributaries of the Swat River are Gabral, Utror, and Ushu, which join the Swat River.

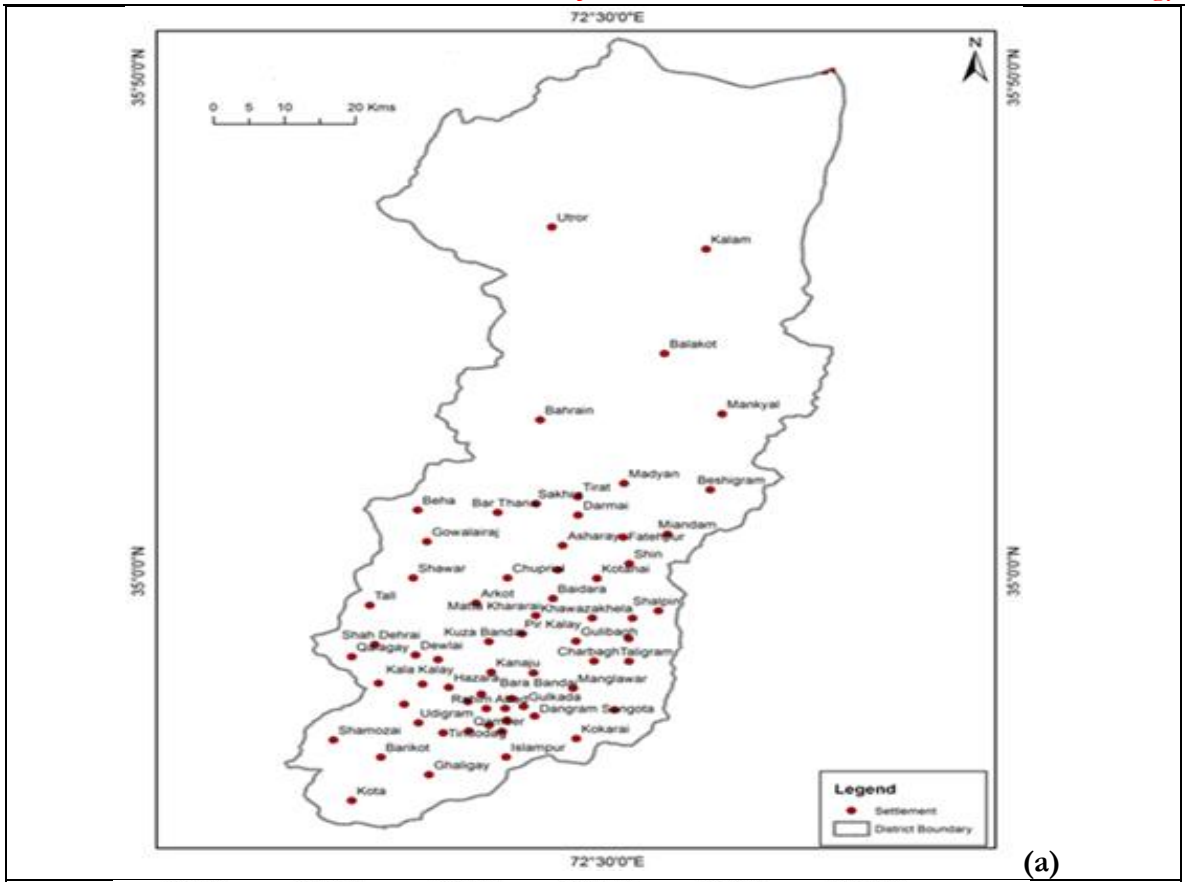


Figure 1. (a) Location map of the Study area. (b) Meteorological station in the study area

Swat Valley receives rainfall from monsoon and western depressions that cause floods [18]. In the Swat Valley in the summer monsoon season, heavy rainfall occurred in June, July, and August. Heavy rainfall caused flash floods and erosion in the mountainous area, as it moved downward, bringing debris and other material [20]. This caused an increase in the surface water of the river (PMD, 2010). River floods occurred that affected the settled area, population, animals, standing crops, infrastructure, all communication and transportation systems [17]. Many sorts of natural atmospheric and calamities occurred in the Swat valley that produced cracks, joints, faults, and folds in the mountain's surface [18]. Blowing from a high-pressure belt to a low-pressure belt brings change in the environment, which performs the work of abrasion and attrition, which finally leads to floods in the summer in the Swat valley [8].

Material and Methods:

The research methodology to conduct this research is composed of four key steps: (1) To review the flood situation and existing FEWS and its role in flood management in Swat, Pakistan; (2) To assess and analyze the perspectives of local experts and communities in the Swat valley. (3) To highlight the challenges faced by the existing EWS (4) To improve the effectiveness of FEWS and its role in flood management in the study area, and recommendations for effectiveness. To analyze the objectives of the study, data were collected from both sources, as shown in Figure 2. Primary data were collected through questionnaire surveys, field observation, and FGDs. Questionnaires were filled out by the line agencies, community-based organizations, and locals to know about the EWS and the process of early warning. 10% of the households were surveyed in the flood sample community. FGDs were conducted with community elders, representatives, and key stakeholders to cross-check the data. Secondary data were collected from Swat meteorological stations, which include precipitation, temperature (maximum and minimum), and were collected from Pakistan Meteorological Department (PMD) and FFD, Lahore, NDMA, PDMA, and DDMA (Swat). The collected data were finally analyzed through different statistical tools and finally presented in the form of maps, statistical diagrams, tables, and descriptions.

