Landuse Changes and their Impacts on Natural Drainage System of Malir River Basin

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***Abstract*— Karachi, a metropolitan city, is facing rapid population growth causing environmental, social and economic stresses and challenges. Beside planned development, unplanned urbanization, urban slums, illegal and informal settlements, and encroachments on natural drains have radically changed landuse and drainage pattern of Karachi. One of the biggest challenges that Karachi is facing now-a-days is localized floods after heavy rain episodes due to increased surface overflow rates coupled with the blockages of natural drains. In Karachi there are two main rivers, Lyari and Malir, which play a major role in draining storm water of the city. At present, these rivers are severely affected by urbanization and bad management that caused blockages at many locations. This paper investigates the changes in landuse and their impacts on natural drainage pattern of Malir River basin over the past 16 years (2000-2015). Geospatial techniques are used to analyze landuse and landcover changes of upper Malir River basin. Satellite derived Digital Elevation Model (DEM) and topographic sheets (1950s) are used to delineate natural drainage pattern of Malir district. Landuse/landcover and river drainage maps are overlaid to identify critical areas where natural river bed has been encroached. Most part of the Malir River basin has been occupied by agricultural fields and urban settlements which caused narrowing of the river and complete blockage at some locations. The blockages shown on the output maps can be utilized for the revival of natural drainage network of Malir River basin. The beneficiaries of this study may include, but not limited to, the urban planners, Sindh development authorities and flood mitigation and management agencies.**

Index Terms*— Flood, Geospatial techniques, Natural drainage, Satellite data, Urbanization

I. Introduction

The world is experiencing the largest urban growth in history with more than half of the world's population living in towns and cities. By 2030 this number will swell to almost 5 billion, with urban growth concentrated in Africa and Asia [1]. Rapid urbanization of mega cities in developing countries has been responsible for not only alterations in the natural phenomena but has posed serious health challenges due to insufficient water and sanitation infrastructures, inappropriate waste treatment and disposal facilities and substandard living conditions. Less privileged communities that migrate to big cities are not only victims of several types of communal diseases but are more vulnerable to natural disasters. Rapid urbanization of a city may alter its natural hydrology giving rise to blockage and frequent flooding of the drains.

Till to date, it was believed that urbanization is one of the causes behind climate change but now it is being observed that this change is badly affecting the urban centers by making them more vulnerable to natural hazards [2]. The extreme weather events like heavy rainfall in short period of time may cause flash floods that can impair transportation, transmission lines and other infrastructure besides public health. With the increase of urbanized and developed areas, land areas become paved and hard which restrict the percolation of water into the ground. In rural areas most of the rain water infiltrates or percolates into the ground which minimizes the surface runoff and raises the ground water table. In urban areas the situation is quite opposite where impervious land surface promotes runoff that may turn into flash floods and destroy everything which comes in its way [3]. After flash floods, water stands in the surrounding area for extended period of time. This stagnant water becomes the production site of mosquitos and other harmful bacteria which cause dengue, malaria and other diseases in the area. Pakistan being a developing country is more vulnerable to these hazards. In a growing city like Karachi, with a current population over 20 million, the need for additional urban lands cannot be disregarded. Although, the allocation of urban zones with better watershed management can largely reduce the above mentioned problems [4].

II. Justification

Water always flows through its natural path where it finds a gradient. If there is any obstruction in its path, it tries to remove it and moves forward. Most of the waterways in Karachi have been obstructed by encroachments of urban settlements, roads, crop field and other structures [5]. When water hits a blocked area, it causes damages in terms of lives and assets. Malir River basin is one of the examples of these blocked waterways where width of the river at many locations is less than 10 meter and at one location it is completely blocked by an agriculture field. Revival of natural drainage network would allow flood water to follow its natural path thus minimizing the damages caused by floods and torrential rainfalls. Sindh Irrigation and Drainage Authority (SIDA) has put a considerable effort in identification and revival of natural drainage network in few districts of Sindh [6]. SIDA has relied mostly on field work for this purpose. Although SIAD's efforts are praiseworthy but the method adopted by SIDA is quite cumbersome that involved intensive budget. Ground data collection is always an expensive and time consuming technique. On the other hand, the use of geospatial techniques, as proposed in this paper, are more precise and time and cost effective.

