Monitoring and Measuring Surface Water in Semi-Arid Environment Using Satellite Data: A Case Study of Karachi

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Abstract: Water is a dynamic and precious resource for all living creatures. Its significance is imperative for different sectors of economy at global and regional level. Sustainable use of land resources such as water is vital to carryout fundamental chores and has become an important area of investigation in developing and developed countries. Pakistan is an under developing country with agro-based economy and it is among the top of those countries which are facing acute water scarcity. World Bank has projected that by 2025 severe food shortage could be caused in Pakistan due to water scarcity.

Karachi is the most populous city of Pakistan with high consumption of water and food but semi arid climate conditions and drastic variability in rainfall pattern make it prone to desertification and drought. In Karachi Hydrological drought is closely associated with agricultural drought. Hence, monitoring, quantification and mapping of water is vital for better planning.

This Study is aimed at monitoring spatio-temporal variation of surface water in Karachi using Geoinformatic techniques. For this purpose four satellite images of Landsat -7 ETM + were used. Through NDWI spatial distribution of water and its seasonal variation was observed and maps of water availability in each Union council of Karachi using software ArcMap 10.1 were also developed for the quick and better interpration. Use of modern state of the art Remote sensing data coupled with GIS for the monitoring of land resources has proved very significant for evaluating the potential of resources in different administrative units for planning and decision making.

Keywords: Water Scarcity, NDWI, Hydrological Drought, Spatio-Temporal Data, Quantification, Landsat-7 ETM +.

INTRODUCTION

Pakistan is among the 25 most populous nations of the world which is facing the problem of water shortage and ranked at the top along with South Africa, Egypt which were the most water-limited countries in 2009. There is a severe water shortage threatening in Pakistan; World Bank report, 2000 declares that Pakistan is rapidly moving from being a "water stressed country to a water scarce country" [1]. High population growth coupled with gross variability of rainfall is creating the key environmental and economic issue these days.

In United States a study was conducted by scientist Aiguo Dai, 2010 in collaboration with National Center for Atmospheric Research (NCAR), and it was concluded that "continuous warming of temperatures in associated with climate change will likely create increasingly dry conditions across much of the globe in the next 30 years, possibly reaching a scale in some regions by the end of the century that has rarely, if ever, been observed in modern times" [2].

A report by (IPCC, 2012) has projected that due to Climate Change and upstream diversions there would be 27 percent decline in the annual run-off from the Indus River by 2050 [3]. Reduced flow of water would be a great menace for land productivity of entire lower Indus plains and devastating for bio diversity at Indus Delta as well. In above scenario it is important to evaluate the availability of surface water at regional and local scale to plan different schemes.

The groundwater is also over-exploited and polluted in many areas of the country; most of the water infrastructures (even some of the major barrages) are in very poor conditions. The entire system of water management is not economically and financially sustainable which has direct negative impact on various sectors of economy especially agricultural production. WRI report of 2013 stated that Pakistan is among the countries which are suffering from extreme stress mainly due to arid to semi- arid location continued to be among countries where water scarcity has been projected for 2025 as well [4-5] See Figure **1**.

Pakistan is at the verge of water crises where overwhelming consumption of water for irrigation is required for practicing agriculture. According to United Nation's Economic and Social Commission for Asia and the Pacific, Pakistan ranked 2nd among some highly water stressed countries of Asia (Figure **2**) [6]. Similarly Environment Report of 2005 stated Inverse relationship between Population rise and per capita water availability in Pakistan since 1951 [7]. Refer Figures **3a** and **3b**.