Analysis, Results, and Discussion:

Existing FEWS and its role in flood management in the Swat Valley, Pakistan:

PMD has a wide network of radar systems and weather observatories, which provide data for FF&EWS in Pakistan. The government of Pakistan has installed EWS in different parts of the country. The Flood Forecasting Division (FFD), Lahore, issues the FEW to the community to reduce the impacts of floods. In the Swat Valley, floods are one of the most destructive natural disasters, causing human losses and damage to properties. The (EW) is applied to provide warning to line agencies and communities to protect the people and properties. Effective FFEWS depends on a timely forecast and dissemination of FEW to the flood-prone regions. (EW) is one of the key elements of DRR, which plays an important role in disaster preparedness by sharing timely information with vulnerable communities in the Swat basin. FEWS play a critical role in flood management in Pakistan. While there are challenges to its effectiveness, community-based approaches and improvements in warning dissemination and response capacity help reduce the impact of floods.

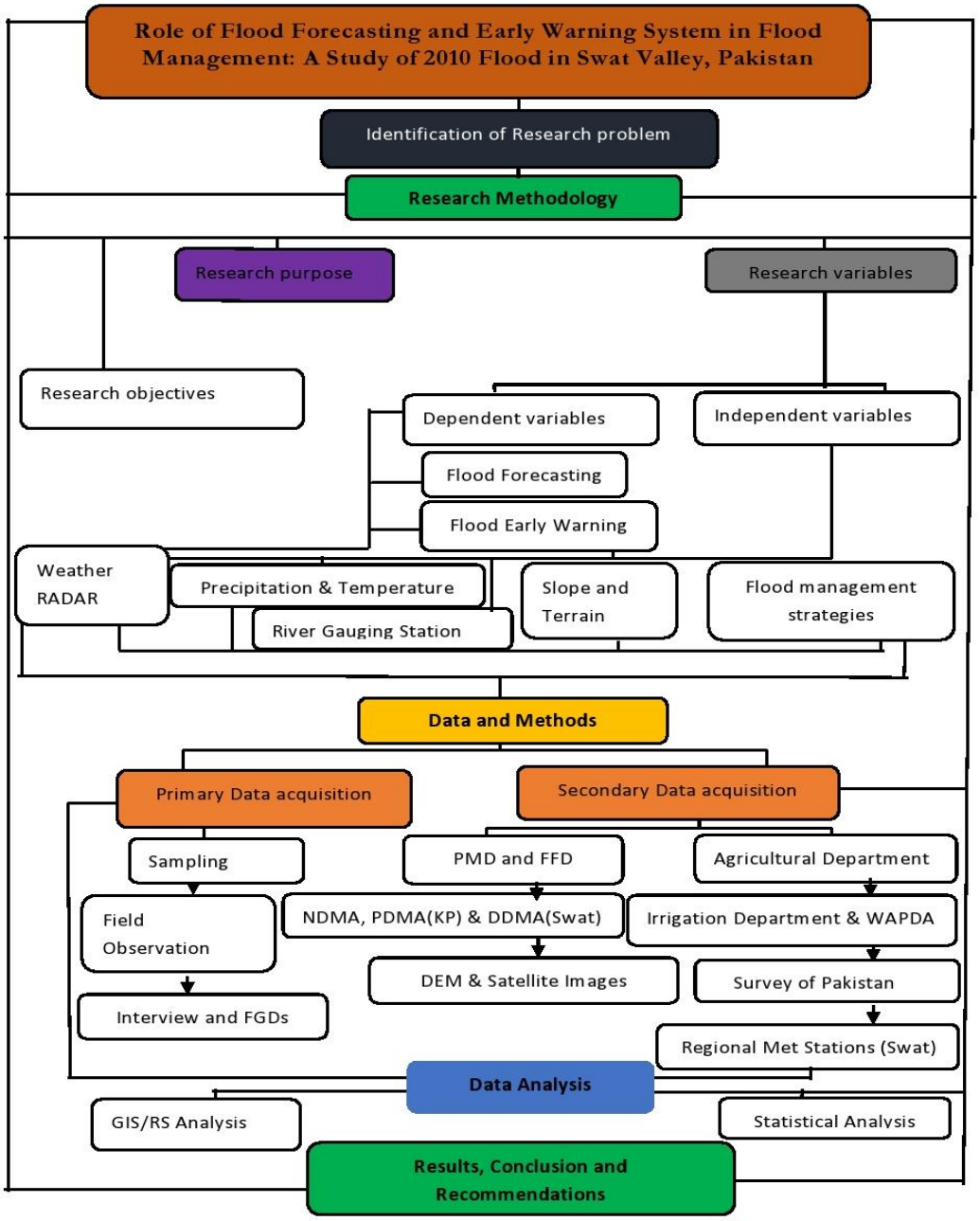


Figure 2. Research framework

Causes of flood in the Swat Valley:

The elevation of the Swat valley from 732 m in the south to over 5,000 m above sea level in the north, due to which it is difficult to monitor floods and disseminate early warning in time, as shown in Figure 3. a). The total area of Swat is about 5,337 km2. Due to elevation, rough terrain, and topography, it is very difficult to estimate flooding. In order to collect data about floods and their impacts on the population, data were collected in the population centers along the river Swat and its tributaries (Figure 3a and b).

