

Flood frequency analysis & modeling and finding flood hazard areas of Panjshir watershed

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Abstract

The researches have shown that the reason of flood damages increment is not the frequency and magnitude of floods but the intense use of flood terrains and limiting the river cross section by construction of (residential buildings, bridges etc...) are the main reasons of hazardous floods creation. In this research GIS (Geographic Information System) has been used to specify flood hazard terrains according to hydraulic model in Panjshir River territory which is one of the most important parts of this research. HEC-HMS software has been used for hydrologic modeling and creation of flood hydrograph in with frequency of (10, 20, 50) years for related catchment areas. Flow scheme for precipitation modeling is according to IDF (Intensity Duration Frequency) Curve which is derived from near station to site. HEC-RAS software has been used to simulate forecast flood on Panjshir River. All mentioned models' documents have been developed in GIS environment, ArcMap Software using their related extensions (HEC-Geo HMS & HEC-Geo RAS). Digital elevation models with 30-meters cell size accuracy are extracted from USGS website and 5 meters DEM from MAIL according site coordinates has been studied & analyzed. One dimensional steady flow analysis results have shown that a major area in river territory is under the flood hazard and destruction which draws a huge damage to our compatriots. Thus, I recommend Flood prevention & control structures in this area in order to improve living conditions of residents. By this, flood hazards are being prevented & a residential area along Panjshir River which a joyful area is being built. Flood frequency in (50) years has been derived from Analysis using Gumbel Distribution Method with respect to (17) years flow, from "Omerz" (Panjshir) hydrometric station.

Keywords: flood frequency, Digital elevation model (DEM), HEC-RAS, HEC-Geo HMS, HEC-Geo RAS, steady flow

1. Introduction

According to the World disasters report (2016), seismic events have killed the greatest number of people of all natural hazards in recent years, 357,092 people from 2006 to 2015, whereas flood events have affected the largest number of people, 830 million people between 2006 and 2015 and it brought \$ 342.5 billion damage worldwide. Afghanistan, currently rated as the poorest country in the south Asia is vulnerable to both of these natural hazards. In October 2015, a 7.5 magnitude earthquake struck Hindu-Kush Mountains in Badakhshan Province (Jorm Area), a northeastern province near to Panjshir, and caused more than 300 deaths, 1700 injuries, and left more than 4000 destroyed houses ^[1]. While Ten years ago in 28th June 2007 ^[2], a flash flood ravaged eight provinces in Kabul Basin and killed more than 113 which the worst casualties were in Panjshir and Kapisa Province (90 deaths, unknown injuries, more than 600 damaged houses and thousands of hectares of agricultural lands).

Due to weakness of disaster preparedness, the 2015 avalanches also led to resettlement process in which an un-estimated amount of people inevitably left the upper Panjshir (Paryan and Hese-Awal) & Uphill areas (Mountainous) of Lower Panjshir and sought refuge in Lower Panjshir (Poor People) and other near provinces Kabul & Parwan Provinces (rich people). This process led

to the formation of settlements in previously uninhabited or less inhabited areas along the Panjshir river bank. The lack of infrastructure (especially flood prevention & control structures), hygiene drinking water and employment/work possibilities are just a few of the challenges that the inhabitants of these rural settlements are facing besides the constant risk of being affected by natural hazards such as flash floods, landslides & avalanches.

2. Materials and Methods

Research level & quality in Afghanistan government is in its worst level. majority of areas have not been technically analyzed of natural disasters. this problem has many causes which some of them are pointed as: insufficient data, administrative corruption, funds, knowledge level... In flood modeling section, we are using the hand calculation methods from 20th century which has very poor amount accuracy. Afghanistan Government has initiated scholarships for its employees in order to upgrade the level of knowledge & quality of researches. As the result of this strategy the engineers in flood modeling section had been able to use computers and software's related to this issue. But still they are using older methods, in which the site data is not considered, and usually they assume it. GIS (Geographic Information System) which is the base for hydrologic and hydraulic modeling now, is an un-used or

less used tool. The simple method of using two software's (HEC-HMS & HEC-RAS) software's with assumed data (e.g. Lag time, Curve Number, Cross Sections, Area etc...). In this research, the newest flood modeling method for small and medium area watersheds has been used, which is fully described in Chapter 3 (Methodology). Briefly, it can be noted that; this method uses the actual data which is overserved via Remote Sensing such as DEM Digital Elevation Model" & Satellite Imagery) and combined remote sensing & site surveying (Soil & Land use data) which leads to more accuracy in research. While these data are assumed or even neglected, in usual researches.

