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Surface Water Drainage and Flooding in Karachi City

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Abstract: Urban flooding is natural phenomenon. It has become a serious problem of cities of both Developed and Under- developed region. The rapid population and areal growth of cities and intensive urban development have intensified this problem. Cities are generally flooded when excessive precipitation takes place beyond the capacity of surface drainage. Urban sprawl and urban encroachment intensify this problem in form of reducing rainwater infiltration and increasing surface runoff. Lack of planning about rainwater and sewerage discharge and population growth aggravate this problem. Like other major cities of the world problem of urban flooding has been intensifying in Karachi City which is the largest city and financial hub of Pakistan. The monsoon rain creates a serious problem for city dwellers and urban planners. In view of the significance of the problem the present study is an attempt to examine the problem of urban flooding in historical perspective and evaluate the surface drainage problem in context of urban growth and urban planning.

Keywords: Urban flooding, Urban sprawl, Flash flood, Torrential rainfall

1. INTRODUCTION

Urban flooding is a phenomenon which occurs as a result of rainfall overwhelmed by drainage capacity (APWA, 1981). There are various factors which are linked with this problem. The most important factors are as follows:

i) the meteorological factors in which occurrence of heavy rainfall within a short duration and long spell of rainfall in which soil infiltration capacity reaches at the saturation level and surface runoff increases.

ii) Urban sprawl is strongly linked with urban flooding. Cities are expanding with alarming rate. Growth of urban built up area particularly construction works in the beds of water ways and in the flood plains and reduction of unlined surface which eventually cause increase in surface runoff considered one of the main reason of this problem.

iii) Urban planning and management has a key role in intensifying and managing urban flooding problem. Urban planners should frame development plans like new housing schemes, industrial areas, highways, airports etc to ensure the natural drainage of the area. This problem is serious in arid and semi-arid areas where drainage is ephemeral and dry beds provide open land for urban development. Construction of rain drain channels and sewerage channels should be constructed to ensure the future population growth.

iv) in the less Developed regions of the world the cities are facing challenges of haphazard growth and unplanned urban structures. Problem of low – income urban housing which enhance growth of squatter settlements and lack of governance on the implementation of land utilization and building by-laws intensify the problem of urban flooding cause loss of life, property and urban infrastructure.

Urban flooding is a significant problem in cities of both developed and less developed regions of the world (Balmer, 1984). In September 2008 severe flood occurred in the coastal city of Houston, USA as a result of torrential rain and hurricane. The urban life had been collapsed for a week. Urban flooding has become a common phenomenon in many mega cities of the world like Mumbai, Chennai, Kolkata, Dhaka etc. It causes catastrophic damages of life and economy. In

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Pakistan the problem of urban flooding has been intensifying in large cities like Karachi, Lahore and Rawalpindi. During the Monsoon season from July to September risk of urban flooding is very high. In August 2004, 600 mm rainfall was recorded in the twin cities of Rawalpindi and Islamabad. As a result flood damaged squatters, roads, and bridges. At least 10 people died 50 injured and more than 100 cattle died. The problem of urban flooding is quite significant in Karachi which is the industrial and business hub of Pakistan. Karachi had experienced severe floods which occurred periodically. In 1977 severe flood occurred in the flood plains of the Malir River and the Lyari River killed 267 people, more than 30,000 were homeless and 100,000 were temporarily dislocated. Houses were destroyed and roads were damaged. The total loss was estimated about 5 billion rupees (KDA, 1981). The present study deals with urban flooding which has now become a serious problem all over the world, affecting urban life, infrastructure, mobility of people and economy of the city. In this context Karachi has been selected for study which is the largest city of Pakistan.

2. MATERIALS AND METHODS

The objectives of the present study are following:

a) to study topography and surface drainage of the City
b) to analyse the historical records of flooding in Karachi City.
c) to compute relationship of rainfall and surface runoff as well as quantify flood frequency in the Malir River.
d) to identify flood prone areas in the City.
e) to identify causes of urban flooding in Karachi City.
f) to evaluate methods of flood control and flood management in the City.

To study the above objectives following methods were used:

a) Collected precipitation data of the last 80 years of Karachi City from Meteorological office.
b) Obtained historical data of surface runoff in the Malir River which is the main river in the City from WAPDA.
c) Conducted a reconnaissance survey of surface geology and surface drainage of Karachi.

d) Field surveys were conducted to identify the sewerage system and problem of urban encroachment in the City

e) Satellite imageries were used to locate urban development over surface drainage and rivers' beds of Malir, Lyari and other small channels.

3. RESULTS AND DISCUSSION

Population and Physical Growth of Karachi City

Karachi started its growth as a walled city in 1729 with a population of 1000 and an area of 0.12 sq km. The British occupied Karachi in 1839 and it was annexed as a part of Sindh in British Indian 1843. In1853, Karachi Municipality was established and a marked expansion and development of the town took place. The city was no more a fortified settlement. In 1923, Karachi Municipality approved Miram's Development Plan for the planning and development of Karachi. Under that plan Bunder Road (M. A Jinnah Road) was extended up to the Central Prison. In 1941 the population of Karachi city increased to 386655 and its area expanded to 115 sq. kms. (KDA, 1984).

Pakistan came into existence in 1947 and Karachi was made its capital. It retained its status as capital till 1960 when the capital of Pakistan was shifted to Islamabad. Soon after the creation of Pakistan large scale migration from India took place. Apart from this influx, a large number of people also migrated to Karachi from different parts of Pakistan . As a result the population of Karachi increased rapidly. In 1951 Karachi with a population of 1.6 million became the largest city of Pakistan. Many new urban housing schemes were developed after the creation of Pakistan As a result the area of Karachi city expanded to 368 sq kms in 1961 and population increased to 1912598. In 1971, separation of East Pakistan (now Bangladesh) took place. About 0.175 million people came from Bangladesh to Karachi. The population of Karachi increased to 3,498,614 in 1972 while the area expanded to 640 sq kms. The population and areal growth of Karachi city continued. Its population increased from 5,153,000 in 1981 to 9,280,000 in 1998. It is estimated that in 2010 population of Karachi increased to 15 million. Its area extended to about 1800 sq. kms. Urban sprawl is big challenge for city planners which has increased built up land, population pressure and encroached settlements. As a result problem of flooding in the city has been intensifying year by year.