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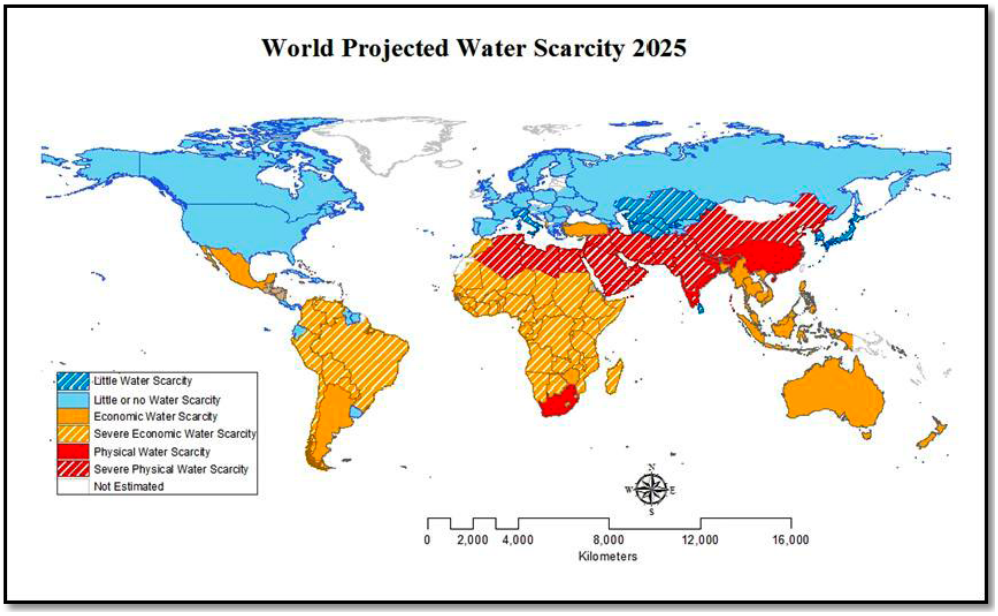


Figure 1: World: Projected Water Scarcity. Source: After IWMI, 2013.

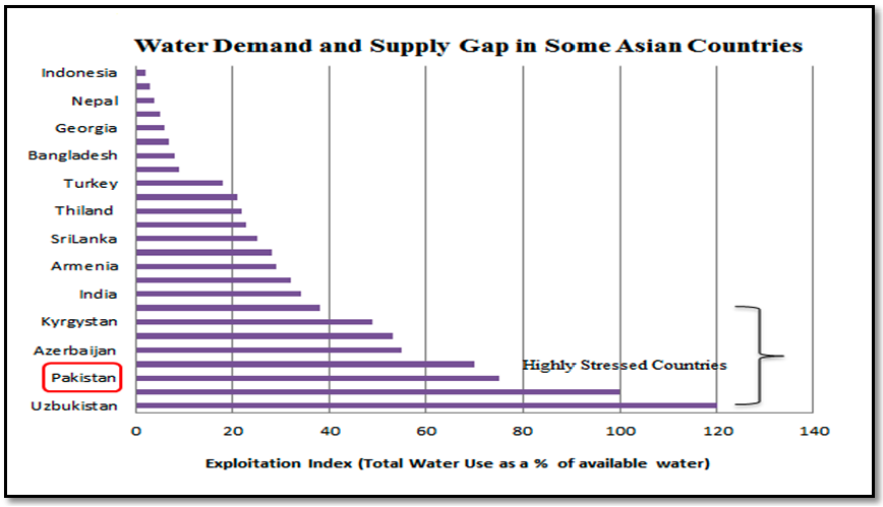


Figure 2: Water Demand and Supply Gap in some Asian Countries. Source: After UN ESCAP, 2012.

In Developed countries Remote sensing and GIS have been widely used as an efficient technology for monitoring and mapping of land resources at various resolution thus benefiting humanity in multiple ways. In Pakistan this technology is also gaining popularity due to its cost effectiveness and quick results for solving real world issues.