2.1 Study area

Panjshir (Literally "Five Lion") is one of "Thirty-four" provinces of Afghanistan, located in northeastern part of Afghanistan. It has been located among "Hindu-Kush" mountain with the area of (3610 Km²). This province is divided into eight districts and contains 512 villages ^[3]. Used to it had been divided into, Upper Panjshir (Paryan & Khenj), Lower Panjshir (Bazarak Rokha and Aa-naba) & Dara districts by local people. It is surrounded by Baghlan, Takhar, Badakshan, Nuristan, Laghman, Kapisa & Parwan which makes it a strategic province. In new governmental divisions it has been divided into (Paryan, Khenj, Bazark, Rokha, Anaba, Dara, Shotul, Aabshar) districts. Panjshir River springhead is Hindu Kush Mountains "Khawak, Anjuman & Chumar Passes" with altitudes more than 3000 meters. It flows from Paryan District to Dalan Sang Area with 150 Km length and get fed by its 19 tributaries (such as: Dara-e-Hazara River, Aab-e-Tul, Aab-e-Khawak, as major sources & Gouth, Aab-e-dara e Parandeh, Aab-e-Manjahoor, Aab-e-Tulkha, Aab-e-Hesar, Aab-e-Pyawusht, Aab-e-Shufa, Aab-e-Tawakh as minor sources along with seasonal streams such as Aw-reing-e-Zamankor, Aab-e-Furaj...) from East to Southwest. Then it flows to south and at Tangi-e-Gulbahar it is mixed with Shotul, Nejrab, Bareek-Aab & Ghorband Rivers. Then they fall into Kabul River at "Naghloo" Area. As Panjshir river's main water source is derived from snow and glacier metls, Thus Panjshir River's flow starts to increase in second half of May month along with precipitations and upraises to maximum level at starting days of June. While it decreases at ending days of June. There is more slope and elevation difference between main river channel and river banks at upper Panjshir so flood hazard is expected very less than lower Panjshir areas. Panjshir River's water is used for drinking and agricultural purposes. At Gurganic Empire "Tamer -e- Lane Empire" the governor of Panjshir districts "Malik Sha-hu" had built a canal which sourced from Panjshir river and started from "Khanez" area of "Bazarak" district. This canal was built for irrigation purposes, which irrigated Lower Bazark areas up to "Zaman Kor" Area including "Hazar Khan Gardens". This canal was destroyed by the course of time but the signs of it, still remained. Afghanistan's National Hero "Ahmad Shah Massoud" had initiated the survey and design of water supply canal from "Saricha" area to "Pushta-e-Mulkan" (Mulkan barrow) which was a considerable support to "Tawakh" and Anaba District farmers and residents. This canal was able to irrigate more than 1000 hectares of Bi-seasonal agricultural and 2500 hectares of barren lands. Also helped to control

and decrease flood hazard in Lower Panjshir areas Specially "Rokha" and "Anaba" Districts. Design and drawings were prepared, but unfortunately due to lack of funds it had not been implemented yet and the new government has not paid any attention about. Parwan canal project is also a disjunction from Panjshir river at "Dalan Sang" Area and crosses through "Ghorband River" over a siphon at "Matak" area. It irrigates 4800 hectares of agricultural lands in "Charikar" district of "Parwan" Province. At 1975 the research project and initial work phases of a dam at "Dalan Sang" area of Panjshir has been done which the work progress had been stopped due to wars. This dam was planned for irrigation uses and renewable-clean energy supply. After wars and Taliban age at 2008, Ministry of Energy and Water (MEW) started researches on this project again which did not proceed to initial work phase yet. It is planned to irrigate more than 60,000 hectares of agricultural lands also generate renewable-clean energy and controlling floods on Panjshir river channel & its tributaries (present and future tributaries) at "Kapisa" and "Parwan" provinces. In this research the (48.97 Km) length of Panjshir river, among (603.588 Km²) on Lower Panjshir has been analyzed for flood hazard which includes Lower parts of Hese-Duwum "Khenj" district (Omerz area), Bazarak district, Rokha district and Anaba district.

