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Evaluation of Impact of Soil Properties on Strength of Flood Levees in Indus River Basin of Pakistan

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ABSTRACT

Flood bunds are earthen embankments constructed along rivers to control the floods. Historically speaking, floods in Indus River Basin (IRB) in Pakistan have been posing serious threats and damages to infrastructure and human lives. A long infrastructure of flood bunds (about 6807km) exists parallel to the main river to agricultural crops, human settlements, livestock, industries etc. from the hydro-disasters arising from the floods in the country. Punjab Province has been severely hit by heavy floods causing severe loss to human lives, infrastructure, crops and livestock, etc. A study was carried out to evaluate the "health" of flood bunds by investigating their geotechnical, geometrical, geochemical and hydraulic properties to ascertain strength against breaching during floods. A length of about 731 km of river Chenab in Punjab Province of Pakistan was selected to investigate vulnerability of flood embankments at 78 sites of 38 flood bunds which were found critical after 2014 flood in Pakistan. Different field activities including density test, measurement of geo-metrical parameters, collection of undisturbed/disturbed soil samples, physical inspections and collection of ground water samples from bore holes were performed. Laboratory tests including soil texture, Atterberg's limits, compaction, unconfined compressive strength, permeability, direct shear etc. were performed in laboratories of Irrigation Research Institute, Lahore, Pakistan. An Index called river embankment breaching vulnerability index (REBVI) has been prescribed and calculated to evaluate the strength of the flood embankments against breaching. A cluster analysis has been carried out for different indicators keeping in view the value of REBVI. On the basis of REBVI and Cluster analysis, it was concluded that 11 out of 78 sites are showing high strength against the breaching action, while 35 sites indicated low potential against the breaching action. In other words, it has been found that consistency of the embankment is very high for 11 sites and high for 35 flood bund sites. The consistency of the embankments is medium, low and very low at remaining 16, 12 and 4 flood bund sites due to moderate vulnerability, high probability of embankment breaching and very high vulnerability respectively.

Keywords: Flood Bunds, levees, Geotechnical, REBVI, Vulnerability index, Indus basin, and Pakistan.

INTRODUCTION:

Floods cause damages to the human lives, agricultural crops, industries, communication networks, irrigation network and other infrastructure on their way (Mustafa & Wrathall, 2011). Some earthen bunds (levees) are - generally parallel to the rivers to ensure that flood-water remains within the flood plains and damages due to floods are minimized. Precisely flood bunds as defined "man-made structures, usually an earthen, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water so as to provide protection from" (Zaidi, 2017). Flood dikes (bunds) are generally constructed hydraulic structures and are as old as the human civilization (Siddiqui, 2018). Man has been making his defense against the natural disasters like floods. However, construction methods have varied over the years with the dawn of new construction methods and materials. Mostly, these are earthen structures, purpose build for protection against floods (Zaidi, 2017). Pakistan is bestowed with many water resources like rainfall, glaciers, rivers, and groundwater reservoir. Almost flows of all rivers are generated in the northern mountains and find their flow to the Arabian Sean in the South. On its way to the sea, many small rivers join the mighty Indus which is called its tributaries. Barrages, head works and other structures have been constructed on almost all rivers including the Indus (Zaidi, 2017). These structures are meant for diversion of water from rivers to link canals, main canals, which flows ultimately to irrigate field in the Indus Plain. Construction of these structures has caused the change in morphology and meandering of the river flows. Natural flow paths of the rivers have changed and stopping/storage of waters on the way is causing the ponding of water (Abbas *et al*., 2015). Flow pattern in the Indus River systems is highly variable, as more than 70-80% flow occur during the monsoon period of three months of July-August (Siddiqui, 2018). Similar is the pattern of rainfall. This pooling up of snow melt and rainfall water cause the heavy floods during the monsoon period of three months (Kron, 2007).

There are approximately 6803 km flood bunds in the country at present, out of these 3332 km (almost half) are in the Punjab (the land of five rivers) province scattered along the five rivers. Statement of these flood dikes in Punjab province is tabulated in **Table 1**. It is very unfortunate that poor care is not taken during construction of these structures. Proper geo-technical, geo-hydrological, and other research investigations are very rarely carried out at the planning and execution stage of these infrastructures. There is always a risk factor associate with the performance of these flood-bunds. There may always a chance that during heavy floods these structures may encounter a failure/breach which can lead to a glossal loss to infrastructure, crops, livestock and human lives posing a heavy financial burden on public exchequer (Zakir-Hassan *et al*., 2017). A study was carried by (Dyer *et al*., 2007) for geotechnical investigations and inspection flood dikes and they found that failure of dikes was due to their periodic wetting and drying. This creates cracks in the flood dikes which causes their failure. Filling of pores due to cracks with water accelerates weathering effects, embankments become soft. This reduces the strength of the flood-bunds against failure. Different causes of failure of these earthen embankments include see-page, piping action, bank erosion, rodent attacks, cuts on banks due to rainfall, and slope instability (Zaidi, 2017). Morris *et al.* (2007) have reported that causes of failure of flood infrastructures/levees can be classified into two groups; first is the material of the flood bunds like soil type, second is the construction methodology of these dikes. It means if soil type is not good the structure may encounter failure, and if the structure is not constructed as per standards engineering codes and design parameters, it can to be a reason for breaching of the structures. An investigation for causes of failure of canal-banks in Sindh province of Pakistan was carried out by (Bhanbhro *et al.,* 2014) and they found that causes of embankment failure include erosion inside the banks, over-flowing of canals, and deficiencies in construction methodology, piping action back-water erosion, and slope failure. Other reasons for breaching of flood embankments include exposure of seepage line, holes by burrowing animals, piping phenomenon, sand-boils, sudden dropping of water levels, erosion of tops and banks (Zaidi, 2017). Identified reasons of failures of flood levees around the lower Mississippi River in USA were identified as scouring actions, over-flowing, and seepage under the banks (Rogers J.D). Levees were overtopped where they experienced settlement difference, with soft soils underneath the structure. Generally speaking, there are three types of failures of flood dikes viz over-flowing of dikes, water-force, and erosion of bank resulting piping action (Zakir-Hassan *et al*., 2017). Morris *et al.* (2007) prepared a report on performance of flood levees consisting of four separate parts, Part A: function and management of flood levees, Part B: Performance and characterization of flood infra-structure, Part C: risks involved their miti-gation, and Part D: good practices and concerned references. In part B of the report, common hazards and causes of failure of flood embankment were des-cribed to include zones of weak and highly permeable material causing slipping or seepage, reduction of crest level, local see-page path at junctions with other structure, settlement due to merging of soft founding strata, localized over-topping, erosion of outside due to over-flowing and inward face due to wave action, seepage and piping and shallow slope instability. Des-cription of geotechnical properties of Penang residual soils with emphasis on landslides were studied by (F. Ahmad *et al.,* 2006). The attempt was made to define the larger granitic residual soil of Penang Island by discussing nature, structural features, engineering be-havior and field properties of soil sample extracted from eight sites. Similar tests like natural moisture content, liquid limit, plastic limit, specific gravity, maximum dry density and shear strength test were used for the characterization of soils of Penang Island.