In 1996 Gao, introduced Normalized Difference Water Index (NDWI) for determining water content in vegetation based on physical parameters [8]. Previously Hardisky *et al*. 1983, had manipulated Normalized Difference Infrared Index (NDII) for the Landsat TM satellite data which was similar to NDWI and now effectively used to obtain land surface moisture [9]. The value ranges between -1 to +1. NDWI generally represented as

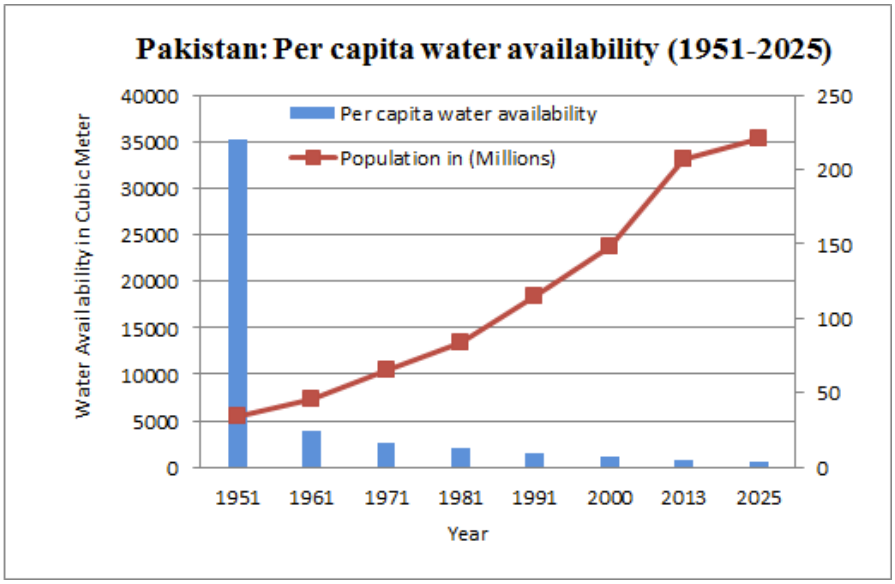
$$NDWI = \frac{R_{NIR} + R_{SWIR}}{R_{NIR} - R_{SWIR}}$$

Where R_{NIR} is the reflectance or radiance in near infra-red channel and R_{SWIR} is the reflectance or radiance in short wave Infrared channel of Landsat-7 ETM+ Multispectral 30 meters resolution image.

Gathering of accurate information about the locations and variations in the extent of water bodies for monitoring and evaluation of land and water resources, flood and drought is very important [10-12]. Several early studies were reported by Smith, 1997

Year	Population in (Millions)	Per capita water availability in m^3
1951	34	35300
1961	46	3950
1971	65	2700
1981	84	2100
1991	115	1600
2000	148	1200
2013	207	850
2025	221	659

a



b

Figure: 3: a) Pakistan: Per capita Water Availability. Source: Environment Report, 2005.

b) Pakistan: Trend of Population Increase and Per capita Water Availability. Source: Authors.

that Landsat data is being used for finding the water bodies extent since 1972 [10-12].

Karachi being located in the arid zone has surface water shortage and its efficient provision to the inhabitants is a challenge for Karachi Water and sewerage Board (KWSB) to bridge the gap between demand and supply (Ihsanullah, 2010) [13]. In Karachi due to lack of surface water barani (rain dependent) farming is practiced at the periphery areas with ground water as the most common source of irrigation. Unreliable and insufficient rainfall compels farmer to bore more wells thus there is noticeable increase in the installation of tube wells has seen to continue farming activities. Sine 1997 approximately 260 tube wells have been installed specially just after low rainfall years that is 1998, 1999 and 2004 (Bureau of Statistics 2011 and Ghazal, L. 2012) [14-15]. Moreover, sprinklers and drip irrigation are also commonly used as efficient modes of irrigation to carryout farming activities in this arid region [16].

Research Objectives

Aims for conducting this study are two folds;

- To measure the availability of surface water using Normalized Difference Water Index (NDWI)
- To monitor and quantify spatio-temporal variation of surface water in Karachi using Geoinformatic techniques.

MATERIAL AND METHODS

Initially relevant literature reviewed on prevailing problem of water crises generally in the world, Pakistan and specially in the study area (Karachi). The prime focus was to unleash the potential of satellite data that

is why applications of remote sensing and GIS techniques were thoroughly reviewed and appropriate data sources and methods were explored to carryout image processing. This Study is aimed at monitoring spatio-temporal variation of surface water in Karachi using Normalized Difference Water Index (NDWI) and quantification of spatial distribution of water resources in Karachi at Union Council level. Four satellite images of Landsat-7 ETM+ 30 and 15 meter resolutions were used due to its high spatial resolution to perform various process.