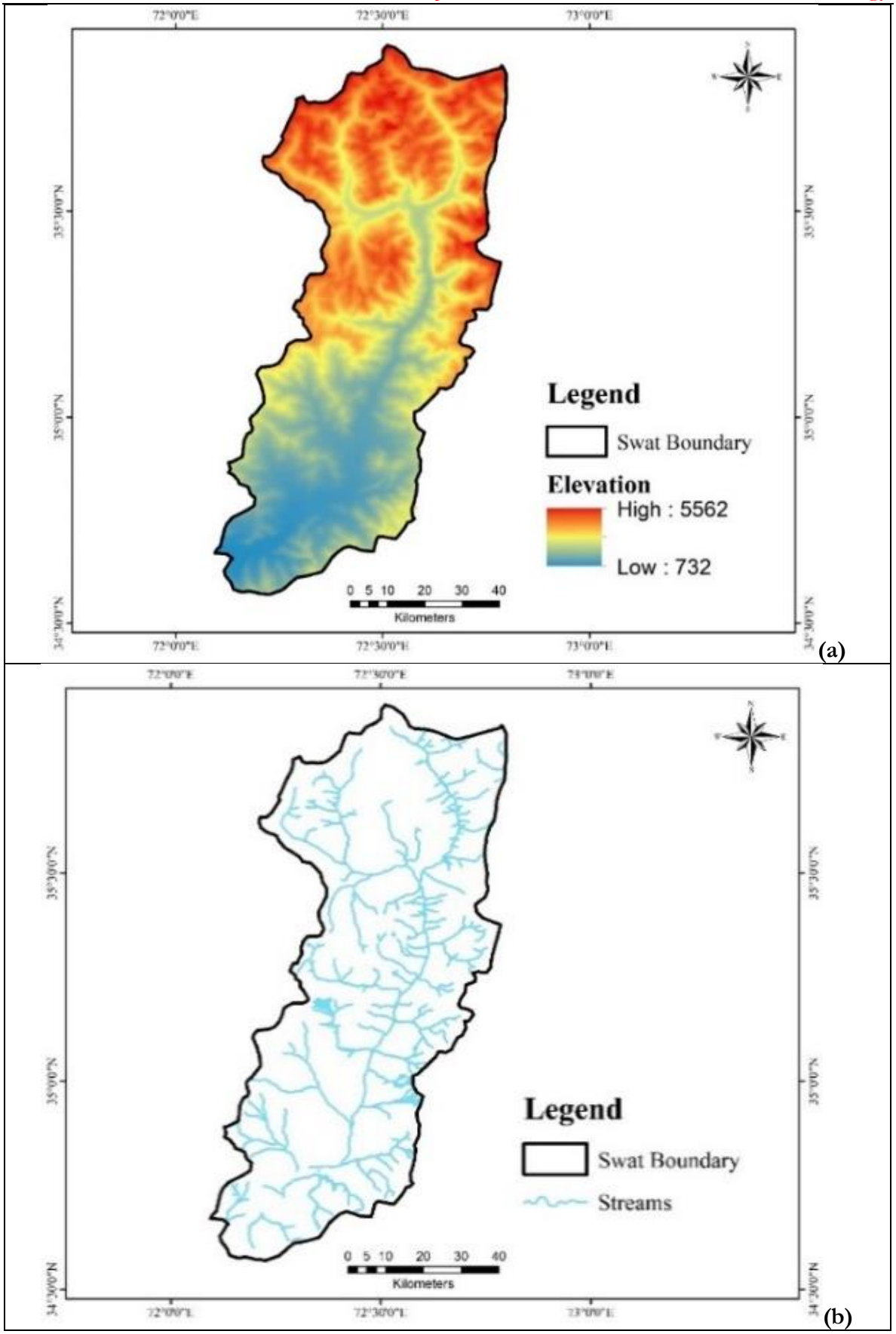


Figure 3. (a) Swat valley DEM (b) River and streams network in Swat valley

To determine whether the residents have any idea about the causes of floods in the Swat valley, the questions were asked of residents of the study area were asked about what they think about the causes of floods. Surprisingly, 32 % of the respondents answered that high temperature is the main cause. About 16 % favor torrential rainfall, 4 % climate change, and 16 % grazing. About 26 % answered that deforestation, and 7% answered that mass movement are the main causes of floods, as shown in Table 1 and Figure 4. The population of Swat is significantly affected by floods. The population of Swat is approximately 2.3 million, who are living on both sides of the river Swat. A substantial portion of this population relies on agriculture, which is heavily dependent on glacier-fed rivers. Thus, flood impacts the agricultural land, crops, and properties.

Table 1. Causes of flood in the Swat Valley

S. No	Causes of flood in Swat Valley	No. of respondents	Percentage of respondents
1.	Grazing	12	16%
2.	High temperature	24	32%
3.	Rainfall	12	16%
4.	Climate Change	3	4%
5.	Deforestation	19	26%
6.	Mass movement	5	7%
	Total respondents	75	100

Source: (Field survey, 2022)

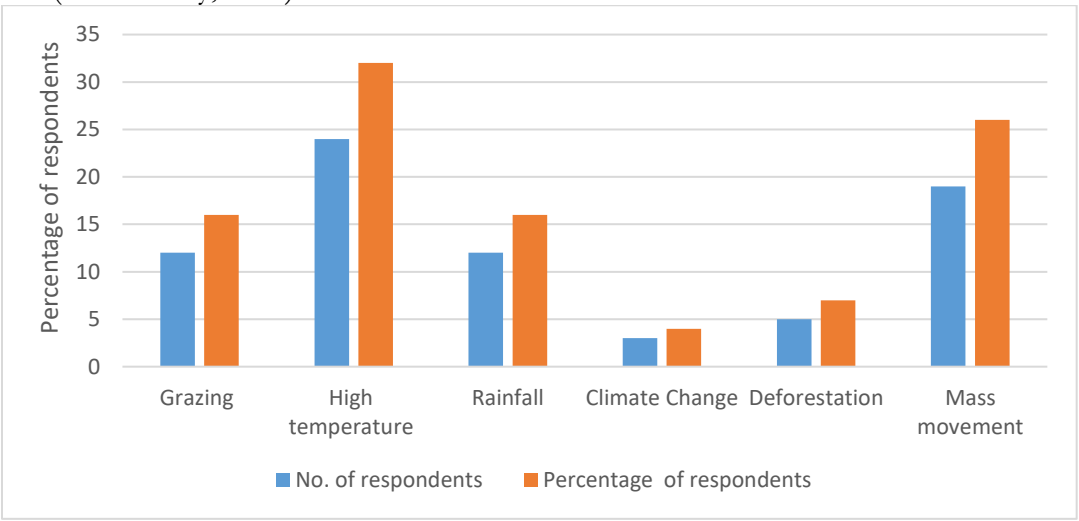


Figure 4. Causes of flood in the Swat Valley

Flood Forecasting and the role of PMD in the Swat valley:

The Pakistan Meteorological Department (PMD) plays a vital role in flood hazard assessment and management. To achieve this, PMD provides relevant forecasting information to key stakeholders responsible for disaster management. These stakeholders are tasked with disseminating flood risk information to vulnerable communities exposed to flooding. PMD works in close coordination with the Flood Forecasting Division (FFD), National Disaster Management Authority (NDMA), Provincial Disaster Management Authority (PDMA-KP), and the District Disaster Management Authority (DDMA-Swat). Through this network, PMD issues flood forecasts that are ultimately communicated to local communities for timely preparedness and response, as shown in Figure 5. The Tehsil Municipal Administration (TMA) plays a vital role in translating flood forecasts issued by higher authorities, such as the Pakistan Meteorological Department (PMD) and Provincial Disaster Management Authority (PDMA), into actionable information at the community level. TMAs are responsible for ensuring that

flood warnings are communicated quickly and effectively to residents, particularly those living in high-risk floodplain areas.

The Pakistan Meteorological Department (PMD) has developed different strategies to manage flood risks, which include comprehensive information on potential hazards, vulnerabilities, and response mechanisms. In this process, PMD closely coordinates with the Flood Forecasting Division (FFD), the (NDMA), and the PDMA) to issue and disseminate early warnings. During flood emergencies, FFD, PDMA, and NDMA act as the lead agencies in organizing emergency responses, working with relevant stakeholders to provide timely forecasts and related information that can help reduce risks. PMD takes key actions such as forecasting, monitoring, and communicating flood warnings, especially when floods reach their peak. The Flood Forecasting Division in Lahore plays a central role in enhancing forecasting capacity for areas identified as highly vulnerable. Information is systematically communicated to stakeholders to ensure effective decision-making and community preparedness. Meteorologists employ various scientific and meteorological techniques to assess the likelihood of flooding in susceptible regions. Alongside flood protection and awareness initiatives, responsible organizations are consistently working to refine forecasting systems and improve early warning mechanisms. In the Flood Forecasting Division (FFD), the forecasting system relies on multiple data sources, including precipitation inputs, observation networks, rain gauges, gauging stations, and radar data. These inputs collectively strengthen the Flood Forecasting and Early Warning System (FF&EWS), enabling authorities to provide more accurate and timely alerts to minimize flood-related damage.

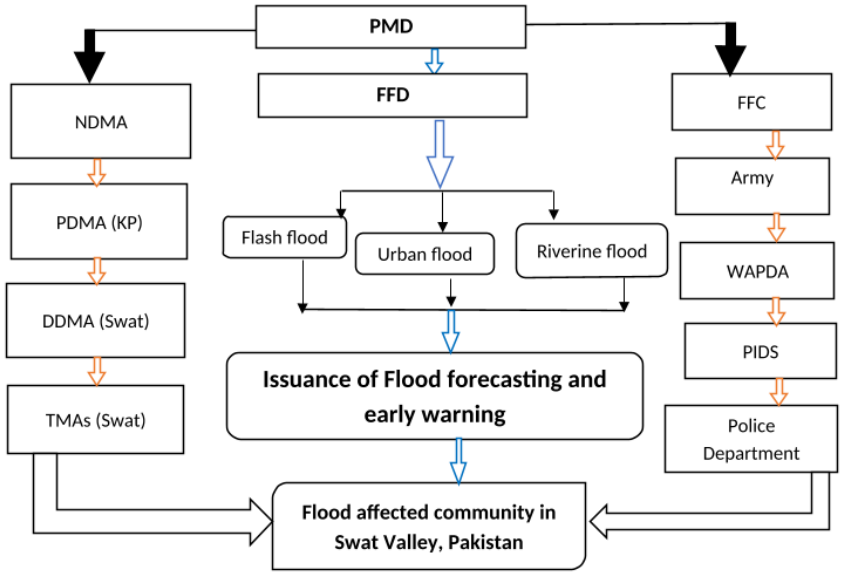


Figure 5. Role of stakeholders in flood management in the Swat Valley, Pakistan

Flood Warning Communication and Dissemination in the Swat Valley:

Swat Valley is highly vulnerable to floods due to its mountainous landscape, heavy monsoon rains, and the presence of snow and glacier-fed rivers. Floods in the valley often take the form of flash floods triggered by intense rainfall and rapid snowmelt, or riverine floods caused by prolonged rainfall leading to the overflow of the Swat River and its tributaries. These events pose serious threats to settlements, infrastructure, and agriculture, making flood forecasting a vital tool for disaster management in the region. The PMD plays a central role in monitoring and predicting floods in the Swat Valley. It operates weather stations, rainfall gauges, and river monitoring systems to collect data on precipitation, water levels, and snowmelt patterns. By using numerical weather prediction models, hydrological models, and satellite-based

monitoring, PMD forecasts potential flood events. This scientific forecasting provides authorities with crucial lead time to prepare and implement protective measures.

PMD is responsible for disseminating timely flood warnings to relevant institutions and the local population. It issues alerts to the Provincial Disaster Management Authority (PDMA), District Disaster Management Authority (DDMA), and local administrations, as shown in Figure 6. Warnings are shared through SMS services, television, radio, and collaboration with community networks. These efforts are aimed at ensuring that communities in vulnerable areas receive the information they need to respond effectively and minimize losses. Despite its important role, PMD faces challenges in the Swat Valley, including limited monitoring infrastructure in remote areas, weak communication networks, and the increasing unpredictability of flood patterns due to climate change and glacial melting. To strengthen its effectiveness, PMD needs to expand its monitoring stations, adopt advanced forecasting technologies, and enhance coordination with district-level authorities. Improving community awareness and preparedness programs will further ensure that early warnings lead to effective responses, ultimately reducing the devastating impacts of floods in the Swat Valley.