Topography and Surface Geology

The topography of Karachi is comprised of plains, river valleys and hilly ranges. The main areas

of Karachi City have been developed in between the interfluves of the Lyari River and the Malir River. The City is bounded by hilly ranges located in the west, north and north-east. The hilly ranges of Manghopir are located in the north-west. It starts from the Hub River Dam area run north to south than turn toward west with the name of Orangi hills and Gorakh Lakki hills. These hills finally dip at Cape Monze at the coast of Karachi. One of the important coastal ranges is known as Jhill hills. At the eastern coast of Karachi the topography is dominated by an eroded hilly range known as Ibrahim Hyderi hills. The north-eastern part of the Malir River is also occupied by hilly ranges. In between the Lyari and the Malir River remnants of hilly ranges are located known with different names like the Mulri hills over which Gulistan-e-Jauhar exist, Drigh road hills, Hill Park, Gizri hills etc. The surface deposits of plains are laid down by surface runoff and river flood deposits of the two main rivers. The strong monsoon winds is an important force of windblown deposits over the surface particularly during Pleistocene epoch when sea level dropped to 100 metres from the present sea level and continental shelf exposed. The outcrops of the hilly ranges are comprised of sedimentary rocks dominated by yellow lime stone belong to tertiary period. Clay, shale and sand stones are also exposed in some of the areas. Generally clay and shale had underlain the beds of lime stones.

The structural geology of Karachi is dominated by two synclinal valleys that are the Malir valley running from north to south-west and the Lyari River valley running from north to south **(Fig 1).** These two synclinal valleys are separated by an anticlinal ridge known as Drigh road anticline. Another anticlinal hilly range is called Manghopir range located in the north-west of the city. These folded structures are eroded by intermittent streams and run off form monoclinal ridges, hogbacks and cuestas. Scarp features are dominated by these structures. Generally angle of dip slopes are in between 30 to 70 degree. Strikes are mostly north to south and north-west to south-west. There are several strike slips faults which indicate the past tectonic activity in the area. The Sona pass, the Mulri hill pass and several faults in the Manghopir and Orangi hills area are examples of strike slip faults. Dip-slip faults like normal faults, reverse fault etc.

The fault scarp of Mulri hills form mesas. The landforms of the coastal areas also indicate tectonic uplifting in the area. Formation of Ibrahim Hyderi hills indicates faults running parallel to the coast. The coast of Karachi is dominated by cliffs, sea stacks, sandy beaches, sand bars and sand spits, swamps, mudflats and salt marshes. Due to hill torrents at the slope of hills alluvial fans and bajada features form depositional surface while the low angle piedmont slopes represent the erosional surface. Weathering and mass wasting are two dominant geomorphic processes in the area. The outcrops in Karachi comprise different epochs of tertiary period and quaternary surface deposits. It comprises from Eocene to Pliocene rocks. The outcrops are exposed in different areas of the City belong to Pliocene locally called Manchhar formation, Miocene locally called Gaj formation and Oligocene locally called Nari formation. All rocks are sedimentary rocks belong to limestone, clays, shale and sandstone.

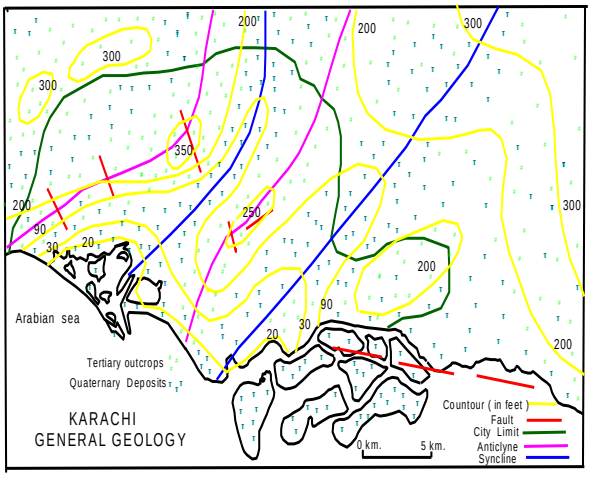

Fig 1: Generalized Geological map of Karachi

Climate

Karachi is located just above the tropical zone i.e. 24° North. It is situated along the coast of Arabian Sea. Both these factors influence the climate of Karachi. Summer is warm with maximum mean monthly temperature in June is 31.4° Celsius while winter is mild i.e. minimum mean monthly temperature in January is 18.1° Celsius. Karachi is a dry place.

The total annual rainfall in the city is about 208 mm. The city receives a tail end of summer monsoon which is the main source of rainfall in the city between June and September. July is the wettest month with mean monthly rainfall is 85 mm followed by western winds bring little amount of rainfall in winter season. Thunder storms also occur in May and October. Sometimes bring occasional torrential showers. To sum up the climate of Karachi is arid with warm summer and mild winter.

Surface water Drainage

The drainage pattern of Karachi is dominated by dendritic. The surface drainage of Karachi City is divided in four parts based upon surface runoff and streams flow.

a) Malir River Basin
b) Lyari River Basin
c) Budnai Basin
d) Coastal Basin

The Malir River basin and the Lyari River basin are two main basins which contribute about 80 percent of the surface runoff. The Budnai basin and the coastal basin are minor basins. All basins collect surface runoff through hundreds of small and large channels which finally drain into sea.

The Malir River Basin

The Malir River basin is the largest basin and source of surface runoff and sediments load. The Malir River forms a result of the confluence of two main rivers the Mol River and the Khadeji River. The catchment area of the Mol River is about 620 square km and the Khadeji River is 580 square km (WAPDA, 1990). The Mol River originates from the Kohistan hills at the height of 640 meter eroding Mol plateau and flows 105 km up to Super Highway where it joins the Malir River **(Table 1 and Fig.2).** .