First of all satellite date of area of interest was geometrically corrected to go through the process of spatial, spectral and radiometric enhancement. Infra red and near infra red bands were seperated from Landsat images to manipulate NDWI. Drainage and land use classified map were also incorporated in order to confirm the NDWI results. classified images used to extract pixel baesd area of target water class in each UC of Karachi. Quantification was done in percentage using Excel. Finally in order to analyze the gathered information and processes in a quick and eye catching way the results of Normalized Difference Water Index (NDWI) and UC based quantification of water for all four satellite data sets were deployed through choropleth Maps using software ArcMap 10.1 for the better interpretation of spatial distribution of water and its seasonal variations. Graphs and table were also produced where necessary for quick understanding. Climate data of Karachi was also utilized as secondary data source to validate the results of seasonal variation in the distribution of surface water as natural factor of water shortage.

Drainage map is also produced for the confirmation of Spatio-temporal variation of surface water, See Figure **4**. Moreover, field visits were also arranged to

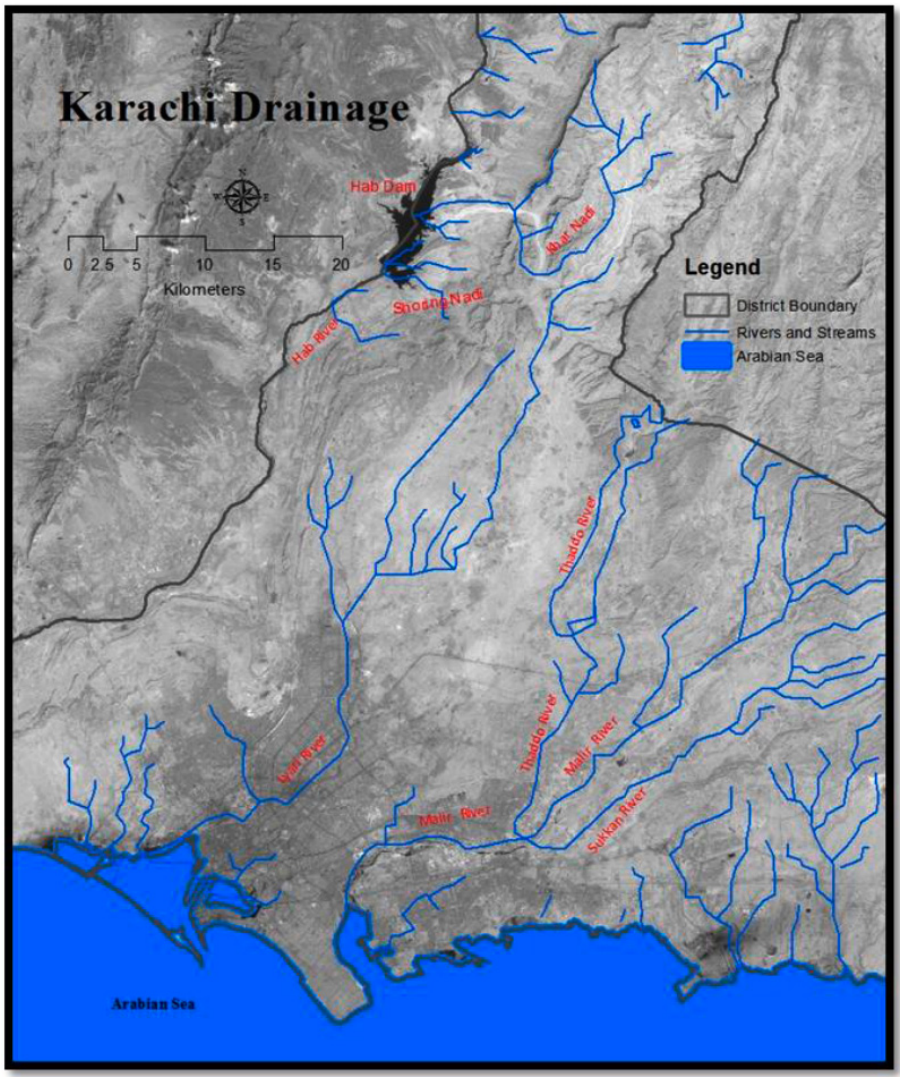


Figure 4: Karachi Drainage Network. Source: Authors.