Jia & Hunt, (2016) conducted a study to develop the numerical model for simulating over-flowing and failure of embankment. The key physical-empirical dam breaching mechanism of earthen embankment through Win DAM model was used to achieve the goal and homogeneous embankment constructed from co-hesive soil materials of simple cross section was assu-med with general flow conditions were utilized. Fol-lowing process was considered -

1) Frictional erosion on embankment top segment
2) Head cut erosion and migration
3) Channel widening

Hanson *et al*. (2001) clarified that erosion to the em-bankment made of cohesive soil was related linearly to an erodibility parameter and the excessive shear stress. (Hossain *et al.,* 2010) carried out a study by re-cording the physio and strength properties, geotech-nical characteristics and slope-stability analysis of fai-led banks of Jumna and Padma Rivers in Bangladesh. Physical and geotechnical characteristics were evalu-ated by conducting particle size analysis, density, liquid limit, plastic limit, compaction, consolidation, permeability, direct shear test and unconfined com-pressive strength tests in accordance with Japanese Industrial standards (JIS) and Japanese geotechnical standards (JGS). They also concluded that permeabi-lity of soil was high with other low strength properties and bank failure mechanism was associated with the formation of tension cracks behind the face. (Pierce *et al.,* 2011) conducted a research study to develop the South Carolina Department of Transportation Geotech-nical material database for embankment design and construction. Geotechnical information was carried out by 197 borrow pits across the state of South Carolina and data was limited to soil description that often in-clude USCS, AASHTO soil classification. Tests for physical properties included visual manual identifi-cation, moisture content, specific gravity, particle size distribution, liquid limit, plastic limit and classifi-cation. Tests for mechanical properties included stan-dard proctor, compaction, direct shear & triaxial com-pression. Major types of flood bunds include Homo-geneous bunds, Zoned bunds and Diaphragm Type bunds. Bunds are small barriers to run off coming from external catchments. Bunds slow down water sheet flow on the ground surface and encourage infiltration & soil moisture. Flood bunds are provided with a particular size and shape to enable them to withstand the anticipated high flood water levels with a free board of 3 ft. to 7 ft. Some peak floods in Punjab in different rivers have been shown in **Fig.1**.

Table 1: Salient features of rivers and flood bunds in Punjab (Source= Punjab Irrigation Department).

River	Length of River (K.M.)	Length of Rivers (miles)	Catchment Area in the Mountains (miles^2)	Length of Bunds (miles)	No. of Spurs / Studs
Indus	547	342	1,18,400	811	131
Jhelum	363	227	12,445	155	43
Chenab	731	457	11,399	1330	309
Ravi	694	434	3,562	630	127
Sutlej	515	322	30,550	406	30
Total:	2850	1782	1,76,356	3332	640

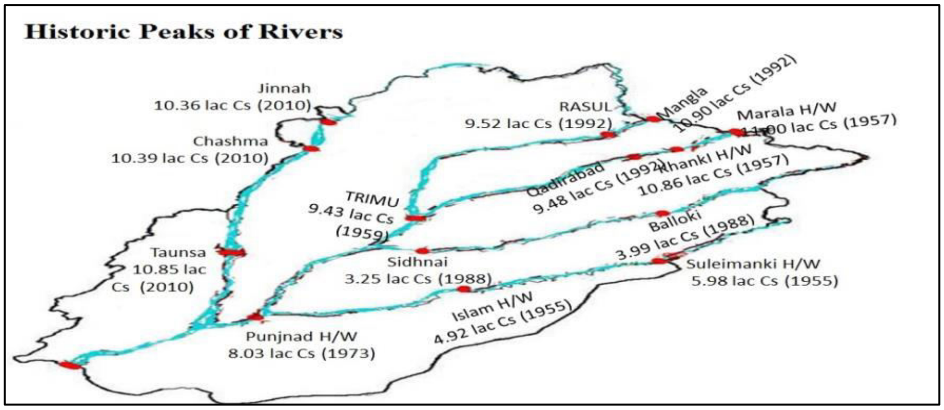

Fig.1: Historic peak discharges at different irrigation structures of rivers PDRP (2014).