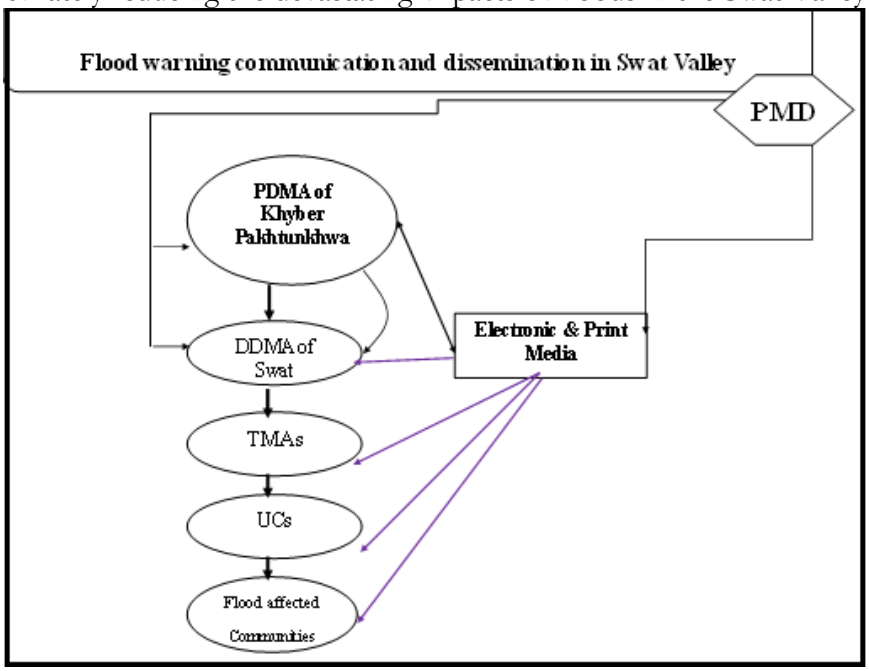


Figure 6. Communication and dissemination of FEW in the Swat Valley

Dissemination of Weather Forecasts and Information:

During the survey, the majority, 66 % of the respondents, say that they relied on television as their primary source of weather forecast, indicating the widespread reach and trust in television as a source of weather information. Radio was the second most popular source, with 11 % of respondents relying on it for weather updates. Mobile apps and social media were also used by 10 % and 13 % of the respondents, respectively, highlighting the growing importance of digital platforms in accessing weather information (Table 2; Figure 7). Interestingly, none of the respondents reported relying on print media as their primary source of weather forecasts, underscoring the dominance of electronic media in this regard.

Table 2. Dissemination of weather forecasts and Information

S. No	Weather forecasts	No. of respondents	Percentage of respondents
1.	Television	50	66%
2.	Radio	8	11%
3.	Mobile Apps	7	10%

4.	Social media	10	13%
	Total No. of respondents	75	100%

Source: (Field Survey, 2022)

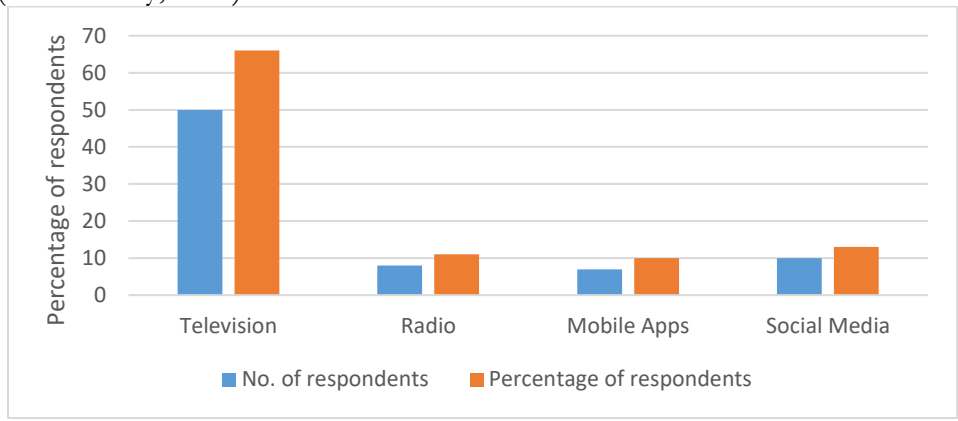


Figure 7. Dissemination of weather forecasts and Information

Accuracy of Weather Forecasts:

The accuracy of the weather forecast is an important factor in determining its usefulness and reliability, as weather conditions can be unpredictable. Among the 75 respondents surveyed, a significant majority 53 % have respond that they found the weather forecast is very accurate most of the time, with 14 % stating that the forecast was accurate, 7 % saying it was somewhat accurate and 5 % saying Not very accurate most of the time". However, 21 % of respondents expressed skepticism about the accuracy of weather forecasts, stating that they were accurate only "sometimes" or "rarely" (Table, 3; Figure, 8).

Table 3. Accuracy of weather forecasts

S. No	Weather forecasts	No. of respondents	Percentage of respondents
1.	Very accurate	40	53%
2.	Accurate	10	14%
3.	Somewhat accurate	5	7%
4.	Not very accurate	4	5%
5.	Not accurate	16	21%
	Total No. of respondents	75	100%

Source: (Field Survey, 2022)