get the first-hand information from the local people about the situation of water availability for performing agricultural activities.

RESULT AND DISCUSSION

In order to observe the Spatio-temporal variation of water in the study area authors have obtained NDWI using band-4 NIR and band -5 (SWIR) of all four Pre and post monsoon Satellite imageries of Landsat-7. Results of NDWI as depicted in (Figure **6a-d)** and graph Figure **8** shows that generally highest amount of surface water was observed in the reservoir of Hab, then in seasonal rivers and some rain dependent (barani) farming areas located at the west and northern Karachi respectively. Maximum water pixels can be seen on the image of 3rd September 2007 Figure **6c** because it was the time of heavy monsoon downpour, Similarly on 1st March 2003 image Figure **6b** water pixels are clear in Hab reservoir and near seasonal rivers because it was the time just after western depression brings rainfall in the study area; contrary as May and June are the drier months with high temperature least amount of surface water is seen in June 1992 as shown in Figure **6a** and May 2011 Figure **6d** respectively. Above mentioned facts regarding Rainfall and temperature can be validated from the climograph of Karachi Figure **5**, while difference in the range of NDWI can be seen in graph Figure **7**.

Area tabulation of classified image is performed in different classes like vegetation, water open land etc then quantification of RS data into percentage is applied to get the area of pixel to pixel features of the area from the Satellite image. This approach is very important to prove the implication of RS and GIS in water studies. ArcView 3.2 was used to tabulate the area of water in each Union council of Karachi. Results of tabulated percentage of water are portrayed through graph and cumulative choropleth maps for quick visual interpretation Figure **9 a-d**. Seasonal variation of surface water distribution is evident from these maps as these images are of pre and post monsoon period and processed to tabulate pixel by pixel area of vegetation available in each Union council. Spatial and Seasonal Variation in water concentration is seen in all maps but one common fact remains the leading share of UC Gadap in Water due to presence of Hab dam reservoir nearby [15]. The Lowest amount of water is seen in June 1992 image, while maximum is depicted in September 2007 as it was summer monsoon period which is directly correlated with the high surface moisture.

Representation of percent change of Spatial distribution of surface water was quantified and variation of water in some rural UCs is presented in graph to give a clear cut picture of seasonal variations in Figure **8**. Prominently UC Gadap's share in total surface water percentage was the most due to