A. Statement of the Problem

Malir River basin of Karachi is encroached by crop fields, illegal embankment and urban areas and, therefore, flood water cannot drain properly causing destruction in the neighborhood. These blockages slow down the drainage of flood water and cause ponding in the surrounding areas. This situation may adversely affect daily life and health of the inhabitants.

B. Objectives

i. To develop landuse/Landcover maps of Karachi for years 2000 and 2015
ii. To identify landuse/Landcover changes from 2000 to 2015
iii. To classify major landuse/Landcovers that may cause blockages
iv. To identify and map the blocked water ways

III. Study Area

Karachi is the largest metropolitan city of Pakistan with more than 20 million people and population density of 10,000 people per square kilometer. It is the world's largest city by population and 7th largest urban agglomeration [7]. Located on the coast of Arabian Sea, as shown in Figure 1, Karachi is one of the oldest city of Pakistan and has great strategic and economic importance due to the presence of a harbor. It is the financial and commercial hub of Pakistan that contributes around 25 percent in the Gross Domestic Product (GDP) of the country. People from all over Pakistan come here for business and other livelihoods. A substantial increase in the urban area of Karachi during last 30 years has been observed due to these reasons. The city is growing towards north and west directions.

Urbanization is the process of concentrating peoples in a relatively small area. During the process of urbanization,

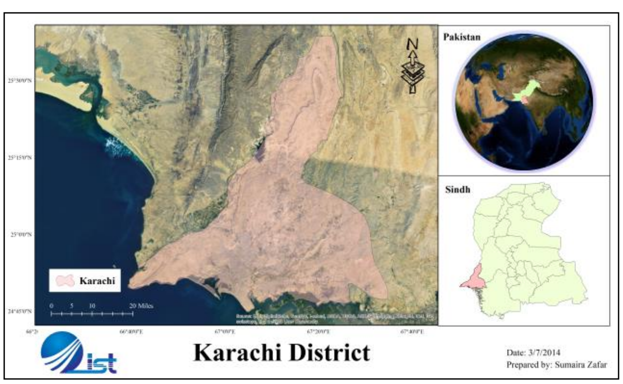

Figure 1: Study area

natural features of an area are disturbed and this situation usually causes serious damages to the society. There are some very generic problems associated with the growing urban centers like need for drinking water, sewerage and sanitation, transportation, disaster management, health facilities, solid waste management, industrial waste dumping sites and many others. Urbanization is also responsible for climate change due to anthropogenic activities. Climate change also impacts urban areas due to unusual extreme weather events like tornados, dust storm and heavy rainfall in a short period of time. In the history of Karachi, a number of floods due to rainfall caused destruction in the city. Table 1 shows a list of some significant floods in Karachi [11]. The highest intensity rainstorm was recorded in 1977.

Table 1: List of Floods in Karachi

S.N.	Flood Date (day-month-year)	Rainy hours	Rainfall (mm)	People killed
1	07-08-1953	24	278.1	--
2	01-07-1977	24	207.0	248
3	na-na-2003	48	284.5	---
4	17-08-2006	--	77.0	13
5	21 to 26-06-2007	--	110.2	228
6	09 to 11-08-2007	--	191.0	21
7	22-08-2007	--	80.0	---
8	18-07-2009	4	245.0	20
9	31-08-2009	--	147.0	---
10	13-09-2011	--	145.0	---
11	na-na-2013	--	150.0	50

na = not available

IV. Malir River system

Malir River basin has total catchment area of about 1,850 square kilometer around south eastern boundary of Karachi (Figure 2). Malir River system consists of two major streams, Mol and Khaddeji, and three tributaries named Konkar, Thaddo and Sukkan. River flows southwards and westwards through Gizri Creek and discharges finally into the Arabian Sea. The central part of the river basin is made-up of sediment deposits comprising coarse conglomerate, sand stone, clay-stone and limestone, whereas, the lower plain is composed of alluvial deposits. In the lower plain, the river is wider and shallower and gets braided. The catchment has a rugged terrain and comprise of rocky waste land covered with sandy soil. Common vegetation in the river basin includes shrub trees and bushes. The lower part of the basin has good grass cover full of orchards and vegetable patches which gradually reduces southwards. Slums are located on both sides of the river with some industrial units. Malir River overflows during the monsoon rainfalls. Storm water stays in the surrounding area for extended period of time due to insufficient drainage which damages the infrastructure and property [5].Disposal of untreated industrial and municipal effluent has also severely contaminated the water of Malir River. This may become a serious health issue since most of this water is used to irrigate crops which are consumed by the citizens of Karachi [8] [9].