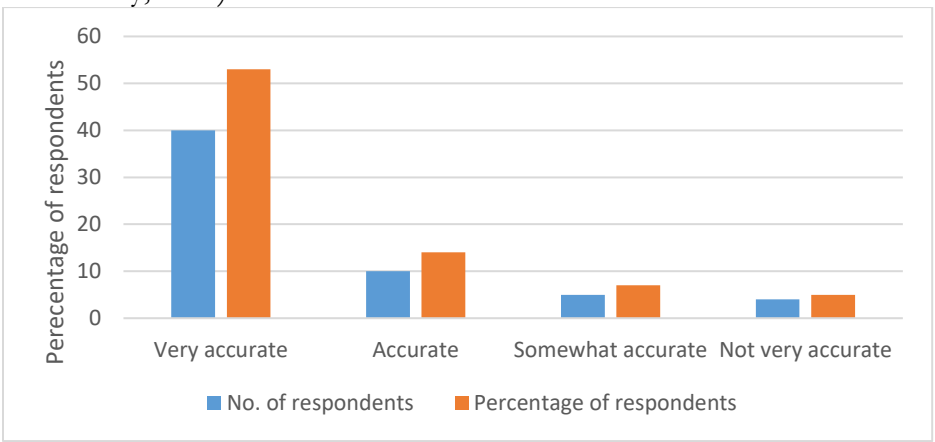


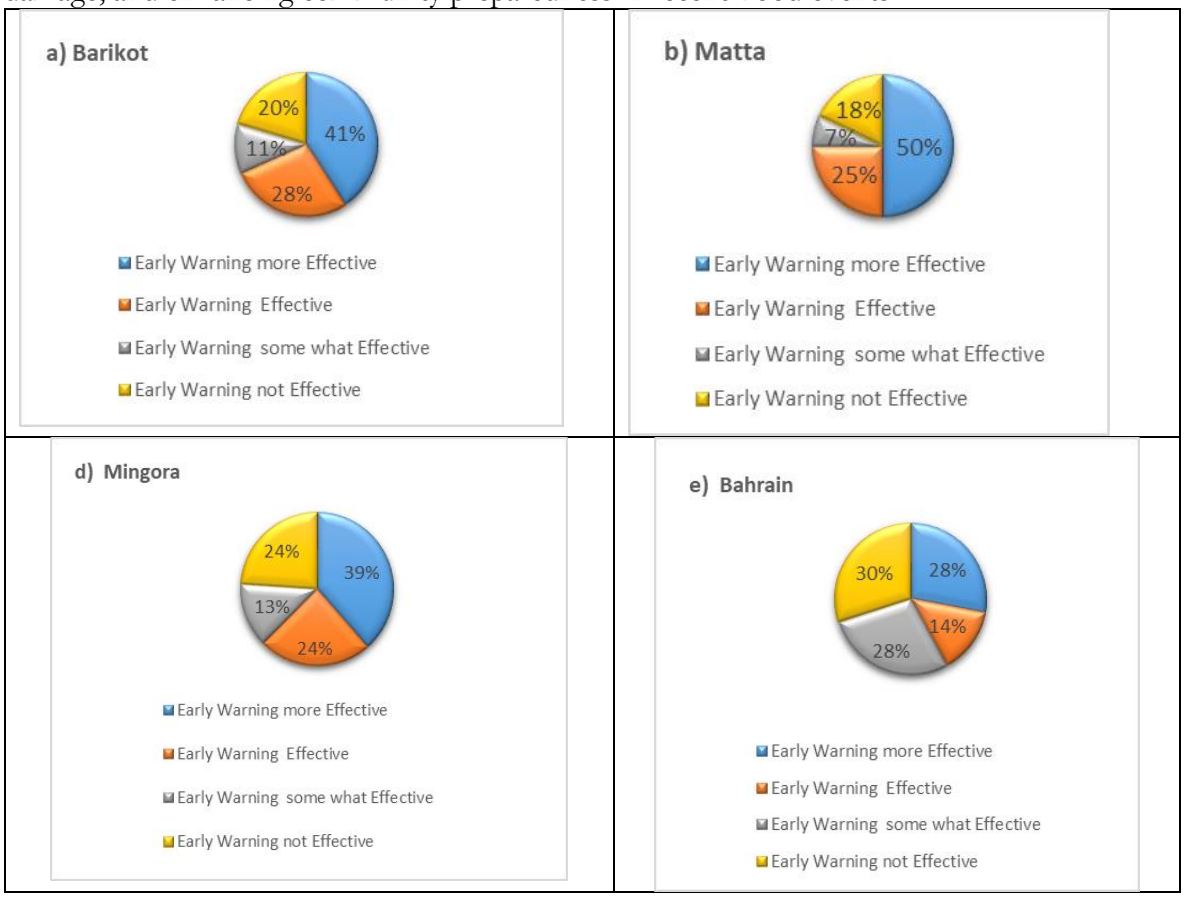
Figure 8. Accuracy of weather forecasts

Effectiveness of FF & EWS in Swat Valley:

During the survey, data were collected in flood-prone areas of the Swat valley. The analysis shows that the majority of communities in the selected areas and tehsils did not receive

early warning of floods (2010); however, the other regions indicated that the EWS was received, which shows the limited FEWS in the different areas and tehsils of Swat. This shows that a significant percentage of the population did not receive early warning in time, which can have serious implications for flood management in the affected communities, as shown in Figure 9. The effectiveness of the Flood Forecasting and Early Warning System (FF&EWS) in Swat has gradually improved over the years, especially following the devastating 2010 floods. Initially, the region lacked localized forecasting tools, automated river monitoring, and effective community-level alert mechanisms.

However, recent advancements such as the installation of real-time telemetry stations, satellite-based rainfall monitoring, and collaboration between (PMD), (PDMA), and international partners like UNDP have enhanced Swat's ability to monitor and forecast flood events more accurately. Community-based early warning systems, including mosque loudspeakers, SMS alerts, and local disaster response teams, have also been introduced to improve last-mile communication. Despite these improvements, challenges persist. The mountainous terrain of Swat makes forecasting flash floods particularly difficult due to their rapid onset and short lead times. In some remote areas, communication gaps and a lack of infrastructure still hinder the full effectiveness of warning dissemination. Additionally, limited technical capacity, maintenance issues with hydrological equipment, and insufficient public awareness remain barriers to optimal system performance. Nonetheless, compared to 2010, Swat's FF&EWS has become significantly more effective in saving lives, minimizing property damage, and enhancing community preparedness in recent flood events.