Table 1: Catchment Areas and Surface Runoff of Mol, Khadeji and Malir Rivers

	Khadeji River	Mol River	Malir River at Super Highway	Malir River at National Highway
Catchment Area (square km)	567	596	1205	1985
Mean Annual Runoff (MCM) (1929---1988)	34	45	74	60
Maximum Annual Runoff (MCM) 1944	187	255	392	424

Source: WAPDA

The Khadeji River starts to flow from the height 440 meter has less catchment area flows up to 55 km from its source (Kohistan region) to Super Highway bridge. There are number of streams which originate from the high relief of Mol and Mahar plateaus and monoclinal ridges (Fig 3). The Thaddo Nadi, the Langheji Nadi, the Jarando Nadi, the Sukhan Nadi and the Bazar Nadi are main streams that join the Malir River. Therefore, main amount of flood water discharge and surface runoff take place through Malir River System which drains into the sea at Gizri creek. The catchment area of Malir River is about 2240 square km (WAPDA, 1981).

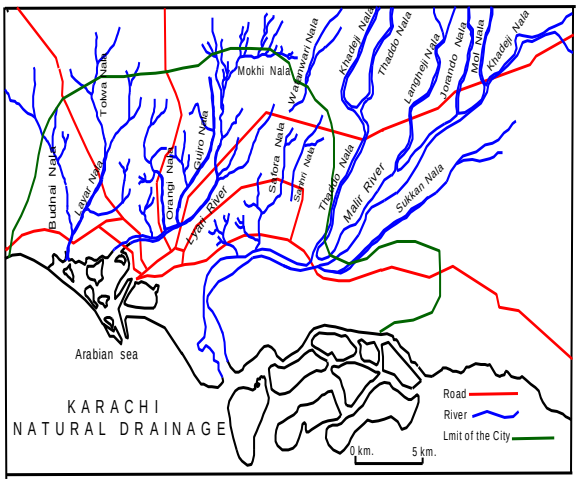

Fig 2: Natural drainage in Karachi

The Lyari River Basin

The Lyari River originates from the hilly ranges of Manghopir anticlines starts from the north of the city and south of the Hub dam where its height is about 190 meters. Its catchment area is smaller than the Malir River because of its shorter length and smaller number of tributaries. Its total length is about 180 kms while its catchment area is about 578 square kms. Mokhi Nala originates from Taiser hills, Orangi Nala originates from Orangi hills and Gujro Nala originates from Manghopir hills are main tributaries which discharge runoff to the Lyari River.

The Budnai Basin

The Budnai basin is drained by Budnai Nadi and number of small but powerful streams originates from ridges of Orangi hills and Jhill hills in Mochko and around Sona pass. The total length of Budnai stream is about 46 kms and its catchment area is about 95 square kilometers **(Table 2)**

Table 2: Drainage characteristics of the River Basins of Karachi

River Basins	Length of streams	Basin Area Sq.km	Drainage pattern	Branching Ratio	Drainage Density Km/ sq.km
Malir River Basin	725	2167	Dendritic	3.4	32.1
Lyari River Basin	180	578	Dendritic	5.6	10.1
Budnai Basin	46	95	Dendritic	5.7	5.3

The Coastal Basin

The coastal areas of Bin Qasim, Korangi and Jhill hills are drained by many hill torrents and small streams which are very active during rainy days **(Fig 3)**.

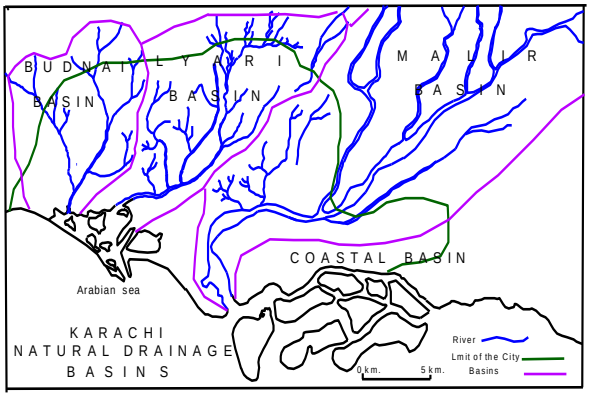

Fig. 3. Natural drainage basins in Karachi

Flooding in Karachi City

Urban flooding is caused by heavy rainfall overwhelming drainage capacity. Cities have been growing with alarming rate. This problem is important both in Developed and under Developed Cities

Table 3: History of severe floods in Karachi

Year	Rainfall (mm)	Surface Runoff (000 cubic metres) in Malir River
1930	408.3	209166
1944	676.3	391997
1956	414.2	104164
1959	688.8	330385
1961	621.8	267201
1967	713.0	348451
1970	475.0	172800
1977	489.0	123708
1994	481.0	124178
2007	465.6	118710

Source: Pakistan Meteorological Department and WAPDA.

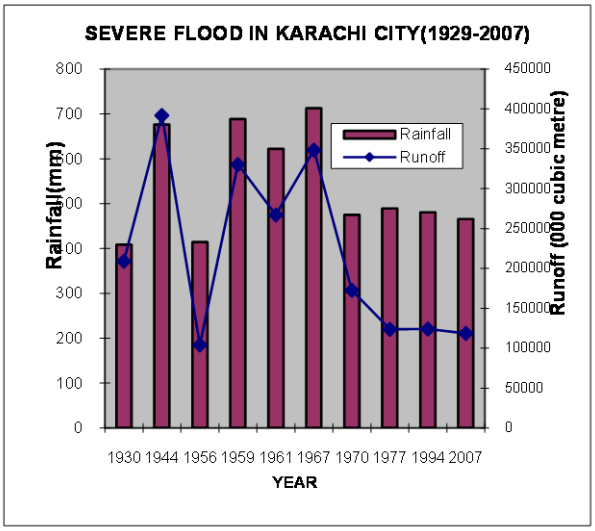

Fig. 4 Severe Floods in Karachi City

Like other mega cities of the world flooding has become a serious hazard in the mage cities of Pakistan e.g. Karachi, Lahore, Rawalpindi, Hyderabad etc. The meteorological data of rainfall and hydrological data of surface runoff reveal that occurrence of flood is not the new phenomenon in Karachi. The severe flood occurred in the city in 1944, 1961, 1967, 1970, 1977, 1994 and 2007 **(Fig 4)**. In 1944, 1961 and 1967 Karachi received 676 mm, 621.8 mm and 713 mm rainfall respectively. As a result severe flood occurred and surface runoff alone from the Malir River reached up to 391997,000 cubic metres, 267,201,000 cubic metres and 348,451,000 cubic metres respectively **(Table 3)**.