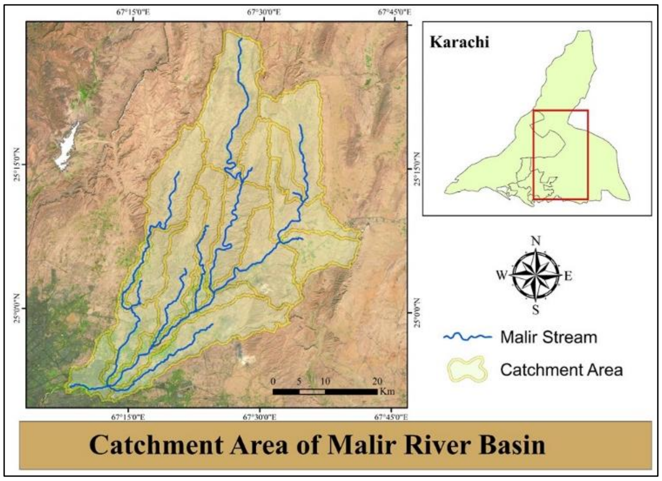

Figure 2: Malir River Basin

V. METHODOLOGY

Remote sensing (RS) data and GIS have been proved to be very efficient techniques for complex geospatial problem solving. Satellite derived information can be used to solve problems at a greater extent. This study utilizes RS and GIS techniques to identify landuse/landcover change and its impact on natural drainage pattern in Malir River basin.

A. Data used for this study

Satellite derived Digital Elevation Model (DEM) along with topographic sheets is utilized for extracting drainage network using geographical information system (GIS) based hydrology tool. Satellite images are used to develop landcover maps of the area. Drainage network is overlaid on landcover map to identify the blockages that cause restriction in the flow of storm water and lead to destruction. Different data sets used in this study are discussed in the following sections.

I. Topographic Sheets

Topographic sheets used in this study were prepared in 1950s after extensive surveys on the scale of 1:50,000 by Survey of Pakistan (SoP). SoP is a national surveying and mapping organization that was Royal Survey of India before the partition of subcontinent of India. Major product of SoP include topographic maps of 1:50,000 and 1:250,000.

II. Landsat 7 and Landsat 8 Satellite Images

Landsat 7 and Landsat 8 images for the months of January 1999 to 2015 (16 images) were downloaded from the internet. Landsat satellite images with spatial resolution of 30 meter and spectral resolution of 7 (or 11 for Landsat 8) bands were used to analyze the change in landuse/landcover (LULC) of the study area. Both Landsat 7 and 8 satellites have panchromatic bands with a resolution of 15 meters. Panchromatic band was merged with low resolution multispectral bands for spatial enhancement of the images. This process is called pan-sharpening through which a high resolution color image is created. In high spatial resolution color image, the major blockages of streams and natural drains can be identified more precisely.

III. DEM (SRTM and ASTER)

SRTM (Shuttle Radar Topographic Mission) DEM is available at global scale with three resolutions; 1 Arc second (30 meter), 3 Arc second (90 meter) and 30 Arc second (1 km). Another global elevation dataset called ASTER (Advanced Space borne Thermal Emission and Reflection) DEM of 30 and 90 meter (1 Arc and 3 Arc second respectively) resolutions are also available free of cost. ASTER data were developed jointly by the U.S. National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). ASTER DEM are produced by stereo images of ASTER sensor. For this study, 1 Arc second (30 meter) DEM of ASTER and SRTM were used to extract stream network of the study area. A comparison of the drainage networks developed by the both datasets was conducted to identify the differences and check their accuracies with the help of topographic sheets.

B. Methods

Topographic sheets of 1:50,000 and 30 meter digital elevation models of SRTM were used to extract stream network and catchment area of Malir River basin as shown in Figure 2. ArcHydro tool of ArcGIS 10x was employed to extract stream network that created a database according to stream name, rank and length (area from toposheets). Preprocessing of DEM removed the pits and saddles. The corrected DEM was used to calculate flow direction, flow accumulation, stream extraction and catchment delineation. Landsat 7 and 8 images for the months of January 2000 - 2015 were utilized to extract LULC of the study area. Major LULCs include urban area, soil, water, agriculture land and mangroves. Streams extracted from topographic sheets were overlaid on LULC of 2000 and 2015 to extract the landcovers and obstructions which are responsible for blockages.