2.2 Sources and use of data

This chapter gives a detailed overview of the data as well as methods used for H&H modeling. Due to the lack of readily available data for H&H modeling, acquisition of accurate topographic and hydrologic data was found to be crucial for the fulfilling of the study goals. While in many countries, high-resolution digital elevation models (DEMs), long term rain data, reliable land use and soil type maps exist and can be obtained from public institutions, studies in developing countries often require a high degree of effort and different methods to obtain adequate data. The three software solutions and the mathematical models used in this study are presented in this chapter in detail. ArcMap is used for all GIS related tasks, HEC-HMS for hydrologic- and HEC-RAS for hydraulic modeling. ArcHydro, HEC-GeoHMS and HEC-GeoRAS serve as the interface between GIS and the H&H modeling.

2.2.1 DEM (Digital Elevation Model)

DEM used in this research project is provided by 'MAIL' Ministry of Agriculture, Irrigation and Livestock. In 2010 the US & NATO missions in Afghanistan captured "DEM" for Afghanistan. This "DEM" was captured by satellites of US Army and "USGS" United States Geological Survey using LiDAR Technique. The cell size is (5, 5) which means the resolution of DEM is 5 meters & the "DEM" type is "DSM". A copy of this DSM was provided for "IRoA" Islamic Republic of Afghanistan's Government. Afghanistan government removed surface objects (such as buildings, tress, etc.) on the "DSM" to develop a "DTM" for whole area of country. Although Afghanistan government developed a DTM, but it needs very much corrections and manipulations. Using this "DEM" and Imagery, Afghanistan government started to create and develop Landcover and Soil Type datasets. I is a surveying method that measures distance to a target by illuminating that target with a laser light. The name LIDAR, sometimes considered an acronym of Light Detection and Ranging (sometimes Light Imaging,

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Detection, And Ranging), was originally a portmanteau of light and radar.

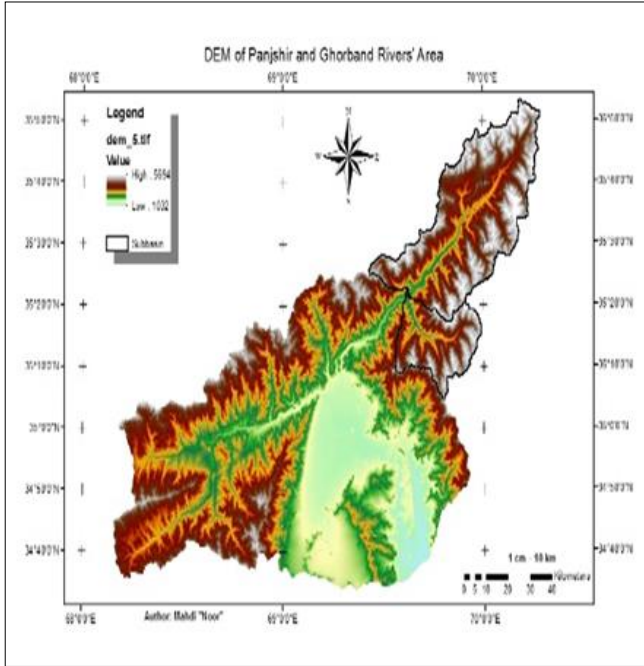


Fig 1: DEM of Panjshir Watershed

2.2.2 Satellite Imagery

Satellite imagery consists of images of Earth or other planets collected by satellites. Imaging satellites are operated by governments and businesses around the world. Satellite imaging companies sell images under license. Images are licensed to governments and businesses (such as Apple Maps and Google Maps) or open-licensed (such as Open Street Maps). Satellite Imageries used for this project was captured by US Government’s Organizations (USGS) in 2012’s ending quarter. The cell size of this dataset is (0.000004166665* 0.000004166665) which means it approximately represents a (45 cm) resolution.

2.2.3 Land cover

Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. As stated in 3.1.1, Afghanistan government started to develop a country-wide Land cover dataset in early years which the source was “2010 & 2013”’s datasets. Land cover for this project was developed for agricultural purposes by “MAIL”. Researcher, (Mahdi Noor); has developed the “MAIL” datasets and classified it using GIS; based on USDA’s (United States Department of Agriculture) TR-55 – Technical Release 55 & “NLCD” (National Land Cover Department of United States) Manual. This classification; classifies LC’s into four major groups of (Water, Residential, Forest, Agricultural) groups.