Areas of Flood

Flood affected areas of the city can be categorized in term of intensity of flood water and damages which are as follows.

Low Lying Zone

a) the old city areas
b) areas along the banks of the Rivers and Nalas.(Hill torrent zone)

The Old City Areas

The City which was developed in between 1726 to 1947 called old city. These areas are Kharadar, Mithadar, Bunder Road, Ramswami,

Arambagh, Chakiwada, I. I. Chundrigar Road, Saddar, Burns Road, Ranchor Line, Denso Hall, Light House, Juna Market, Bolton Market, Memon Masjid, Jodia Bazar, Ranchor Line, Gari Khata, Garden, etc. These localities are congested and densely populated. The wholesale business and commercial activities are also located here. The area is a low lying are bounded by the Lyari River and Karachi harbour. Drainage is very poor. Several Sewerage Nalas drain the sewerage and rain water of the old city. British developed a drainage system known as the Shone system of drainage. Due to low levels of the city the dumping of the sewage into the sea on the basis of gravity was not possible. The sullage water drained into wells in different parts of the city from these wells through pumping stations water were ejected to the sewage farm, 21 kms away from the city. One sewage farm was developed along the Lyari River where vegetables were grown with this sewage water and other sewage farm was developed near to Parsi Tower of Silence (Mahmoodabad).With the growth of city the system has been insufficient and silted up. The drains / nalas have been chocked and silted up. As a result whenever a torrential rain come the old city is inundated with rain water. In addition the flood water of the Lyari River create a severe flood in this area and the low lying areas along the Lyari River like Dhobi Ghat, Sher Shah Colony, Chakiwada, Bihar Colony, Agra Taj Colony, Ramswami etc. sink under 2 to 3 meters of water.

Areas along the banks of the Rivers and Nalas

The city is drained by two main streams called the Lyari River and the Malir River. Besides these two main streams several small streams locally called nalas which join the two main streams. These are ephemeral streams. Whenever heavy rain takes place huge discharge of runoff overflows and spreads over their flood plain. The explosive pressure of population growth and unchecked growth of encroachment and squatter settlements hundreds of colonies have been developed in and along the beds of the Lyari River, the Malir River, the Gujro Nala, the Orangi Nala, the Safora Nala, the Sukkun Nala etc. **(Fig 5,6)**. Populations of these areas are most seriously affected by torrential rain and river flood.

Hill Torrent Zone

Areas of Foot hills

The synclinal basins of Karachi City are bounded by remnants of anticlinal ridges and hills. Whenever torrential rains burst over these ridges and hills the hill torrents generate flash flood over the foot hills and adjoining areas. Due to population pressure these hills and ridges are now covered with planned and unplanned housing colonies like the planned housing scheme of Gulistan-e-Jauhar over Mulri Hills, the Hawks Bay scheme at the foot hill of Jhill hills, the Taiser Town over the Taiser hills. Similarly Orangi Town, Pahar Ganj, Nusrat Bhutto Colony, Pathan Colony, Baldia, Mochko etc have been built over Orangi hills, Manghopir hills etc. Collapse of houses, damages of roads, land slide and mud flow are common in these areas due to flash flood.

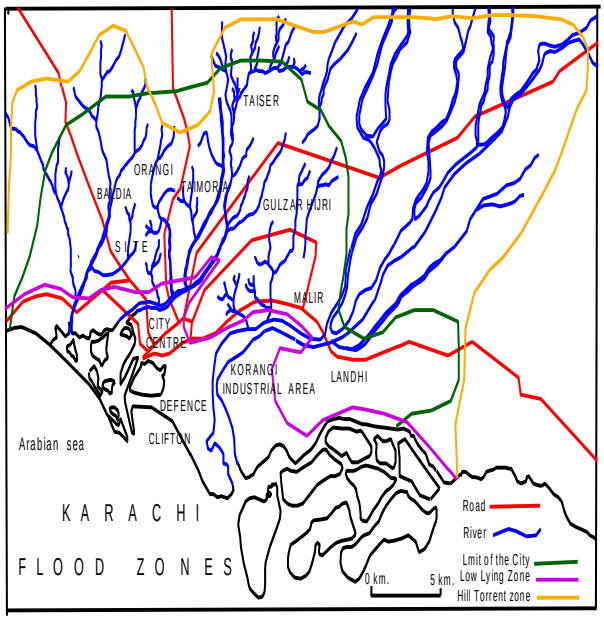

Fig 5: Flood zones in Karachi

Causes of Flood in Karachi City

The primary cause of flooding in Karachi city is torrential rainfall due to tropical storm and monsoon which saturate soil and create huge surface runoff. Floods in urban conditions are flashy in nature and occur both on built up surfaces like roads and streets, parking lots, yards, parks etc. and creeks of urban areas like the Lyari, the Gizri, and the Korangi creek.

Torrential rainfall and Surface Runoff

Although the climate of Karachi is arid and rainfall is low and highly variable but whenever torrential rain comes and heavy rainfall occurs within a short duration surface runoff intensify. This is because rate of water percolation into soil is lower than the amount of rain water falls on the surface.