VI. RESULTS

A. Selecting Suitable DEM for Building Drainage Network

Stream network extracted from ASTER and SRTM were compared to check the accuracy of these DEMs. The objective of this assessment was to find out which DEM is more reliable in terms of accuracy and precision for the development of drainage network. Figure 3 shows stream networks of topographic sheets and DEMs. The comparison showed that the stream network extracted from SRTM was fairly accurately overlapped the streams of topographic sheets, whereas, ASTER DEM created network was not in a good agreement with topographic sheets. Some previous studies also confirmed the precision of STRM data in comparison with ASTER DEM [10].

B. Landuse/Landcover change detection (2000 and 2015)

The term *landcover* is used to show the physical land type on the surface of the earth, whereas, *landuse* describes how the landcover is modified. Landcover may generally include; water, snow, grassland, forest, bare soil, etc., whereas, landuse are agricultural land, built up land, recreation area, wildlife management area, etc. Land degradation results mainly due to the population pressure which leads to intense landuse without proper management practices. Overpopulation produces extra burden on civic facilities like drainage, drinking, water, health facilities and residential land areas. Landuse/landcover change for Karachi city was mapped using satellite images of January 2000 - 2015. LULC of the study area extracted from Landsat 7 and Landsat 8 images for 2000 and 2015, respectively, are presented in Figure 4 and 5. These figure show that the urban area increased from 9.7 percent to 21.55 percent of the total land area, agriculture land decreased from 7.35 percent to 5.95 percent of the land area, and vegetation increased from 3.66 percent to 5.25 percent during last 15 years. Percent change values of each landuse/landcover class for 2000 and 2015 are also shown in Table 2.

C. Blockages

Stream network extracted from SRTM DEM was overlaid on Landuse / landcover map of Karachi to identify the blockages. Figure 6 shows three (03) sites with blockages in 2000. The site at the top shows that most of the area is covered by soils and agriculture land. In second site, at middle of the map, agriculture land and urban settlements are present along both sides of the river. Third site, at the bottom of map, is also covered with agriculture land.