MATERIALS AND METHODS:

Description of study Area

Study area falls in the Punjab province of Pakistan along the river Chenab where a study on 38 flood levees has been carried out to evaluate the "health" of flood bunds by investigating their strength, geometry, and chemistry of construction materials, design, and hydraulic properties to ascertain their strength against breaching during floods. The Chenab River is a major river of India and Pakistan. It forms in the upper Himalayas in the Lahaul and Spiti district of Himachal Pradesh, India, and flows through the Jammu region of Jammu and Kashmir into the plains of the Punjab, Pakistan. The river Chenab was called Iskmati or Ashkini in Vedic times by Indians. The river is generally considered to be the second healthiest river of Pakistan after River Indus. It originates from Bara lacha 31°11′20″N 72°11′57″E-which is high mountain connecting Lahaul district in Himachal Pradesh to Ladakh in Jammu and Kashmir and joined by River Jehlum at Trimmu and then by River Ravi, confluence with Sutlej to form Panjnad River in Bahawalpur district, Punjab, Pakistan 29°20′57″N 71°1′41″E. It then forms the Panjnad by joining River Sutlej near Uch Sharif before falling into the River Indus at Mithan Kot. Its total Length is 960 km (597ml). Average discharge is 800.6m^3/s (28,273 f^{t3}/s). This river forms at the confluence of streams Bhaga & Chandra. Upper most part is snow covered and forms the Northeast part of Himachal Pradesh from Tandi to Akhnur the river traverses through high mountains. Its length is 770 miles/1,232 Km. its catchment area is 26,100 Sq.miles/41,760 km^2. The River enters Pakistan a little over Head Marala with very sharp changes in slope (130 ft/mile above Tandi reduced to 2 ft/mile close to Trimmu) its tributary Rivers include twelve major tributaries (6 each in occupied Jammu & Kashmir and Pakistan). Doara, Dowara, Halsi, Bhimber, Palku and Budhi join close to Marala. There are Marala, Khanki, Qadirabad, Trimmu, Punjnad barrage on this river. The flood bund sites are shown in **Fig. 2**.

Field investigations and surveys

Field surveys were carried out for observing the physical condition of the flood bunds. During the field investigation, disturbed and undisturbed soil samples were collected from the proposed sites of embankments for field and laboratory testing. In order to know the nature of bank materials, the soil samples were collected directly from the broken parts of the flood embankments. Total 78 sites were selected to investigate the geo technical attributes of earthen embankments where three sites i.e., top of flood-bund, countryside of flood-bund, and river-side of the flood embankment were selected for sampling of soil strata by drilling a bore-hole. Laboratory testing of all samples were performed to determine the classification of soil materials as per the index properties. The laboratory tests were performed in laboratories of Irrigation Research Institute (IRI), Irrigation Department, and Lahore. The testing measures/procedure was in accordance with American Standard for Testing Materials (ASTM, 1961) and (British Standard 1377 1990). The tests include particle size analysis through sieves set, Bulkdensity, Liquidlimit (%) and Plasticlimit (%), Modified AASHTO compaction and Permeability test. The collected soil samples were classified based on A S T M D 421- 58 (1965) & 422- 63 (1963) (Jumikis, 1962; Ahmad *et al.*, 2018).

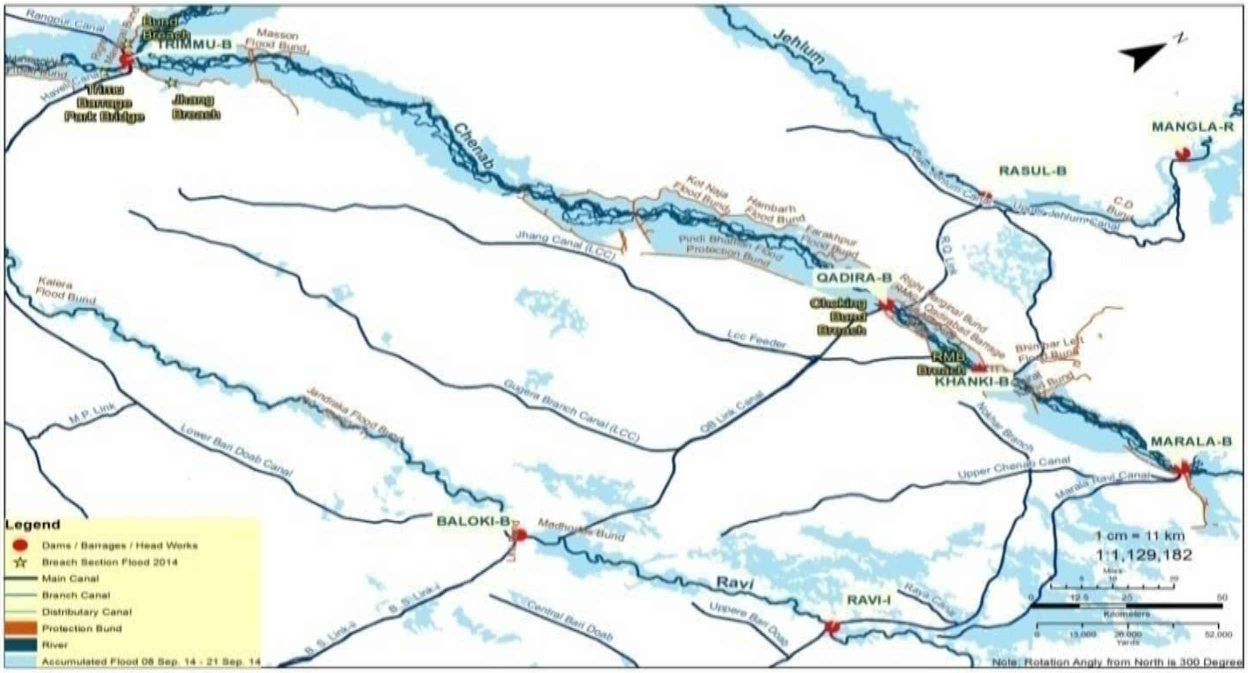

Fig. 2: Map of study area showing locations of flood embankments sites along River Chenab.