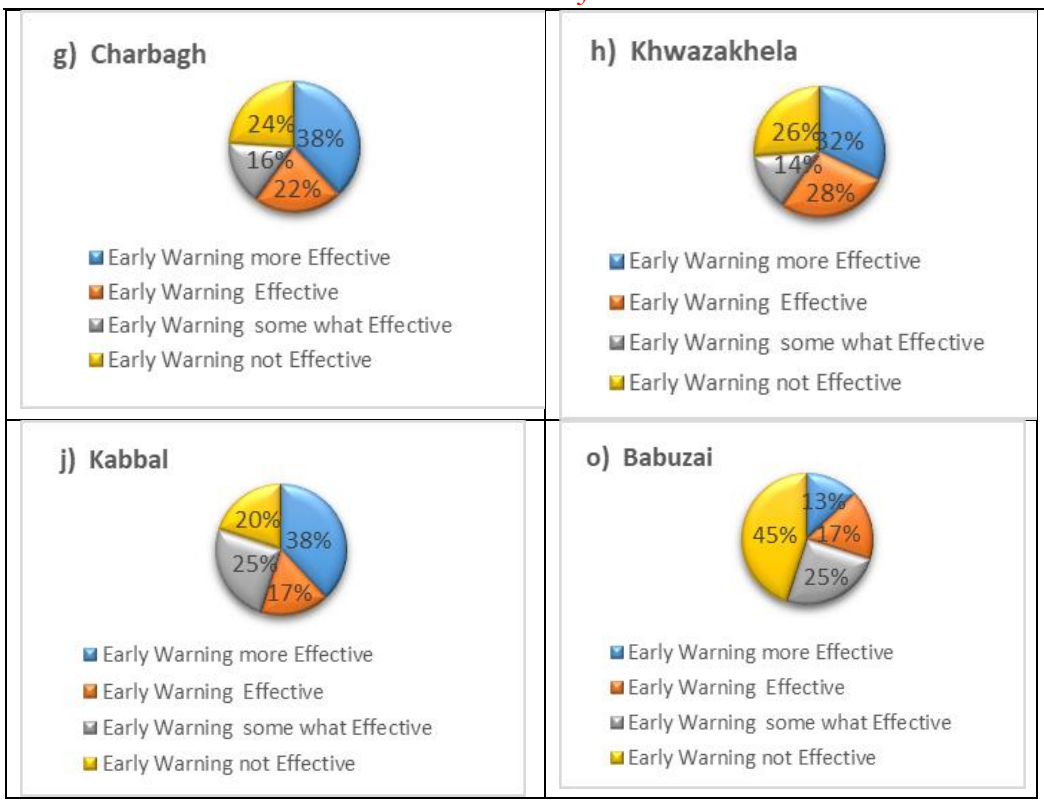


Figure 9. Effectiveness of (FEW) in the Swat Valley, Pakistan

Protections against Flood Hazard in Swat Valley, Pakistan:

During the FGDs, questions were asked about the protection against floods. The respondents shared the view that flood management line agencies are responsible for floods in the study area. The analysis shows that 16 % answered that migration is the best option to protect themselves. While 22 % answered that evacuation, 10% of the respondents answered that the government should provide places for flood-affected communities. About 20 % answered that the embankment is the best solution, while 7 % respondents have the view that they are ready, if a flood event occurs in the future. 4 % in KhwazaKhela says mentally prepare and evacuation. Similarly, 8 % respondents said that there should be no construction zone in flood-prone areas. In the affected areas, 18 % of the respondents answered that implementing flood risk management practices along with using flood-resistant materials provides the most reliable protection against flood hazards, while 4% in Babuzai answered that flood management minimizes the impacts of flood (Table 4).

Table 4. Protection against flood (FGDs)

S. No	Tehsil	Protection from flood hazard	No. of respondents	Percentage of respondents
1.	Barikot	Migration	12	16%
2.	Matta	Evacuation	17	22%
3.	Mingora	Government to provide a Place and given (EW)	7	10%
4.	Bahrain	Embankment formation	15	20%
5.	Charbagh	Mentally prepare	5	7%
6.	KhwazaKhela	Mentally prepare	3	4%
7.	Kabbal	Proper flood management	13	18%
8.	Babuzai	Proper flood management	3	4%
	Total No. of respondents		75	100%

Source: (Field survey, 2022)

Discussion and Findings:

Globally, (FF&EWS) are recognized as one of the most effective non-structural measures for reducing the impacts of floods. The analysis reveals that the flood forecasting system is adopted by many countries to control floods in the flood-prone regions. FF organization issues a flood forecast (FEW) to the vulnerable communities to take measures in advance. (FF&EWS) It is a systematic process that plays a crucial role in predicting floods and disseminating timely warnings to vulnerable communities. These systems are widely considered one of the most effective non-structural measures for minimizing flood-related damage. In the Swat Valley, the assessment of (FF&EWS) is particularly important due to its geographical location, topography, and frequent exposure to severe floods. The main objectives of this research were to assess the role of (FF&EWS) in the Swat valley, to evaluate the effectiveness of communication and dissemination mechanisms to local communities. To achieve these objectives, both primary and secondary sources of data were utilized. Primary data were collected through field surveys, while secondary sources included government reports, meteorological records, and published literature.