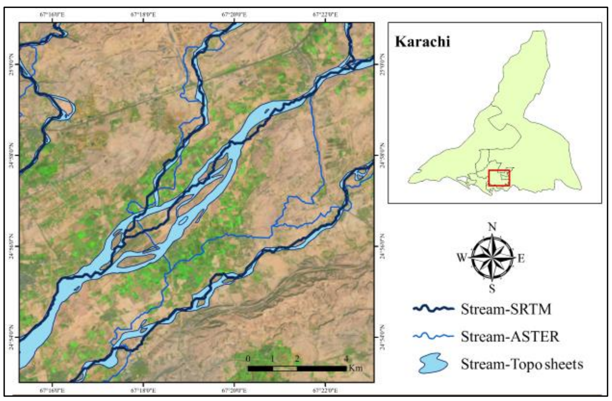

Figure 3: Stream Network Comparison

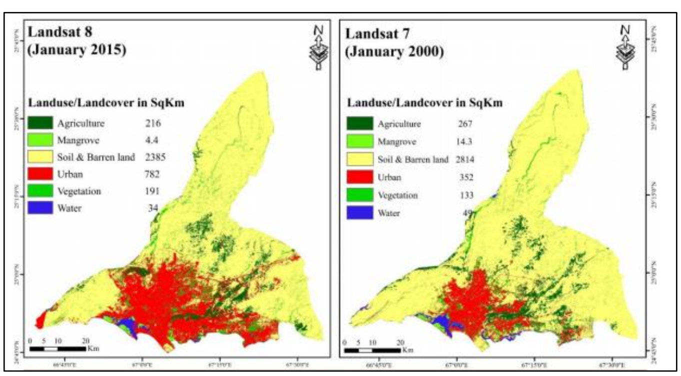

Figure 4: Landuse/ landcover change map

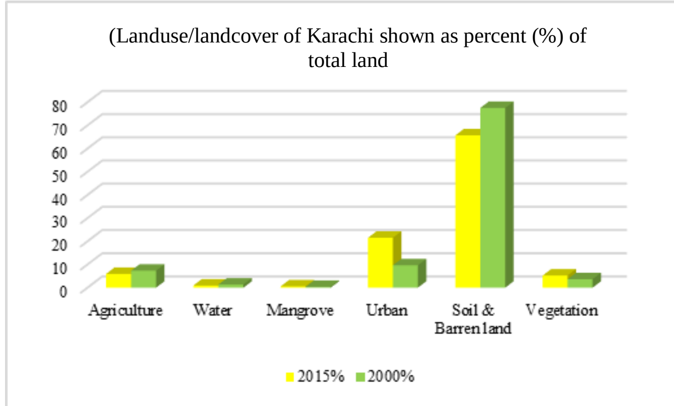

Figure 5: 2000 and 2015 Landuse/Landcover of Karachi

Table 2: Landuse/Landcover Statistics

Landuse/ Landcover	Area 2000 (sqkm)	Area 2015 (sqkm)	Percent of Total area in 2000	Percent of Total area in 2015	Percent Change (2000-2015)
Agriculture	266.79	216.03	7.35	5.95	-19.02
Water	49.18	34.42	1.36	0.95	-30.02
Mangrove	14.02	20.89	0.39	0.58	49.03
Urban	352.01	781.93	9.70	21.55	122.13
Soil/Barren land	2,814.00	2,385.04	77.54	65.72	-15.24
Vegetation	133.00	190.69	3.67	5.25	43.37
Total	**3,629.00**	**3,629.00**	**100.00**	**100.00**	---

Figure 7 and 8 show the recent (2015) situation of the area. In Figure 7, the first site at the top of the map presents that most of the area is urbanized with some patches of agriculture land and a decrease in the soil area. It can be seen in the next two sites (Figure 7) that major agriculture land has been converted into urban settlements although some natural vegetation is also present along the river side. This vegetation grows due to the nutrient rich sewage water which passes through Malir River. This change in landuse/landcover along the river sides has also reduced the width of the river. At many locations, it is less than 3 meter and at some locations it is completely blocked. Figure 8 indicates previously main stream location that is now being used as an agriculture land. From this figure it is obvious that the river is completely blocked at this site. This situation is harmful for the people living along the river sides.