More detailed investigations were undertaken including plasticity index (PI) followed by ASTM D 423-61, (1961) and Burmister, 1949). Modified AASHTO compaction test to measure the degree of compaction of flood bund by (ASTM D1557-70/AASHTO T180 and (Qureshi and Akbar, 1995), Unconfined compressive Strength (UCS) test by ASTM D2166/ D2166M and (Manojit *et al.,* 2012) and (Qureshi and Akbar, 1995), Permeability test (to find out ease with which water flows through soil and/or rocks) by ASTM D 2434 and Jumikis A. R. (1962) and Direct shear test (to find out the shear strength para-meters like C and ø) by using ASTM D 3080 and (Qureshi & Akbar, 1995). Detailed observations on embankment structures were measured by using different appropriate field techniques. Geochemical analysis (to find out pH, Organic Matter, sulphates, and chlorides, Ec etc.) of soil and water samples collected from flood bunds were carried out using procedure followed by BS 1377 (1990). To investigate the geometry of embankments/flood bunds, detailed observations including bank top height, base width and bank slope were recorded. The design cross sections were collected from concerned Sub divisions. Existing cross sections of flood bunds (top width, height and slope of bunds at River and Countryside) were observed at site and then compared with the designed parameters.

Lab Testing

The samples collected in field were analyzed & tested in lab at IRI as per standard procedures and method. Different test performed have been enlisted in **Box-1**.

SN	Box 1; Test/Investigation
1.	Grain Size Distribution (GSD)/Sieve Analysis
2.	Atterberg Limits (Liquid and Plastic Limits, Plasticity Index)
3.	Modified AASHTO compaction
4.	Direct Shear Test
5.	Unconfined Compressive Strength
6.	Permeability Test
7.	Chemical Analysis of soil sample
8.	Chemical Analysis of groundwater sample
9.	Preparation of Bore logs and Gradation Curves

RESULTS AND DISCUSSION

Field density test, measurement of geometrical parameters, collection of undisturbed/disturbed soil samples, physical inspections and ground water samples from bore holes were collected during field investigation. The results of particle size analysis (soil gradation/ texture), bulk density, Atterberg's limits, Modified AASHTO compaction, unconfined compressive strength, permeability, angle of internal friction etc. were achieved after performing lab tests in laboratories of Irrigation Research Institute (Irrigation Department Lahore, Punjab, Pakistan). On the basis of results achieved during investigations from field and performing different tests in labs, A River Embankment Breaching Vulnerability Index was derived. An index called the River Embankment Breaching Vulnerability Index (REBVI) was selected derived based on weightings of bank material to delineate the risk of vulnerability of the embankment (Mondal *et al*., 2012; Noshin *et al*., 2018). Cluster analysis was performed based on vulnerability index for each indicator. The lab results consisting of absolute values of all parameters were converted into ranks and weights as tabulated in **Table 2**. Procedure adopted for devising, calculation and interpretation of results of REBVI (**Fig. 3**).

Table 2: Transformation of absolute values into weighted values (W).

Weight Value (W)	Texture	Compaction (%)	Cross-sections	Plasticity Index	Permeability (cm/sec)	Unconfined Compressive Strength (Kg/cm^2)	Angle of Internal Friction (Degrees)
0	Silty Clay	High (>90)	According to Design	Medium Plastic (10-20)	Impervious <0.0000001	Stiff (1-2)	Very Dense 40-43
1	Clayey Silt	Medium (80-90)	Over Design	Low Plastic (5-10)	Very Low 0.00001-0.0000001	Medium (0.5-1)	Dense 35-40
2	Sandy Clay	Low (<80)	Under Design	Slightly Plastic (1-5)	Low 0.001 - 0.00001	Soft (0.25-.5)	Medium 30-35
3	Sandy Silt			High plastic (20-40)	Medium 0.1 - .001	Very soft (0-0.25)	Loose 28-30
4	Silty Sand			Very High Plastic (>40)	High >0.1		Very Loose 25-28
5	Clayey Sand			non plastic (0)			
6	Sand						
Rank Value	1	2	3	4	5	6	7