Table 5: Annual total rainfall and surface runoff in Malir River(at Super Highway) Karachi

Year	Rainfall (mm)	Annual Runoff (000 cubic metre)	Year	Rainfall (mm)	Annual Runoff (000 cubic metre)	Year	Rainfall (mm)	Annual Runoff (000 cubic metre)
1929	104.9	8571	1956	414.2	104164	1983	282.1	39874
1930	408.3	209166	1957	41.2	1443	1984	270	165715
1931	18.5	2670	1958	226.1	54233	1985	154.6	20805
1932	324.6	176705	1959	688.8	330385	1986	91.6	32132
1933	511	299817	1960	129.5	11042	1987	0	86
1934	214.2	84646	1961	621.8	267201	1988	160	44807
1935	90.4	6696	1962	278.7	99248	1989	185.2	52220
1936	107.2	19742	1963	43.7	6817	1990	137.4	22900
1937	297.8	111119	1964	138.9	30819	1991	24.5	2690
1938	120.2	20658	1965	129.5	40971	1992	237	85670
1939	115.4	2238	1966	70.1	17626	1993	35.5	3290
1940	275.5	17885	1967	713	348451	1994	481.5	229266
1941	48.6	3404	1968	28.9	6895	1995	259.8	15885
1942	333	146500	1969	39.4	6713	1996	99	7892
1943	74.4	6791	1970	475	172800	1997	150.1	42043
1944	676.3	391997	1971	68.6	8096	1998	82.4	15453
1945	165.9	46043	1972	44.2	2998	1999	14.5	373
1946	99.6	17453	1973	213.4	93649	2000	46.9	6872
1947	59.2	7776	1974	7.2	1365	2001	100.4	8520
1948	142	3845	1975	163.8	21444	2002	55.8	6877
1949	323.6	151416	1976	406.1	55581	2003	324.9	175702
1950	85.9	21384	1977	489	123708	2004	65.9	5220
1951	77.1	5322	1978	206.3	196957	2005	97.2	7200
1952	224.3	73310	1979	381	18179	2006	301.1	51212
1953	262.1	112018	1980	193.8	5599	2007	465.6	225122
1954	289.6	77484	1981	185.6	43952	2008	121.6	3238
1955	155.6	34240	1982	161.2	15543			

Source: WAPDA and Pakistan Meteorological Department

Heavy shower takes place in the city either due to the affects of tropical storms usually in June which rarely attack the coastal areas but they bring heavy shower for a short period cause flooding. Just like on June 6, 2010 due to the tropical storm Karachi received 130 mm rain within a day caused huge surface runoff. The heavy monsoon rain mostly occurs in July and August is the main cause of flooding in the city. However its chance of occurrence is estimated about 3 to 5 years **(Table 5).**

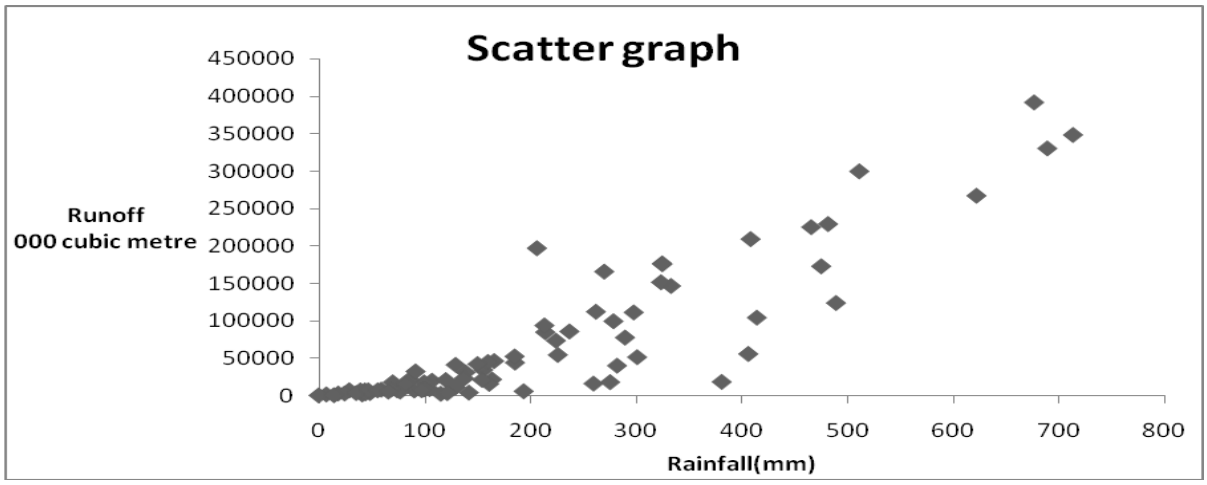

Fig 6: Scatter Graph between Rainfall (X-axis) and Surface Runoff (Y-axis)

Correlations (Pearson)

Correlation of X(rainfall) and Y(surface runoff at Super Highway Bridge Malir River = 0.889

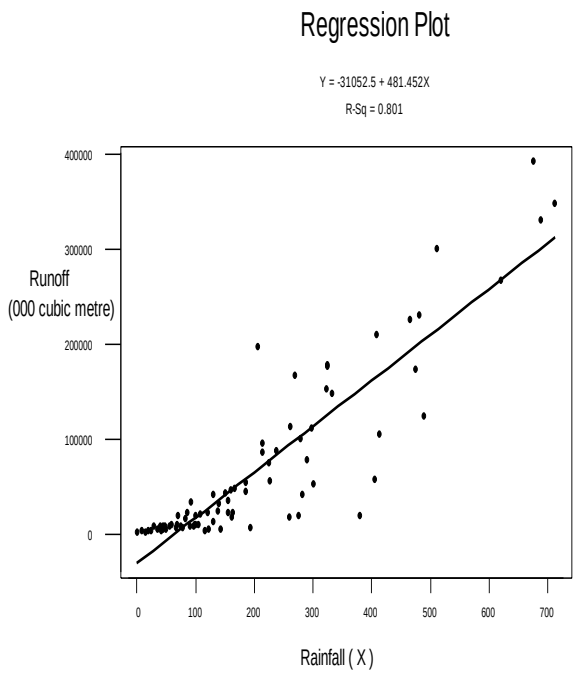

Fig 7: Regression Plot between rainfall and surface runoff in the Malir River

Regression

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The regression equation is
y = - 31053 + 481 x

Predictor   Coef  StDev      T        P
Constant   -31053      7209   -4.31    0.000
x          481.45      27.18 17.72     0.000

S = 40895   R-Sq = 80.1% R-Sq(adj)=79.8%

Analysis of Variance

Source       DF SS    MS          F         P
Regression 15.24893E+11 5.24893E+11313.85
0.000
Error        78 1.30449E+11  1672425432
Total        79 6.55342E+11
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The value of correlation coefficient i.e 0.889, regression table and regression graph clearly indicate strong relationship between amount of rainfall and surface runoff in the catchment area of the main river of Karachi. The time-scale graph shows occurrence of severe and low level flood against time **(Figs. 6, 7, 8 and 9)**.