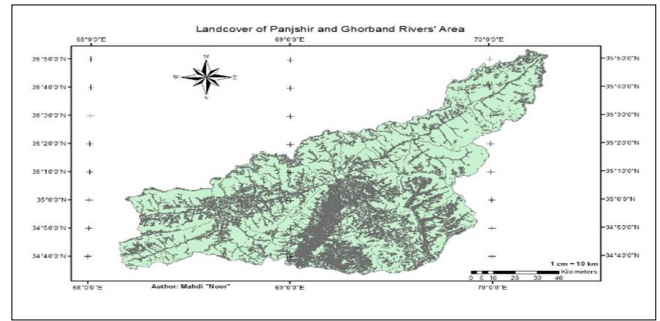


Fig 2: Land Cover dataset of Panjshir and Ghorband watersheds

2.2.4 Soil Type

Soils were originally assigned to hydrologic soil groups based on measured rainfall, runoff, and infiltrometer data. Since the initial work was done to establish these groupings, assignment of soils to hydrologic soil groups has been based on the judgment of soil scientists. Assignments are made based on comparison of the characteristics of unclassified soil profiles with profiles of soils already placed into hydrologic soil groups. Most of the groupings are based on the premise that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated, will have similar runoff responses. The classes are based on the following factors:

- Intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet)
- Soil not frozen
- Bare soil Surface
- Maximum swelling of expansive clays

Same as 3.1.3, soil type dataset for this research project was developed 2010 & 2013s datasets by “MAIL” which was not developed for hydrologic uses. Researcher, (Mahdi Noor); has developed the “MAIL” datasets and classified it using GIS. Hydrologic Soil groups classifications are based on USDA’s (United States Department of Agriculture) TR-55 – Technical Release 55 & USDA’s Natural Resources Conservation Service (NRCS), National Engineering Handbook, Part 630, Chapter 7 (Hydrologic Soil Groups). This classification; classifies soils into four groups (A, B, C, D).

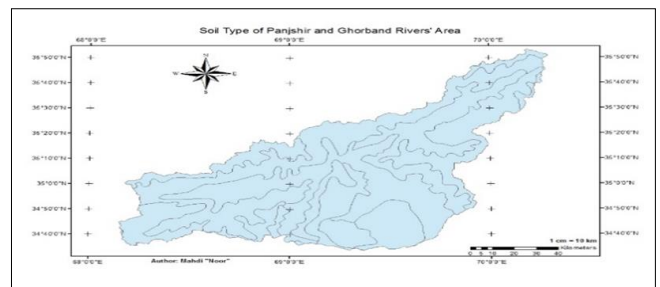


Fig 3: Soil dataset of Panjshir and Ghorband Watersheds

2.2.5 TIN

TIN (Triangulated Irregular Network) dataset is developed from 5 meters DEM which was provided by “MAIL”. Although it’s possible to convert the raster to TIN directly in ArcMap software, but after consulting with hydrologists and GIS Experts; the researcher decided to use the recommended and better technique. First the raster the data was converted to Point, then it was converted to TIN. This technique increases the accuracy and resolution of resulting TIN.

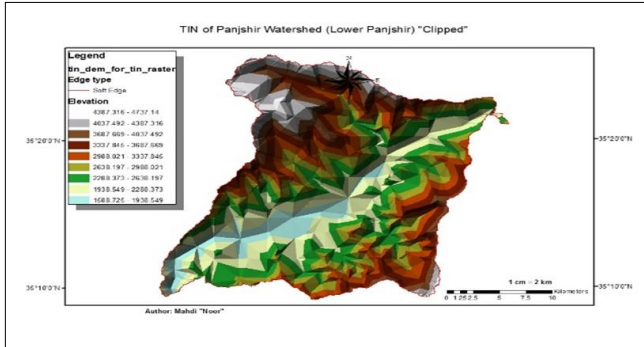


Fig 4: TIN of Panjshir Watershed

2.2.6 Discharge

Discharge data is provided by “MEW” (Ministry of Energy and Water)’s “WAPIKA” Department shows in (table I). This data is collected from “Omerz” Hydrometric station which is located in “Khenj” District of Panjshir Province (Ending area of Upper Panjshir, Next to Lower Panjshir in this research classification). Discharge data is used for Gumbel Distribution, in order to calculate maximum flow (flood). As the recorded data in early years is between (2010-2015), (5 years); is not enough for calculating a Gumbel distribution, thus the data which is recorded between (1964 – 1980) for 17 years is used for this project. Usually, gap filling is done for quasi circumstances, but; as it needed a wide and full discussion, and was not compatible and permitted according Kardan University’s Undergraduate rules, the researcher (Mahdi Noor) was inevitably neglected from discussion. The coordinates of discharge point is, “Lat, Long” (35.37582500 N, 69.64085278 E) with approx. altitude of 2042 meters. Drainage area is (2447.5 Km²).