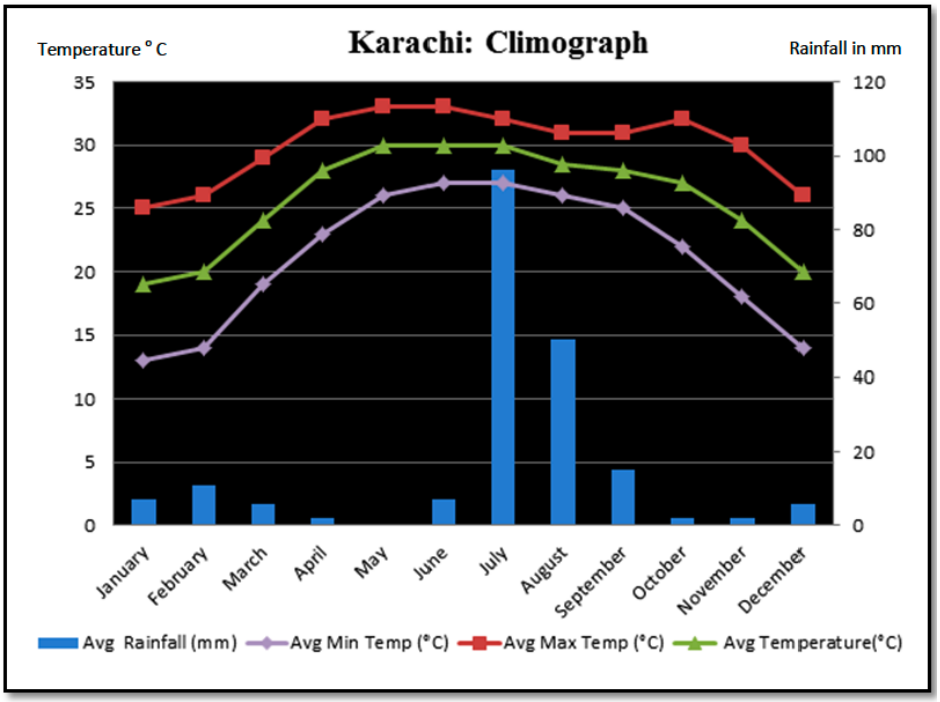


Figure 5: Karachi: Climograph. Source: Authors, 2012.