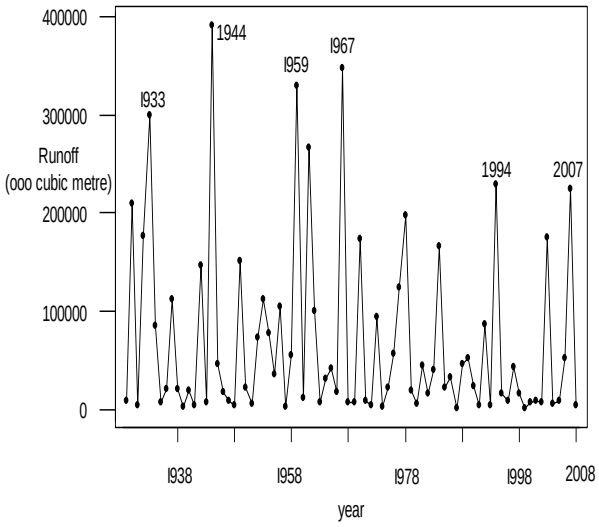

Fig 8: Time Series Graph of Surface Runoff in the Malir River.

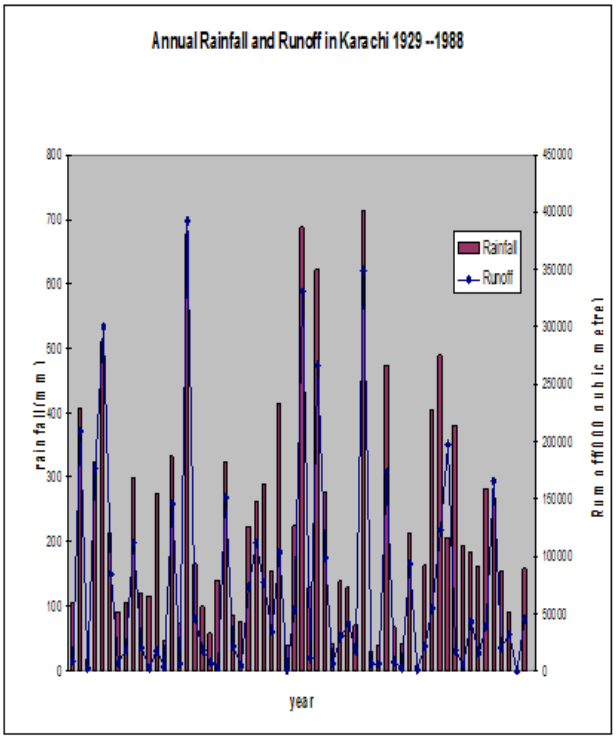

Fig 9: Annual Rainfall and Runoff in the Malir River, Karachi (1929-1988)

Frequency of Floods

Hydrologists study flood frequency on the basis of recurrence interval, or return period. To

calculate the recurrence interval of flooding for a river, the annual peak discharges are collected and ranked according to size. The largest annual peak discharge is assigned a rank (m) of one, the second a

two and so on. The recurrence interval R of each annual peak discharge is then calculated by adding one to the number of years of record (n) and dividing by its rank (m)

$$R = N + 1 / M$$

N= 80 years record (total number of years)
R= 80 +1/1 = 81 years (chance each year 0.81 percent)

R= 80 +1 / 2 = 40.5 years (chance each year 2.5 percent)
R= 80 + 1/ 3 = 27 years (chance each year 3.7 percent)

Table 6: Annual peak discharges and recurrence intervals in rank order for Malir River

Year	Surface Runoff (000 cubic metre) in Malir River	Magnitude Rank (M)	Recurrence Interval (R)
1944	391,997	1	81.0
1959	330,385	2	40.5
1967	348,451	3	27.0
1961	267,201	4	20.25
1930	209,166	5	16.2
1977	172,800	6	13.5
1994	124,178	7	11.5
1970	123,708	8	10.12
2007	118,710	9	9.0
1956	104,164	10	8.1

The above table shows the highest peak discharge in the Malir River caused flood in 1944. Its recurrence interval is about 81 years while its chance of occurrence is about 1 percent each year (Table 6 and Fig 10). Similarly chance of 104164,000 cubic metre discharges in 1956 in each year is 12 percent while its recurrence interval is 8 years. This clearly shows frequency of flood occurrence in Karachi. The Malir River is the largest natural drainage in Karachi which passes through the thickly populated areas of Malir, Landhi, Shah Faisal Colony, D.H.S, K.C.H.S, Mahmoodabad, Manzoor Colony, Azam Basti, Akhtar Colony, Qayumabad, Korangi etc. and the Korangi Industrial Area. It is the main source of floods in the above affected areas. The worst hit was in 1977 in term of its magnitude of life and damages. The abnormal rainfall of 30th June 1977 created a historic disaster and havoc in Karachi. In only 7 hours, 9.4 inches of rainfall with maximum intensity of 2.6 inches per hour during a period of 110 minutes was recorded. Deaths due to collapse of houses and electrocution were 367. The city was cut of through railroad and air from the rest of the country. All roads were full of flood water. The peak discharge of water in the Malir River aggravated the whole situation. Due to the lack of flood protected embankments and presence of encroached settlement in the bed many houses washed out. The Pakistan Air Base (Drigh Road) and P.N.S Mehran were also flooded. A flood wave hit the Korangi Industrial Area particularly National Oil Refinery, Korangi Thermal Power station.