Table 1: Annual discharge of Panjshir River

Yearly summary				
Year	Min	Max	Mean	Run off (Mm ³)
1694	6.80	272.0	37.10	1176.0
1965	5.00	224.0	37.90	1201.0
1966	4.32	300.0	35.60	1127.0
1967	4.65	237.0	32.60	1032.0
1968	5.44	318.0	39.60	1253.2
1969	4.85	279.0	43.50	1377.0
1970	7.20	226.0	30.30	959.8
1971	4.46	252.0	27.37	866.6
1972	4.10	306.0	33.60	1061.0
1973	4.56	342.0	42.50	1341.4
1974	4.85	219.0	25.70	811.9
1975	4.10	228.0	28.40	897.5
1976	4.46	210.0	28.20	894.0
1977	6.28	284.0	24.40	772.0
1978	5.98	305.0	36.50	1154.0
1979	3.14	326.0	35.50	1125.0
1980	5.37	213.0	29.10	920.0

2.2.7 Rainfall

Rainfall data of Panjshir watershed (“Omerz” and “Tangi-e-Gulbahar” stations is provided by “MEW” (Ministry of Energy and Water)’s WAPEKA Department. The data from WAPEKA has been compared with ArcSWAT (Soil and Water Assessment Tool) developer organization and Texas A&M University global weather data which is available at (<http://globalweather.tamu.edu>) and 2-year and 24hours Rainfall has been derived.

2.2.8 IDF Curve

Fig: 5 shows in IDF (Intensity Duration Frequency) Curve data is used for runoff modeling at HEC-HMS Software, Meteorological Models, Frequency Storm. As there isn’t any calculated IDF Curve for Panjshir watershed the nearest available IDF Curve which is the IDF Curve for “Bagram” district of Parwan province is used in this project. The IDF curve of “Bagram” district is calculated by “USACE – AED” (United States of America, Army Corps of Engineers – Afghanistan Engineering District) which is named (AED Design Requirements – Hydrology Studies) and was published at (January, 2010 – Version 1.6). (AED Design Requirements) is the only available public hydrologic manual and reference for engineers in Afghanistan up to now.

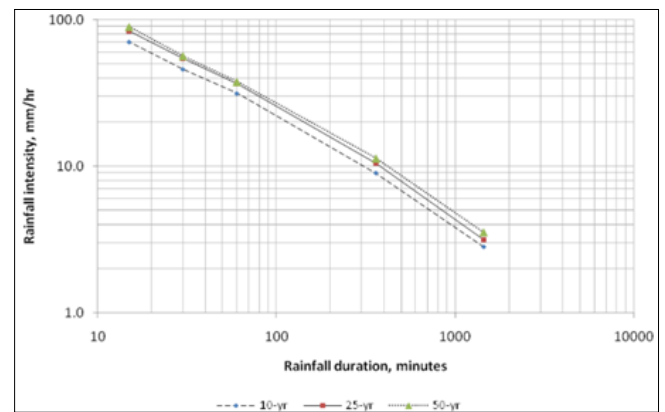


Fig 5: IDF curve

3. Results

Panjshir river is the only available and beforehand water source for “Parwan”, “Kapisa” & “Kabul” Provinces. By reserving water in uprising & overflow season with multi-purpose dams on “Dasht-e-Riwat” village of Khenj District and Panjshir’s outlet “Dalan Sang” area sufficient amount of water and energy is conserved for above provinces also it makes thousands hectares “Bagram” and “Koh-e-safi”’s barren lands to agricultural lands and support to Control flood in Lower Panjshir areas and “Kapisa” Province.