Swat Valley, located in northern Khyber Pakhtunkhwa, is prone to recurring floods triggered by rainfall, cloudbursts, and accelerated melting of snow and glaciers. The risk is particularly high during the late monsoon season from July to September. The valley's mountainous terrain, coupled with rapid hydrological responses, makes it highly vulnerable to flash floods and riverine flooding. The catastrophic 2010 floods in Pakistan, particularly in the Swat valley, exposed the severe limitations of the existing flood forecasting and early warning systems (FFEWS) in mountainous regions. The unprecedented monsoon rainfall, combined with rapid glacial melting in the upper Swat River Basin, led to massive flooding that displaced thousands, damaged infrastructure, and destroyed agricultural lands. Despite the presence of national forecasting institutions such as the PMD and the FFC, the early warning dissemination in Swat was inadequate. Communities received little to no notice before the floods struck, largely due to the absence of localized monitoring systems and community-level preparedness mechanisms. Research by [11] and [12] highlights that the 2010 flood event revealed institutional gaps in data sharing, forecasting precision, and risk communication. Most of the hydrological monitoring stations were located downstream, offering limited utility for a mountainous region like the Swat Valley, where flash flooding can develop within hours. Additionally, communication breakdowns between federal authorities and the District Disaster Management Authority (DDMA) in Swat resulted in delayed response and confusion during evacuation and relief efforts. The lack of a digital or automated telemetry network in the region further impaired real-time flood prediction and reduced the lead time necessary for early action.

Flood analysis shows that the Swat Valley has suffered recurrent floods, especially in the years 1973, 1992, 1993, 1994, 1995, 1996, 2001, and 2005. However, the flood of 2010 was unprecedented in scale and devastation. It resulted in the loss of 86 human lives, nearly 9,800 animals, and massive destruction to infrastructure, agriculture, and property. This catastrophic event highlighted the urgent need for an effective forecasting and warning system tailored to the valley conditions. Previous studies have emphasized that the forecasting system during the 2010 floods was primarily designed for the Indus basin plains and not calibrated for the rapid hydrological events of northern high-altitude areas. Consequently, warnings were inadequate, and local communities were affected. At that time, there was minimal community awareness about flood risks and no established protocol for local-level dissemination, such as mosque loudspeakers, mobile alerts, or community volunteers. The absence of effective communication mechanisms in 2010 contributed to widespread losses. Thousands of people were unprepared, leading to significant destruction of homes, agricultural assets, and livestock. These failures underscored the need to integrate scientific forecasting tools with grassroots-level

communication strategies and institutional coordination to protect vulnerable communities in the Swat Valley.

The analysis revealed that the Swat Valley is currently beyond the effective range of Pakistan's RADAR network. Although the government has adopted flood forecasting technologies at the federal and provincial levels, their coverage remains limited in mountainous areas like Swat. Consequently, the valley is poorly catered to by the national (FF&EWS), leaving communities exposed to sudden and devastating floods. Another important dimension of flood vulnerability in the Swat Valley is unplanned urbanization and expansion of the built environment. Field surveys highlighted that new settlements are increasingly being established along the riverbanks and floodplains to accommodate the growing population. This practice has significantly raised land values but has also exposed communities to greater flood risk. The occupation of active floodplain zones has intensified the scale of flood disasters in recent years.

The research findings indicate that meteorological conditions in 2010 were conducive to severe flooding; however, the magnitude of the disaster was exacerbated by human-induced factors such as unregulated urban growth, housing in flood-prone zones, and a lack of floodwater control structures. These conditions compounded the natural hazard and transformed it into a large-scale disaster with severe socio-economic impacts. The installation and improvement of (FF&EWS) in the Swat Valley is urgently needed to minimize future flood losses. By providing timely meteorological information and reliable forecasts, vulnerable populations should be relocated to safe areas before floodwaters encroach upon settlements. The Pakistan Meteorological Department, which is actively involved in national flood forecasting, must strengthen its systems to predict heavy precipitation and flash flooding in high-altitude valleys. Developing methodologies that integrate advanced forecasting technologies with community-based dissemination strategies will make it easier to identify high-risk areas and reduce the devastating impacts of both flash and riverine floods in the Swat Valley.

Conclusion:

One of the most important recommendations is the improvement and expansion of flood forecasting infrastructure in the Swat Valley. The existing radar network does not effectively cover the northern mountainous region, leaving many areas without timely forecasts. Therefore, installing additional weather radars, river gauge stations, and automatic weather monitoring systems in the upper catchments of the Swat River is crucial. This will provide more accurate and localized forecasts, enabling authorities to anticipate floods with better precision and lead time. The 2010 flood revealed major gaps in the communication of early warnings to vulnerable communities. To address this, a multi-channel dissemination system should be adopted, combining modern technologies with traditional methods. Mobile SMS alerts, social media, and community radio should be integrated with mosque loudspeakers and local volunteers to ensure messages reach even the most remote settlements. The language and format of warnings should be simple, clear, and action-oriented so communities can respond effectively.

Local communities must be placed at the center of the early warning process. Establishing community-based early warning committees, training local volunteers, and equipping them with basic communication tools can significantly improve preparedness. These community structures can act as the "last mile" link in the warning chain, ensuring that technical forecasts from the Pakistan Meteorological Department (PMD) are translated into practical instructions for people living in flood-prone areas. Flood management in the Swat Valley cannot rely only on forecasting and warnings; it must also be linked with sustainable land-use planning. Settlements on floodplains and riverbanks increase vulnerability, as seen in 2010. Therefore, strict enforcement of zoning regulations is needed to prevent construction in high-risk areas. Moreover, flood forecasts should be integrated into district-level disaster preparedness plans, evacuation drills, and the identification of safe shelters to ensure the timely relocation of affected populations. Finally, stronger coordination between PMD, PDMA, DDMA, irrigation

departments, and local administrations is necessary for effective flood management. Joint training programs, simulation exercises, and knowledge-sharing platforms should be developed to improve institutional capacity. Investment in technical expertise, forecasting technology, and grassroots awareness campaigns will not only strengthen Swat Valley's resilience but also serve as a model for flood-prone regions across Pakistan.

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This statement indicates that the research was conducted without external financial support.

Competing Interest Declaration: "The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

Data Availability Statement: The data used in this study are available from the corresponding author upon reasonable request. The datasets generated and analyzed during the current study are not publicly available due to privacy concerns and ongoing research, but are available from the corresponding author on reasonable request to provide research data. All the relevant processed data and analysis results are included within the article, and its supplementary materials are available on request.

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