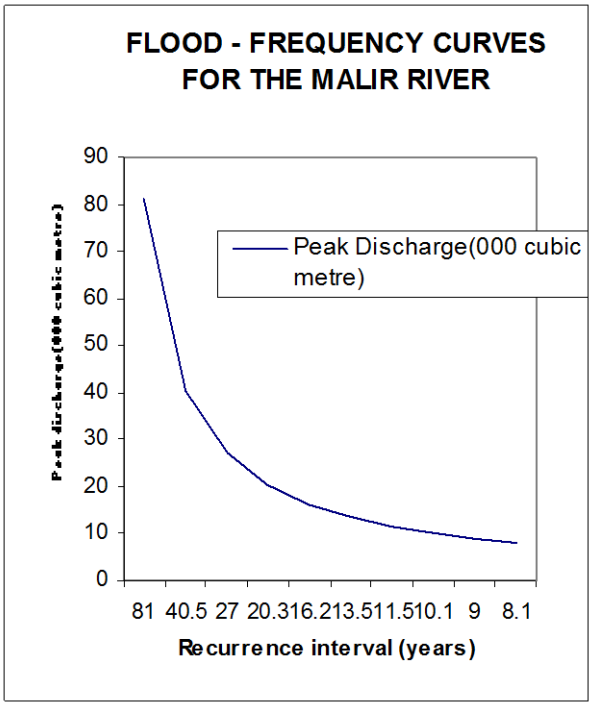

Fig 10: Flood Frequency curve for the Malir River

Human Factors of Urban Flooding

Torrential rainfall is the primary cause of flood in the city. However this natural cause is aggravated and intensified by human factors which are mentioned below:

Urban sprawl, inadequate land use and encroachments in and along natural waterways:

Sprawling of cities is a big issue all over the world. It is a fact that increase in built up area decrease the absorption amount of soil eventually increase surface runoff (WRC,1979).The second important problem is the construction of housing schemes without ensuring the natural drainage

pattern of the city. The third and the most serious issue is the emergence of encroachments and squatter settlements built on the beds of all natural drainage which cause either disappearing of beds or narrowing the natural drainage channels. One of the cause of worst flood of 1977 was the existence of encroachments and squatter settlements in the bed and along the banks of the Malir River. Portion of Mahmoodabad, whole Manzoor Colony, Rehman Colony, Kashmir Colony, Liaquat Ashraf Colony, Azam Basti etc. exist on the bed of the Malir River. Similarly the Defence Housing Society has also grabbed some lands which were beds of the Malir River. As a result the width of the river at Qayumabad has reduced to 550 feet instead of its original width of 5000 feet. The same things happen in case of the Lyari River, Gujar Nala, Orangi Nala, Safora Nala, Sukkun Nala etc. The width of these natural water ways become narrow and narrow due to encroached settlements as city is expanding. Therefore urban sprawl on one hand cause of increasing quantity of surface runoff and on the other hand by narrowing water ways the capacity of discharge of rain storm water is decreasing. As a result streets and roads become water ways and city life is paralyzes.

Lack of flood protected embankments along rivers and natural nalas

The city is drained by two main rivers and several natural nalas. But unfortunately no plans were made in the development plans of housing schemes of Karachi Development Authority to make protected flood embankments on the banks of rivers and nalas not only for the safeguard of citizens and also protect beds and courses of natural water ways from land grabbers and encroachers. The only effort was made by the Sindh Government with the help of Federal Government in 1984 to prevent the 1977 flood disaster 12 miles long flood embankments were built on both sides of the Malir River which start from the bridge of the National Highway to the mouth of the river at Gizri creek. There is no doubt that after the construction of the embankments the adjoining areas have been so far protected from the flood situation which happened in 1977 **(Photo 1)**. But the height of the embankments was based upon the surface runoff of 240,000 cusecs which return period is 50 years while the maximum runoff in 100 years is 409,000 cusecs.

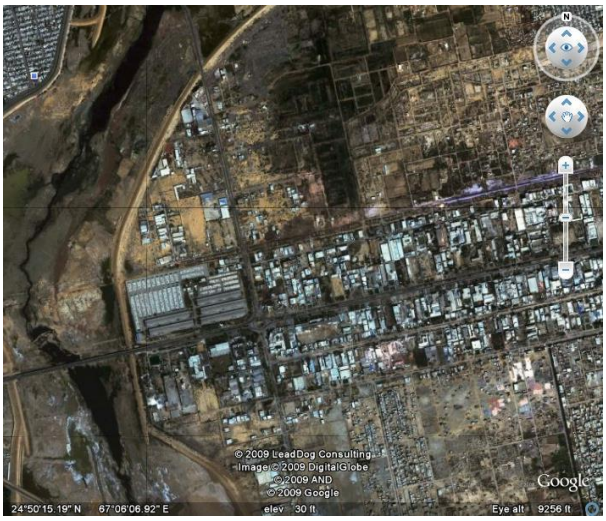

Photo 1: A satellite image of the Malir River Embankments which protect Korangi Industrial Area and residential areas from flood.

Therefore if water discharge in the Malir River exceeds from 240,000 cusecs than flood water may overflow from these embankments. The width of the channel has reduced due to settlements cause future threat of flood disaster. Another scheme of embankments on the Lyari River was made in late 1990s when the plan of Lyari Expressway was prepared. The plan has been delayed due to slow removal of encroached settlements along the river beds. If it's completed than the threat of flood to adjoining areas can be safeguard. However there are no plans of the City Government either made or is executed to build embankments along several natural nalas like Gujro Nala, Safora Nala, Budnai Nala etc. or to protect their courses from land grabbers and encroachers.

Blockage of rain drains and sewerage channels

It comes out from the study that whenever rainfall of 30 mm occur within 12 hours in the city all major roads like M.A Jinnah Road, Shahra-e-Faisal, Sher Shah Suri Road, I.I. Chundrigar Road, Saddar, Guru Mander etc. and roads of residential areas are inundated **.** This meager amount of rainfall becomes a serious problems for commuters because of the poor and overcapacity sewerage and rainwater collection system which has been improved by the City Government in many parts of the city but still needs more attentions.