Major solutions to prevent/control flood in peak time are described below:

1. Construction of river banks, barriers and retaining walls (Flood Control Structures)
2. Construction of supplementary channels in order to distribute/divert flow (Regulatory Floodway)
3. Filling low elevated areas with soil or other materials (e.g. Gravel, Boulders etc...)
4. Changing Channel Conveyance Properties (Cleaning, Widening etc...)
5. Levees and Reservoirs

The second and third solutions can be very much expensive so they only usable on Urban and Industrial areas after doing economic analysis. While the first solution is very usual and can be used everywhere. Especially on rural areas which is used to keep residential areas, agricultural fields & Lands, out flood hazard.

3.1 Construction of River Banks, Barriers and Retaining Walls (Flood Control Structures):

Figure 6 shows riverbanks, in which the (A, F, E, G) and (K, V, U, T) points show the floodplains. (A, B, C, D, E, F, A) area is closed with (A-B-C-D-E) closed-wall & area (K, L, M, N, P, T, U, V, K) is closed with (K-L-M-N-P-S) open-wall boundary. At overflow time, water level raises up to line (P-T) (Inclined areas are not going to be under flood). Constructing open boundaries are suitable for rivers with steep slope which the rain/snowfall runoff of both sides are cumulated and joins directly to the river. Closed boundaries are suitable for river with mild slope, in which the rain/snowfall that are cumulated in areas which are located on lower elevation than walls; are cumulated and fallen gradually through routes and gates which are built in boundaries/retaining walls, into river channel when the peak flood is passed. Also the (a, b, c) routes are considered at boundaries in width, in order to prevent break and puncture at main boundary/wall (e.g. UN, VM, FC, walls on figure 5.1).

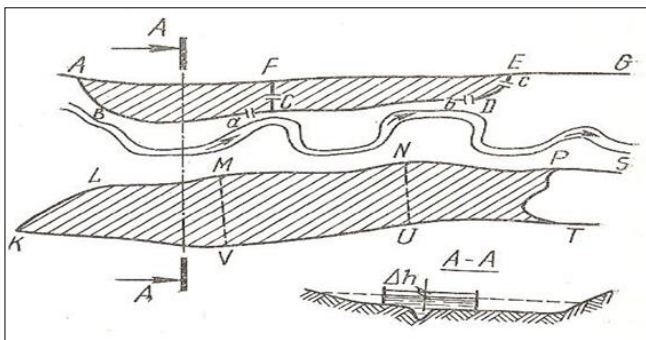


Fig 6: Open & Closed Boundaries

By increasing boundary areas, water surface level increases and it may cause overflow and overflow which ravages more areas by flood. This may lead to significant damages and flood hazards and it should be considered when the boundary area is being specified. This is the reason which many countries do not permit building construction in such populated areas with a legal pretext or they permit with special conditions. This issue is very complicated which needs technical and economic analysis.

3.2 Flood Control Structures Materials (Most used in Afghanistan)

Figure 7 shows Flood control structures need a huge amount of materials due to their length. So its rational to build them using local and cheap materials. Usually below materials are used very much in such kind of structures.

- a. Multi-face irregular shape stone and rocks (usually natural crushed rocks). Except mild-stone, mudstone and sandstones which are weak and collapsible in water & weak against freezing process. The X-sections should be between 25-30 cm and weight should be around 30-50 kg which cannot be conveyed by flood and be resistant against ice blocks.

- b. Boulders, gravel and crushes which are derived from rocks.
- c. Sand and Soil-mixed sands which is used to prevent water entering into stone works.
- d. Woods, stakes, branches of trees, bushes which can be tied together in order fill pores of stones or woods.
- e. Steel nets, cables, anchors etc... (Should be coated by corrosion resistant materials)
- f. Railings, Tripods etc... (Used according area)
- g. Gabions which are filled by stones.

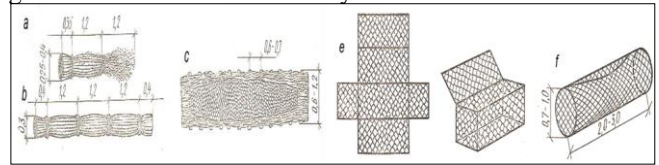


Fig 7: Materials Used for Flood Control Structures

3.3. Regulatory Floodways

The "Regulatory Floodway" means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations.

3.4 Levees

A levee or foodbank is an elongated naturally occurring ridge or artificially constructed fill or wall, which regulates water levels. It is usually earthen and often parallel to the course of a river in its floodplain or along low-lying coastlines.