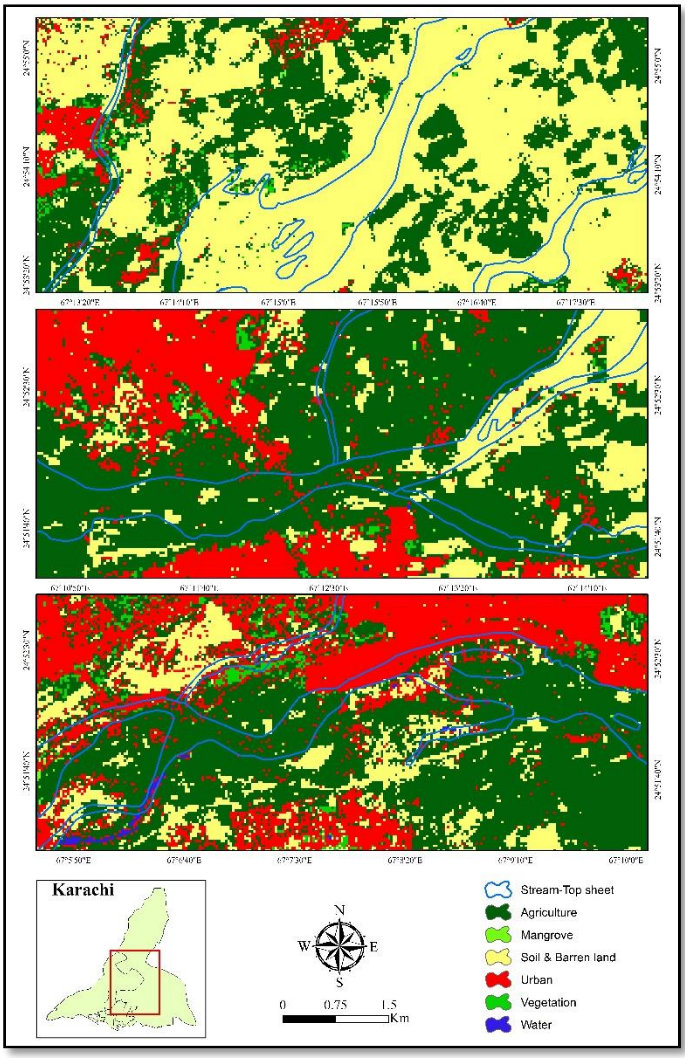

Figure 6: Blockages in Malir River in 2000

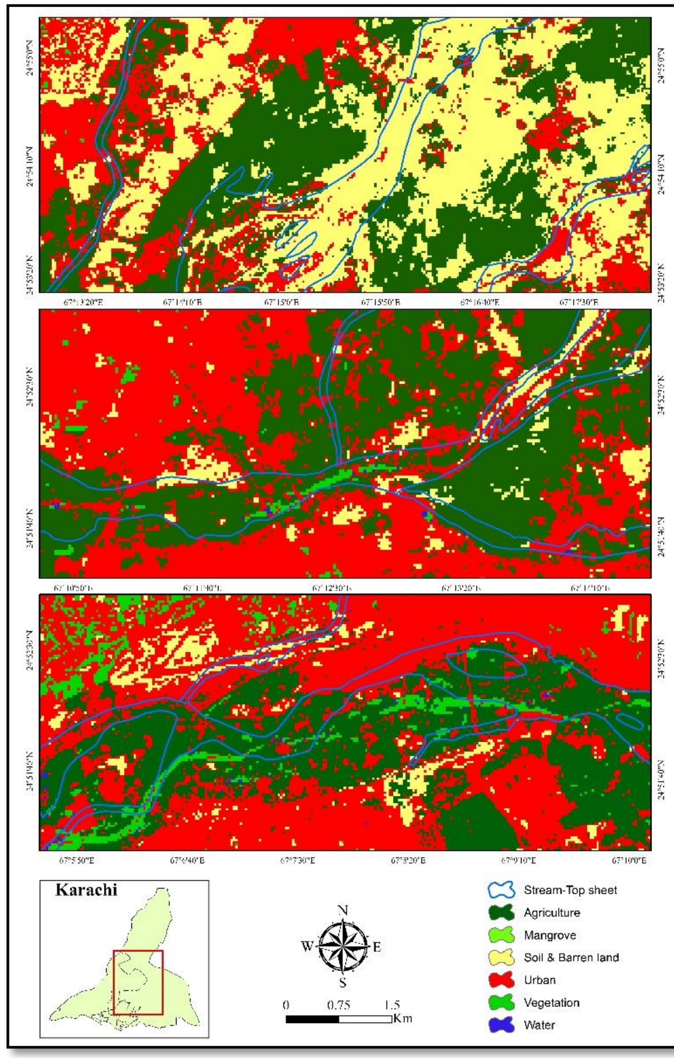

Figure 7: Blockages in Malir River (2015)

D. Validation from field

A field survey of study site was conducted on 1st August 2015. The field visit was arranged in the raining season but due to the less number of rainy hours in the season, the quantity of water in the river was not very significant. Ten (10) sites visited in a single day. Table 3 presents the locations of survey points. Six (6) sites were completely blocked due to agriculture and natural vegetation, one (1) was partially blocked with size of the streams not greater than five (5) meters and only three (3) sites had clear channels. Area near mouth of Malir River was mostly covered with soil and natural vegetation. According to an elderly farmer, who was interviewed (at site# p10), the worst flood situation has occurred in 1977 and after that the authorities made dam walls at several locations along the river.

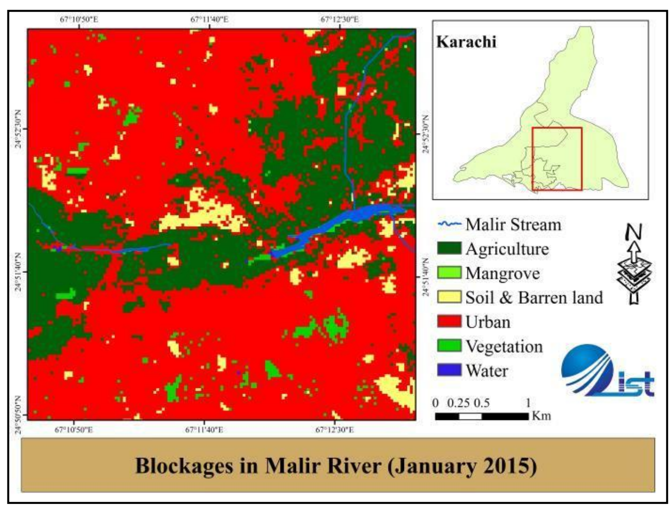

Figure 8: Blockages in Malir River (2015)