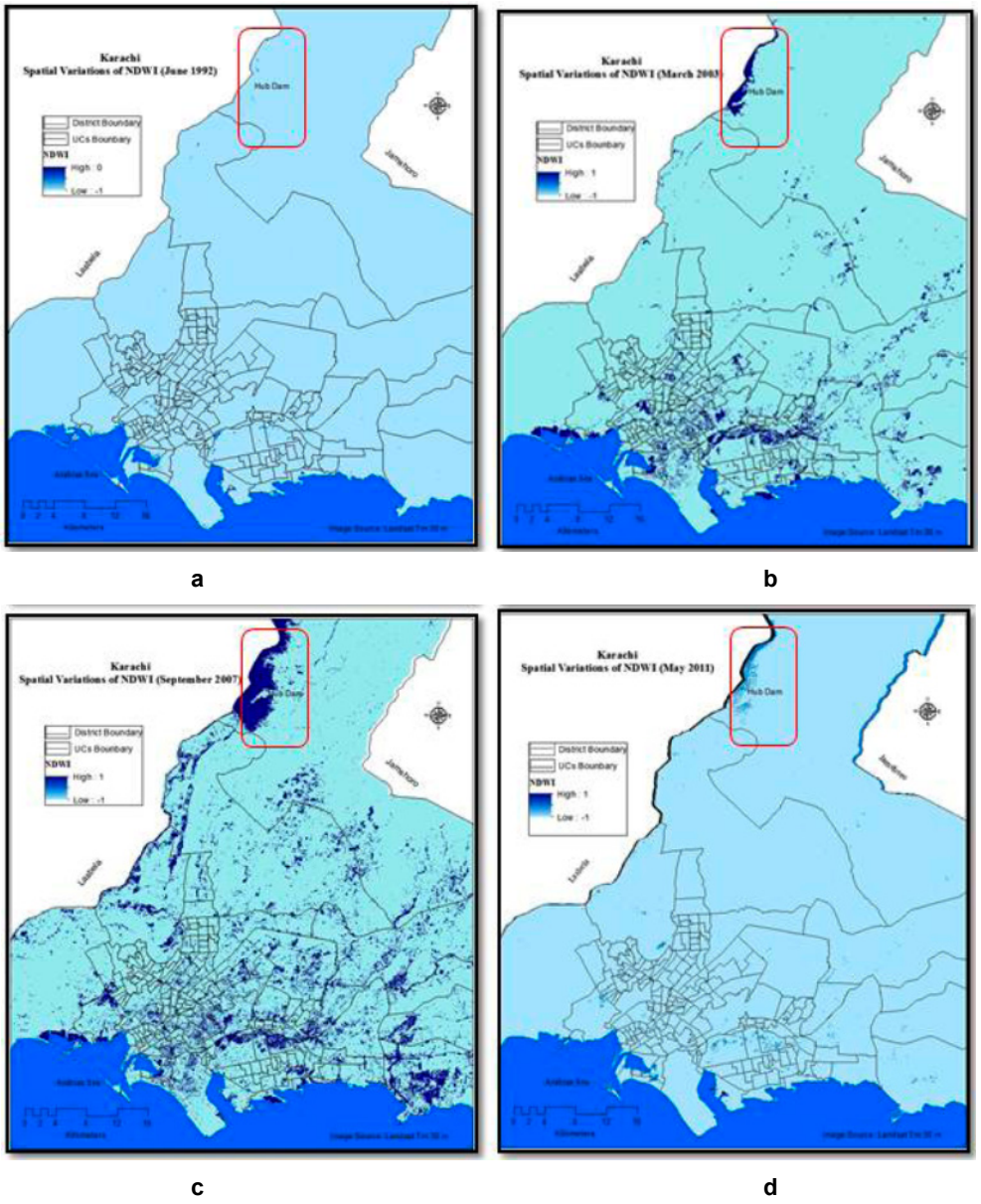


Figure 6: Normalized Difference Water Index. **a**) June 1992. **b**) March 2003. **c**) September 2007. **d**) May 2011. Authors.

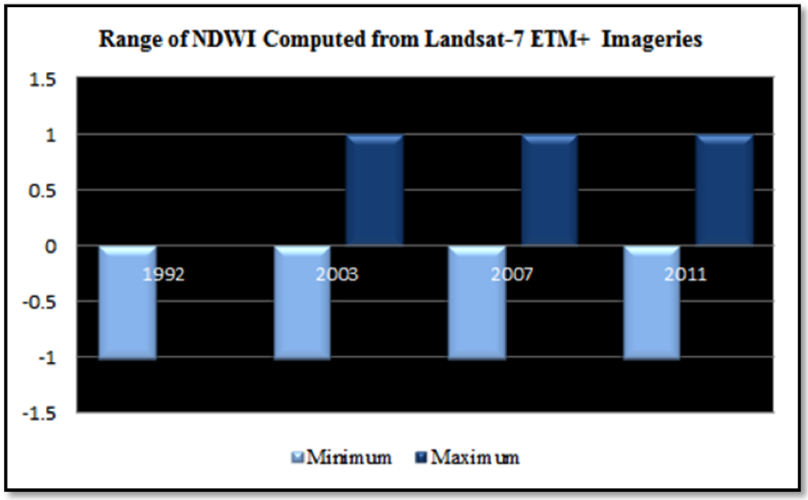


Figure 7: Range of NDWI Computed from Landsat-7 ETM+ Imageries. Authors.

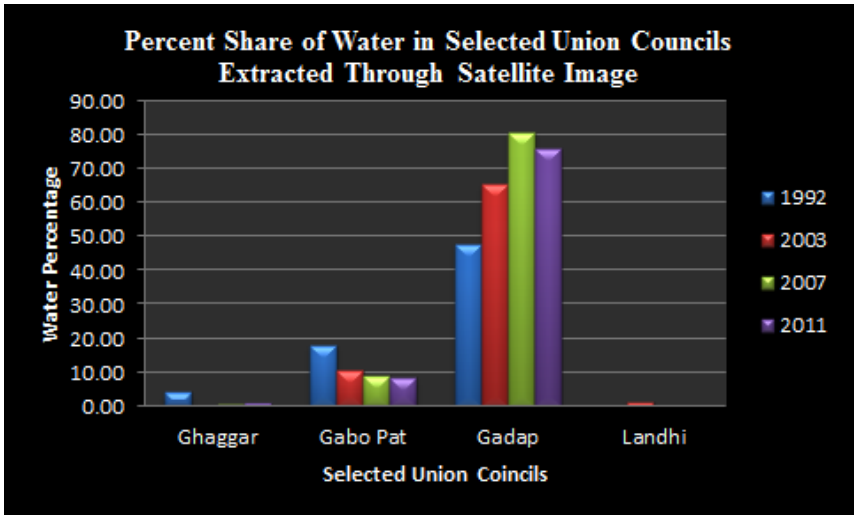


Figure 8: Karachi: Surface water variations in selected Union Councils extracted through Satellite data. Authors.