3.5 Reservoirs

Reservoirs are designed completely or partially to aid in flood protection and control. Many large dams have flood-control reservations in which the level of a reservoir must be kept below a certain elevation before the onset of the rainy/summer melt season to allow a certain amount of space in which floodwaters can fill. The term dry dam refers to a dam that serves purely for flood control without any conservation storage.

4. Conclusion

The first and objective of this research project was to derive a maximum runoff value for Lower Panjshir area which has been derived from HEC-HMS (419.3 m3/sec), & (399.854 m3/sec) as Gumbel Distribution's result (Both for 50 years return period). Gumbel's Distribution Method's result (399.854 m3/sec) has been used as calibrated data considering its standard error value (10.654) and its coefficient of variation which is (% 16.42) as the IDF Curve is not from the research area (It was near research area). Collected runoff from approx. (2900 km2) of area (Upper Panjshir) has been used to simulate flood on (49 kilometers) of river and its banks on Lower Panjshir area which was starting from "Omerz" end point upto "Tangi-Gulbahar" near point.

The analysis on HEC-RAS & HEC-GeoRAS shown, 49 kilometers of river have (2.176 km2) channel area, which is being covered on flood time and when the flood reaches to its maximum value, then its overflows to banks and covers (9.682 km2) area with river channel. After deduction of

channel area, it results as (7.506 km²). This means, (7.506 km² which is equal to 750.6 hectares) areas around river channel are directly under flood hazard.

5. References

1. AED (Afghanistan Engineer District) Design Requirements, Hydrology Studies (Provisional), Version 1.6, 2010.
2. Chin DA. Water-Resources Engineering, 0-13-148192-4, Pearson Prentice Hall, New Jersey, 2006.
3. HEC (Hydrologic Engineering Center) HEC-HMS Technical Reference Manual, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2000.
4. HEC (Hydrologic Engineering Center) (CPD-83) HEC-GeoRAS User's Manual, 2012.
5. HEC (Hydrologic Engineering Center) HEC-GeoHMS User's Manual, Version 10.3, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2013.
6. HEC (Hydrologic Engineering Center) HEC-HMS User's Manual, Version 4.2, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2016.
7. HEC (Hydrologic Engineering Center) (CPD-68) HEC-RAS User's Manual, Version 5.0, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2016.
8. HEC (Hydrologic Engineering Center) (CPD-69) HEC-RAS Hydraulic Reference Manual, Version 4.1, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2016.
9. Herman LK. The unit hydrograph method, In Physics of the Earth, IX, Hydrology, O.E. Meinzer, ed., National Research Council, McGraw-Hill, New York, 1942.
10. IFRC (International Federation of Red Cross and Red Crescent Societies) World Disasters Report 2016, Imprimerie Chirat, Lyon, France, 2016. Available at: <http://www.ifrc.org/wdr2016> (Accessed December 2016).
11. Subramanya K. Engineering Hydrology, Third Edition, 13-978-0-07-064855-5, Tata McGraw-Hill, West Patel Nagar, New Delhi, 2008.
12. MAIL (Ministry of Agriculture, Irrigation and Livestock): Planning and Policy Department, GIS and AGROMAT Section.
13. Merwade V. Creating SCS Curve Number Grid using HEC-GeoHMS. School of Civil Engineering, Purdue University. Online, 2012. available at <http://web.ics.purdue.edu/~vmerwade/education/cngrid.pdf>
14. Merwade V. Terrain Processing and HMS-Model Development using GeoHMS. School of Civil Engineering, Purdue University. Online, 2012. available at <http://web.ics.purdue.edu/~vmerwade/education/geomhs.pdf>
15. Merwade V. Watershed and Stream Network Delineation using ArcHydro Tools. School of Civil Engineering, Purdue University, 2012. Online available at http://web.ics.purdue.edu/~vmerwade/education/terrain_processing.pdf
16. MEW (Ministry of Energy and Water): Water Regulation Affairs Department, Hydrology Section.
17. NRCS (Natural Resources Conservation Service) Technical release number 55. (TR55), urban hydrology for small watersheds, U.S. Department of Agriculture, Washington, DC, 1986.
18. NRCS (Natural Resources Conservation Service) Soil Mechanics Level 1, Module 3, USDA Textural Soil Classification, Study Guide, United States Department of Agriculture, 1987.
19. NRCS (Natural Resources Conservation Service) National Engineering Handbook, Part 630-Hydrology, Chapter 1, 4, 6, U.S. Department of Agriculture, Washington, DC, 2004.