Table 3: Blockage in Malir River based on Survey

S.No	Site#	Landcover/Landuse	Geographical position
1	p1	Agriculture and natural vegetation	67° 9' 54.828"E
			24° 52' 17.94"N
2	p2	Agriculture and natural vegetation	67° 9' 59.4"E
			24° 52' 13.728"N
3	p3	Agriculture and natural vegetation (stream width about 5 meter)	67°10'0.12"E
			24°52'12.54"E
4	p4	Agriculture and natural vegetation	67°9'43.416"E
			24°52'16.788"N
5	p5	Near stream (stream width 12 meter)	67°9'31.608"E
			24°52'5.16"N
6	p6	Agriculture and natural vegetation	67°9'16.668"E
			24°52'7.644"N
7	p7	Soil and Natural vegetation	67°5'29.976"E
			24°49'26.832"N
8	p8	Soil and Natural vegetation	67°5'20.184"E
			24°49'57.036"N
9	p9	Soil, Natural vegetation and urban area	67°8'46.968"E
			24°52'11.676"N
10	p10	Agriculture and Urban area	67°9'25.524"E
			24°51'49.896"N

Table 4: Blockage in Malir River and its tributaries based on satellite data

S.No	Rivers of Malir Basin	Blockage Type	Geographical Position*
1	Sukkan Nadi	Agriculture field/Siltation	67°22'24.272"E
			24°57'16.871"N
2	Bazar Nadi	Agriculture/Settlement	67°19'21.075"E
			24°59'2.247"N
3	Jarnado Nadi	Siltation and Agriculture	67°22'33.461"E
			25°0'15.589"N
4	Malir Nadi	Agriculture/Sewage/Siltation/Urban	67°10'18.873"E
			24°51'57.589"N
5	Mol Nadi	Agriculture	67°24'14.539"E
			25°3'33.235"N
6	Khadeji Nadi	Agriculture	67°25'40.299"E
			25°2'31.542"N
7	Thaddo Nadi	Agriculture/Siltation	67°15'40.689"E
			24°58'2.917"N
8	Konkar Nadi	Agriculture	67°14'11.128"E
			25°1'3.743"N[1]
*Coordinate system: WGS 1984 UTM Zone 42N			

CONCLUSIONS

Planned, unplanned development and slum areas have occupied the old Malir River beds which had been inactive due to the short rainfalls in Karachi in the past. Now, due to the change in global weather and climate patterns, extreme events like rainfalls with shorter duration and higher intensity, cyclones and tornados are severely affecting urban settlements which are situated on the floodplains. Even a more serious situation arises when these settlements or agricultural lands are located exactly on the natural waterways blocking them completely. The analysis done in this paper shows the blocked locations in Malir River natural drainage system due to the changes in landuse/landcover of Karachi over the past several decades. Landuse/landcover maps of Karachi are developed for year 2000 and 2015 using satellite data. These maps also show that urban area has swelled causing a substantial decrease in open spaces (barren lands). The unplanned urban area has also disturbed the natural waterways in the area. Houses and other infrastructure are built without any consideration of flood plains and natural drainage pattern increasing the risk of flood related damages due to heavy rains. Agriculture is another culprit in the area that blocked drainage channels at many locations. It is proposed, therefore, that revival of these natural drains should be done with special consideration to the blocked locations as mentioned in this paper. It is hoped that clearing of these drains will reduce the vulnerability of the local residents by mitigating the flood hazard in the Malir River basin.

FUTURE WORK

This study is still in progress. In the next phase, extended field survey of further streams will be conducted to pin point the areas which are severally blocked. Satellite derived rainfall data will be used for flood modeling in the Malir River basin to identify flood zones. The impact of landuse/landcover changes on flood zones will also be evaluated.

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