The first mechanized sewerage system in the British India was initiated in Karachi in 1884 when a scheme was prepared to establish Shone's Ejector System in the old city area to pump sewage to the nearby lands proposed to be developed into sewage farms. Under this system glazed earthen-ware pipes were used, laid down below the surface linked with five ejector stations. The sewage water was pumped to two farms one in the present SITE area and other in Mahmoodabad, located at that time at the fringe of the city. These farms are now abandoned and encroached by land grabbers. Similarly for rainwater open rain drains were constructed in the nearby M.A. Jinnah Road, Soldier Bazar area, I.I Chundrigar Road, Bath Island etc **(Fig. 11)**.

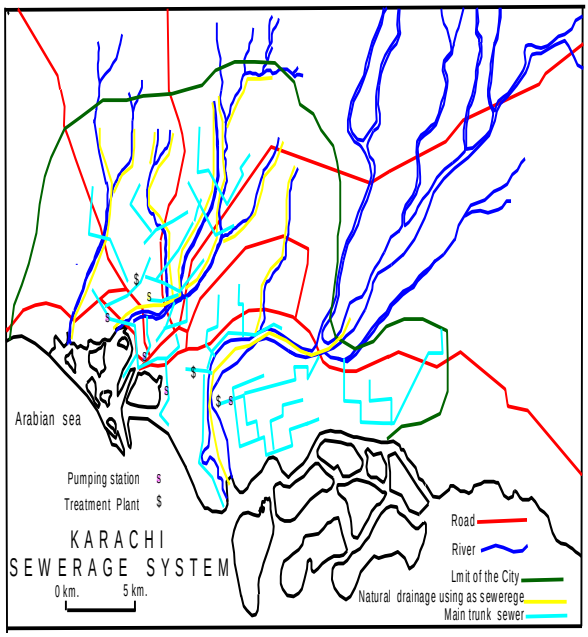

Fig 11: Sewerage system in Karachi

After the creation of Pakistan due to tremendous growth of population in the city, a new Sewage disposal scheme was prepared in 1952. In this scheme the city was divided into four sewerage districts each to have network of trunk and sub-trunk leading toward the two treatment plants. The sewerage District No1 covered the areas of SITE, Qasba Town, Orangi Township, Baldia Township, Rizwia Society, Golimar, Firdous Colony, Nazimabad, North Nazimabad, Jail Road and Central City Area including north of M.A. Jinnah Road. The second district covered the areas of Landhi, Korangi, Malir, Drigh Colony, Mahmoodabad, Defence Housing Society etc. In 1981 it was pointed out that existing system was overloaded and only served 30.02 percent of area and 28.7 percent population of the city. The population using 181 MGD of water generated 120 MGD of sewage but only 20 MGD was treated in two treatment plants. In the Master Plan 2000 of KDA 10 new treatment plants were proposed to build. However two new treatment plants were built up to 2005. As a result of this shortfall of sewerage system in the city the natural water ways started to become the sewage drains which not only pollute subsurface water but also discharge industrial waste water and sewerage water without any treatment into the sea. Sedimentation of these channels as a result of sewage waste and garbage has increased the threats of flood in the adjacent residential and industrial establishments. Similarly the city has been lacking required number of rain drains. There is no doubt that during the period of 2000 to 2009 many new broad rain drains were built but in the old city its number is very few. Similarly the capacity of pumping out the rain water in all under passes of the city is not effective and during torrential rain theses underpasses are closed and present picture of deep lakes **(Photo 2)**.

Photo 2: The newly constructed underpass looks like a lake during torrential rain

Inadequate Street cleaning practice that clogs street inlets

Cleaning of street inlets and rain drains is big problem in the city causes logging and as a result streets are inundated. Millions of rupees are allocated every year for cleaning of rain drains and sewerage inlets especially before the monsoon period (June to Sep.). However the work is done on ad hoc 7bases.

Therefore not all drains are made clean eventually create obstructions for the draining of rain water and due to overflow roads and streets are inundated (KDA, 1984).

Lack of small dams on natural streams

Dams on rivers are considered an important measure to minimize the occurrence of flood. In Karachi the highest discharge of flood water comes through the Malir River and its tributaries. Despite feasibility studies about the proposed dams on the two mainstreams the Khadeji Nadi and the Mol Nadi which mainly contribute water to the Malir River dams have not been constructed. The only small dam was built on the Thaddo River in 1994. Another small dam has been completed on a hill torrent stream in the Sona pass –Hawks Bay area. It is important to construct more and smaller dams on the streams located at the outskirts hilly areas of the city like on the Jarando, Langheji, Watanwari etc. Which ultimately contribute flood water to streams which pass through the densely populated areas of the city.

4. CONCLUSION

The Karachi basin is drained by the two main rivers, the Malir River and the Lyari River and their tributaries. The Mol Nadi, the Khadeji Nadi, the Langheji, the Jarando and the Thaddo are main tributaries which discharge surface runoff and water of hill torrents into the Malir River which flows in the densely populated areas of Karachi City. Similarly the Gujro Nala, the Orangi Nala drain out surface runoff to Lyari River. Both the Lyari and the Malir River drain into the Sea. The capacities of the natural drainage of these two rivers have been affected by sedimentation. Whenever the periods of high tides and high magnitude of rainfall coincide, the sea level rises up and rivers fail to discharge water into sea. The disastrous flood of 1977 was an example of this phenomenon. Urban construction and encroachments along the surface drainage have been intensifying flood problem in the city. Urban sprawl is a big challenge for Karachi city. This growth of urban development has reduced absorption capacity of soil and increase amount of surface runoff. The sewerage and rain drains have same outlets in most part of the city. The natural water channels have now been used as discharge of sewerage and industrial wastewater. Due to lack of planning, monitoring and management the drainage of rainwater and sewerage water either have choked or have encroached by land grabbers.

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