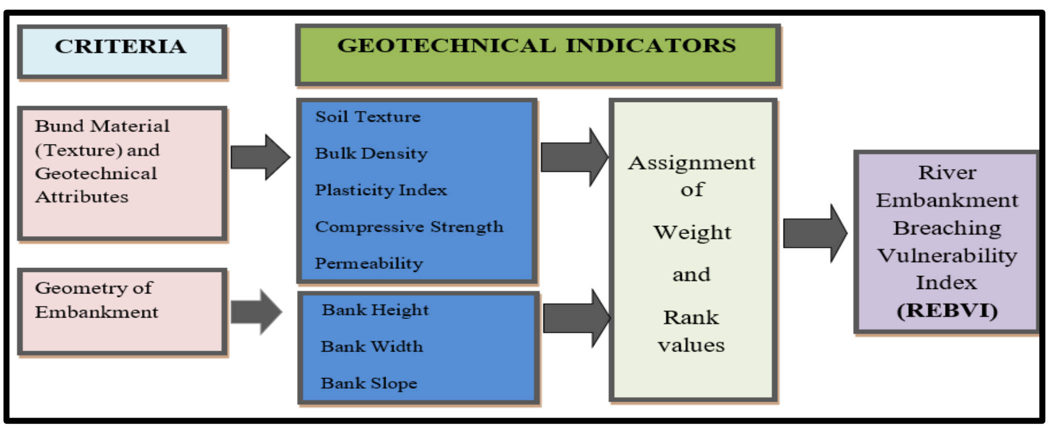

Fig. 3: Methodological adopted for the present study after (Mondal *et al*., 2012).

River Embankment Breaching Vulnerability Index (REBVI)

In the next stage the breaching phenomenon of the flood-bund was described on the basis of a multi-criteria analysis. Different soil parameters like characteristics of bank materials of flood levees, geotechnical properties determined from lab analysis, and geometrical factors measured in the field. Different parameters like soil-texture, geotechnical properties, and cross section of the levee are associated with the embankment breaching phenomenon. This involved following step -

1) Assigning of ranking to different parameters from 1 to 7, where 1 represents high-ranked and 7 means lowest-ranked parameters
2) Assigning weights to the values within parameter from 0 to 6, where 0 means very less vulnerable and 6 means very highly vulnerable.

After assigning the normal weights and ranks to all individual parameters were combined together in a linear framework to determine a single value of REBVI for each test site (Mondal *et al*., 2012; Noshin *et al*., 2018). This was done for all sites in the study area REBVI was calculated by using the following equation **-**

$$REBVI = (R_{ST} \text{ x } W_{ST})+(R_C \text{ x } W_C)+(R_X \text{ x } W_X)+(R_{PI} \text{ x } W_{PI})+(R_p \text{ x } W_p)+(R_{UCS} \text{x } W_{UCS}+(R_\Phi \text{ x } W_\Phi)$$

where R represents rank value, W is for weight value, ST represents soil texture, C is compaction, X shows cross section, PI stands for plasticity index, P indicates permeability, UCS stands for unconfined compressive strength, and Φdenotes the angle of internal friction. All parameters were integrated and a single value of REBVI was calculated for each site. Highest values of the index indicate that the embankment is the most vulnerable site and there is least potential to safeguard against breaching. The lowest value of the REBVI indicates that the site is the least vulnerable to breaching and is strong enough to prevent the breaching action. The soil texture, compaction, physical parameters, plasticity index, unconfined compressive strength and angle of internal friction are the most important geotechnical properties of flood embankments which can be used describe the strength and stability. Geotechnical properties are enlisted in Annexure A. Soil texture of the flood bunds along River Chenab showed that most of the soils were Silty Clay and Sandy Silt. Range of Compaction was 57.2% to 95.3 % with average value of 88.6% and SD±6.195. Most of soil samples were low to medium plastic (1.0 to 15.9) with average value of 11.2 and SD±3.674. Unconfined compressive strength test results showed that the maximum compressive strength of flood bund was 1.81kg/cm^2 in Left Embankment along Nullah Deg RD 4-5, alternatively, the lowest was recorded from the Maddudas Flood Bund RD 43-44 (0.39 Kg /cm^2). Average value of all test results was 1.3kg/cm^2 and SD±.293. The permeability of soil samples collected from flood bunds were in the range from 0.0006 to 0.0033 cm/sec with average value of .00090 cm/s and SD±.001. The values of REBVI were determined for all sites and results are tabulated in Annexure A. Some descriptive statistical parameters are presented in **Table 3**. The least value of REBVI was recorded for Muzaffar Garh F/B RD (75+600) and highest score REBVI value was recorded for Rangpur flood band (RD 303+500).

Table 3: Statistics of REBVI at all sites.

S N	Parameter	Value (REBVI)
1	N	78
2	Min	27
3	Max	81
4	Mean	51.06
5	STD	10.98

Cluster Analysis

After obtaining the index values for all sites, cluster analysis was carried out on the basis of vulnerability index as shown in **Table 4**. Five clusters were designed for description of results as shown in **Table 4**.

Table 4: Probability of embankment breaching clusters according to REBVI.

Cluster	Range off REBVI	Consistency	Cluster Description	Location /Sites	No. of sites (%)
I	< 40	Very High	High potential to prevent embankment breaching	Muzaffar Garh F/B (RD 82+750, 75+600) Khangharh F/B (RD 43+100, 77+700) Chandarbhan F/B (RD 54+300) Gardez (RD 5+500) jalalpur Khaki (RD 45+500) Chenab F/B (RD 23+000) LMB Qadirabad (RD 17+000) Embankment along Nullah Deg (RD 4-5, 13-14)	11 (14%)
II	41-50	High	Low embankment breaching	Punjnad RMB (RD 33+600) Jhang F/B (RD 0+556) LMB Trimmu (RD 25+810, 42-43) Muzaffar Garg F/B (RD 148+400)	35 (45%)

				Chenab F/B (RD 87+100, 6+500) Escape Channel F/B (RD 6+225) RMB Qadirabad(RD 54+450, 55-56) Hassuwali F/B (RD 42+390, 44+825, 57+240) Akbar F/B (RD 6+600) Khangarh F/B (RD 25+120, 29+990, 84+400) Chandar Bhan /B (RD 55+400) Nagni F/B (RD 15+500) Gardez F/B (RD 13+500) Jalalpur Khaki (RD 6+100, 7+500) Balochwah (RD 3+500) Dadal F/B (RD 16+456, 22+500) Kot Naja F/B (RD 49-50) Massan (RD 47-48) Maddudas F/B (45-46,48-49) LMB Marala (RD 44-45, 49-50, 59-60) Rangpur F/B (RD 287+500) Nullah Deg Left Embankment F/B (RD 11-12) Dhundoo F/B (RD 19+500)	
III	51-60	Medium	Moderate potential of embankment breaching	Pindi Bhattian F/B (RD 48-49, 53-54, 58-59, 67-68) LMB Marala (RD56+000) Budhi Nullah (RD 3-4) Punjnad (RD 36+000) LMB Trimmu (RD 20+350) RMB Qadirabad F/B (RD 52+800, 59-60) Muzaffar GarhF/B (RD 54+950) Nagni F/B (D 10+500) Sat Burji F/B (RD 64+500, 65+900) Balochwah F/B (RD 4+500) Left Embankment Nukah Deg Kingra Bride (RD 9+700)	16 (21%)
IV	61-70	Low	High probability of embankment breaching	Punjnad RMB (RD 39+100) Muzaffar Garh F/B (RD 157+140) Hassuwali F/B (RD 33+990) Shehar Sultan F/B (RD 0-1) Dhundoo F/B (RD 21+000) Gardez F/B (RD 15+500) Balochwah F/B (RD 16+500) LMB Qadirabad F/B (RD 21+000) Massan F/B (RD 34-35) Maddudas F/B (RD 43-44) Rangpur F/B (RD 279+500, 290+500)	12 (15%)
V	> 70	Very Low	Very High probability of embankment breaching	Rangpur F/B (RD303+500) Shershah (RD 18-19) Jhang F/B (RD 2+336) LMB Trimmu (RD 43-44)	4 (5%)

CONCLUSION AND RECOMMENDATIONS:

Geotechnical and geometrical properties of the flood bunds play a vital role for strength of the infrastructure and breaching phenomenon is mainly dependent on these parameters. Results indicated that the test sites at Rangpur site (RD 303+500), Shershah (RD 18-19) Jhang site (RD 2+336) and LMB Trimmu (RD 43-44) are most vulnerable sites. Grain Size Analysis of soil samples collected from 78 sites indicates that 18 % sites are of very uniform soil, 64 % of medium uniform while 17% of very non uniform. Results of Plasticity Index (PI) indicate that 23% soil samples are medium plastic, 12% slightly plastic, 43% low plastic and 22% non-plastic. Relative Compaction results indicate that the relative compaction has higher values at 22% of flood bund sites, 61% sites are medium compacted and 17% are low compacted. Results of Unconfined Compressive Test (UCS) indicate that soil at 5% of flood bund sites is very soft, at 4% sites it is soft, 68% sites are medium, and 23% are stiff. Permeability Results indicate that soil no site is impervious, 23% sites are low in permeability, and 77% are medium permeable.

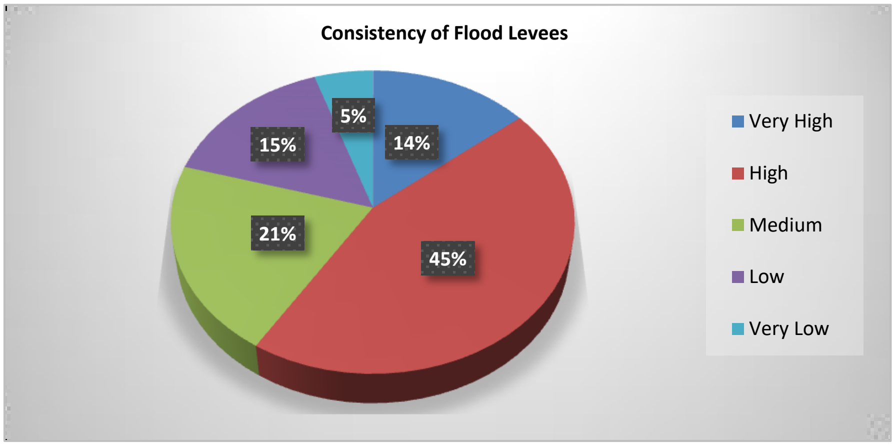

Fig. 4: Consistency of the flood leaves.

Direct Shear Test results indicate that the angle of internal friction of the soil samples shows that 1% soil samples are very loose, 23% are loose, 76% are medium and no dense. Geometry of the flood bunds was measured in field, results have revealed that 4% sites were according to the design, 12% were over design and 84% sites were under-designed. Geochemical Analysis of soil samples collected from flood bunds reveal that TDS at 4% of sites is above limit while 96% sites are showing their results within limits; Organic Matter of all soil samples collected from different flood bunds is within limit. Sulphate quantity in the samples is 90 % within limits and 10% above limits. The results of analysis of water samples collected from bore holes at different sites indicate that chloride values are within permissible limit and the result of analysis of TDS show that all water samples are within limits. Cluster Analysis based on River Embankment Breaching Vulnerability Index (REBVI) was grouped in five clusters as shown in **Fig. 4**. It has been found that 14% sites exhibit very high consistency, 45% sites show high consistency, 21% medium indicate medium consistency, 15% are at low consistency level, and 5% sites exhibit very low consistency. Maximum sites are at high and medium consistency level. Activities of farming community for irrigation and other agronomic practices have been identified one of the causes to weaken the flood bunds. Burrowing animals are another threat for the flood embankments. The important re commendations are followings -

1) Cross-sections of flood bunds need to be maintained as per original design, strict quality control during construction stage.
2) The construction material like good earth coupled with best construction methods can improve the strength and can reduce the vulnerability of flood embankments.
3) Clay, silty clay, and clayey silt, mixed in proper ratio can yield the good earth as construction material for flood bunds and it can yield best values of geotechnical parameters.
4) Additional pushta (embankment) to be constructed on country-side slope where hydraulic gradient line (HGL) is exposed.
5) Periodic visiting of the flood bunds is recommended before and after flood season.
6) Geophysical survey is recommended using latest techniques & tools to determine the under-ground situation/conditions.

7) Activation of wetting channels may be ensured to ensure wetting of the same before flood season.
8) Future construction must be ensured as per standard specifications and material (silt from 18 to 50%, sand less than 52% and clay from 7 to 17% and 95% compaction of all layers).
9) Slope stability analysis to keep the phreatic line protected shall be conducted at critical sites.
10) Hydrological studies may be conducted to get the flood expectations/frequency and design may optimized accordingly.
11) Site specific corrective steps may be adapted to safeguard the flood bunds against heavy floods.
12) Geosynthetics materials can be applied to strengthen the existing flood bunds in addition to stone-pitching
13) Clay core and sand core can also be used as a measure to strengthen the existing flood bunds.

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Annex-A

Characteristics of flood bund material, geotechnical attributes and River Embankment Breaching Vulnerability Index (REVBI).

Name of Site/ Bund	Location/ RD	Texture	Compaction (%)	Cross Section	PI	Permeability (cm/sec)	Un-Confined Compressive Strength (Kg/cm2)	Angle of Internal Friction (Degrees)	Vulner-ability Index
Pindi Bhattian F/B	RD 48-49	Clayey sand	87.7	Under Design	5.53	0.00257	0.98	30.60	52.00
	RD 53-54	Clayey silt	82.8	Under Design	6.35	0.00301	0.90	29.80	55.00
	RD 58-59	Sandy silt	88.6	Under Design	4.83	0.0032	0.89	31.00	54.00
	RD 67-68	Sandy silt	82.9	Under Design	5.98	0.00292	0.98	28.80	57.00
Buddhi Nullah	RD 3-4	Sandy silt	87.8	Under Design	11.28	0.00122	0.57	29.20	53.00
Punjnad RMB	RD 33+600	Sandy silt	90.2	Under Design	5	0.00216	0.67	31.30	48.00
	RD 36+000	Sandy silt	80.9	Under Design	2.93	0.00168	0.64	30.20	54.00
	RD 39+100	Sandy silt	91.1	Under Design	-	0.00201	0.64	32.50	64.00
Jhang F/B	RD 0+556	Sandy silt	92.6	According to Design	9.12	0.000943	0.56	28.20	44.00
	RD 2+336	Sandy silt	91.7	According to Design	-	0.00308	0.00	29.40	77.00
LMB Trimmu	RD 20+350	Sandy silt	93.9	Under Design	7.93	0.00151	0.67	29.00	55.00
	RD 25+810	Sandy silt	84.1	Under Design	10.21	0.00137	0.54	31.00	46.00
	RD 42-43	Sandy silt	80.7	Under Design	5.76	0.00223	0.79	30.30	50.00
	RD 43-44	Sandy silt	83.2	Under Design	-	0.00137	0.18	31.50	78.00
M/Garh F/B	RD 157+140	Sand	77.1	According to Design	-	0.00317	0.81	30.60	65.00
	RD 148+400	Silty sand	77.7	According to Design	7.43	0.00178	0.58	31.10	47.00
Chenab F/B	RD 87+100	Sand	81.8	Under Design	10.81	0.00332	0.69	32.00	49.00
Escape channel F/B	RD 6+225	Clayey silt	80.4	Under Design	6.15	0.00184	0.66	31.00	48.00
RMB Qadirabad	RD 52+800	Clayey sand	88.2	Under Design	9.44	0.00109	0.94	31.10	52.00
	RD 54+450	Silty clay	88.5	Under Design	5.49	0.00116	0.84	31.20	47.00
	RD 55-56	Silty clay	90.7	Under Design	4.14	0.00119	0.87	31.00	49.00
	RD 59-60	Sandy silt	94.0	Under Design	6.49	0.0015	0.82	29.20	55.00
Hassuwali F/B	RD 42+390	Clayey silt	86.92	Over Design	3.31	0.00113	0.89	30.70	49.00
	RD 33+990	Sandy silt	90.12	Over Design	-	0.00148	0.72	31.40	61.00
	RD 44+825	Silty clay	88.32	According to Design	9.42	0.00125	0.74	31.90	41.00
	RD 57+240	Clayey silt	95.37	Over Design	6.33	0.00123	0.85	31.50	43.00
Akbar F/B	RD 6+600	Sandy silt	87.5	Under Design	5.78	0.00144	0.62	31.20	50.00
Shershah F/B	RD 18-19	Sandy silt	90.78.	Under Design	-	0.00116	0.75	30.00	71.00
Muzaffar Garh F/B	RD 82+750	Silty clay	87.0	Under Design	14.98	0.00112	1.10	32.00	37.00
	RD 75+600	Clayey silt	80.4	According to Design	10.25	0.000583	1.01	31.00	27.00
	RD 54+950	Clayey silt	82.5	According to Design	-	0.00199	1.10	32.00	52.00
Khangarh F/B	RD 25+120	Silty clay	92.6	Under Design	14.97	0.00135	0.96	33.00	41.00
	RD 29+990	Sandy silt	87.18	According to Design	6.75	0.00132	0.90	31.00	44.00
	RD 43+100	Clayey silt	90.1	According to Design	7.21	0.00114	1.01	32.00	34.00
	RD 77+700	Clayey silt	83.49	According to Design	11.81	0.000924	1.10	30.00	34.00
	RD 84+400	Silty clay	89.66	Under Design	9.43	0.00147	0.81	31.00	47.00
Shehr Sultan J Head Spur	RD 0-1	Sandy silt	82.27	Under Design	-	0.00135	1.05	30.00	67.00
Chandar Bhan	RD 55+400	Silty clay	85.7	Under Design	14.53	0.00127	1.00	31.00	43.00
	RD 54+300	Clayey silt	82.48	Under Design	6.11	0.00069	1.10	31.00	37.00
Nagni F/B	RD 10+500	Silty clay	82.99	Under Design	-	0.00092	1.00	31.00	58.00
	RD 15+500	Clayey silt	79.53	Under Design	7.75	0.00137	1.00	31.00	50.00
Dhundoo F/B	RD 19+500	Silty clay	79.23	Under Design	5.49	0.00183	0.90	30.50	49.00
	RD 21+000	0	79.89	Under Design	9.26	0.00119	0.71	30.00	62.00

Gardez F/B	RD 5+500	Silty sand	80.51	Under Design	9.36	0.000751	1.10	31.00	40.00
	RD 13+500	Silty clay	75.74	Under Design	5.16	0.00133	1.01	30.00	50.00
	RD 15+500	Sandy silt	77.28	Under Design	-	0.00169	0.91	31.00	68.00
Sat Burji F/B	RD 64+500	Clayey silt	81.34	Over Design	1.08	0.0015	0.91	30.00	56.00
	RD 65+900	Clayey silt	85.69	Over Design	-	0.00141	1.11	31.10	55.00
Jalalpur Khaki F/B	RD 6+100	Sandy silt	83.32	Under Design	9.5	0.00132	0.71	31.10	50.00
	RD 7+500	Sandy silt	76.19	Under Design	7.22	0.000689	0.71	31.50	47.00
	RD 45+500	Sandy silt	81.19	According to Design	1.66	0.000975	1.21	31.90	37.00
Balochwah F/B	RD 3+500	Silty sand	74.73	Over Design	12.62	0.00142	0.86	32.00	46.00
	RD 4+500	Silty clay	81.36	Over Design	4.52	0.00138	0.91	30.00	55.00
	RD 16+500	Silty clay	84.68	Over Design	-	0.00138	0.82	30.00	67.00
Chenab F/B	RD 23+000	Sandy silt	84.19	Under Design	9.96	0.000601	1.01	33.50	39.00
	RD 6+500	Silty clay	81.99	Under Design	15.93	0.00103	0.81	31.00	43.00
LMB Qadirabad	RD 17+000	Clayey silt	85.93	Under Design	11.28	0.000987	0.72	33.00	39.00
	RD 21+000	Sandy silt	92.94	Under Design	-	0.00115	0.72	33.00	64.00
Left Embankment Nullah Deg U/S	RD 9+700	Silty sand	87.1	Under Design	9.7	0.000778	0.00	31.20	58.00
Dadal F/B	RD 16+456	Clayey sand	74.53	Under Design	2.53	0.000675	1.05	30.40	47.00
	RD 22+500	Silty clay	83.5	Under Design	9.51	0.0006	1.00	29.70	49.00
Kot Naja FB	RD 49-50	Sandy silt	89.7	Under Design	5.5	0.00163	0.86	31.00	50.00
Massan F/B	RD 34-35	Sandy silt	88.9	Under Design	-	0.0017	0.95	32.00	66.00
	RD 47-48	Clayey silt	57.26	Under Design	9.23	0.00178	1.05	32.00	44.00
Maddu Das F/B	RD 43-44	Silty clay	89.06	Under Design	-	0.0011	0.39	31.00	69.00
	RD 45-46	Silty clay	88.11	According to Design	11.62	0.00102	0.43	30.00	50.00
	RD 48-49	Silty clay	88.18	Under Design	10.74	0.000961	0.47	31.20	44.00
LMB Marala	RD 44-45	Sandy silt	87.39	Under Design	12.65	0.00116	0.74	33.30	46.00
	RD 49-50	Clayey silt	84.69	Over Design	10.9	0.00101	0.81	33.10	41.00
	RD 56+000	Silty sand	89.75	Under Design	9.64	0.00111	0.81	31.70	51.00
	RD 59-60	Sandy silt	94.56	Under Design	10.6	0.00209	0.86	32.00	44.00
Rangpur F/B	RD 279+500	Silty sand	76.59	Under Design	-	0.00169	0.90	31.10	69.00
	RD 287+500	Sandy silt	80.4	Under Design	5.34	0.00249	1.05	30.90	44.00
	RD 290+500	Silty clay	77.18	Under Design	4.5	0.00169	0.81	27.40	67.00
	RD 303+500	Sand	80.26	Under Design	-	0.0027	0.00	31.20	81.00
Embankment along left bank of Deg Nullah from Choor Bridge to Jaistywala	RD 4-5	Silty sand	90.76	Under Design	14.77	0.000638	1.81	31.00	34.00
	RD 11-12	Silty clay	91.82	Under Design	6.2	0.000612	1.17	28.70	41.00
	RD 13-14	0	95.34	Under Design	14.86	0.000561	1.72	32.00	36.00

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