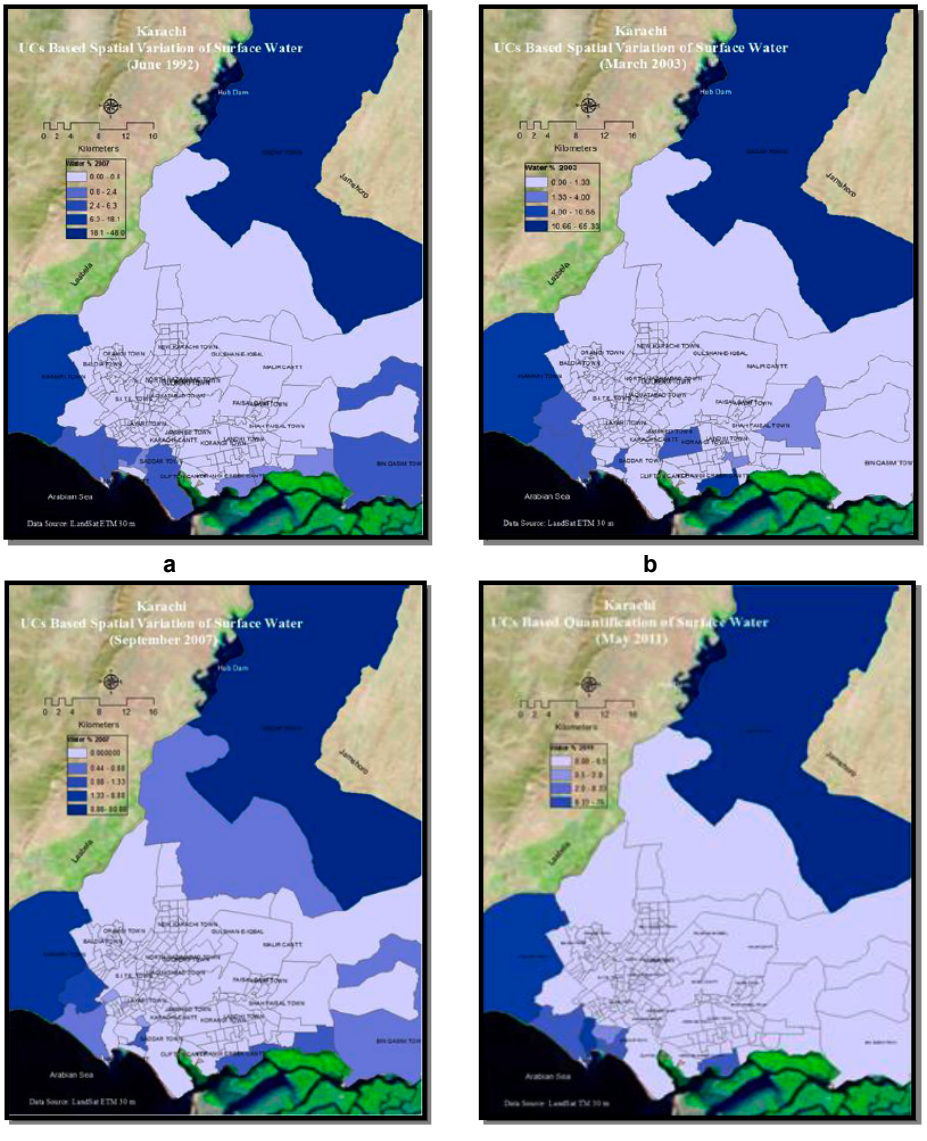


Figure 9: Karachi: Surface Water in Union Councils extracted using Landsat-7 ETM images. **a**) June 1992. **b**) March 2003. **c**) September 2007. **d**) May 2011. Source: Authors.

presence of hab reservoir, followed by Gabo Pat, Ghaggar, Landhi and Sognal. Seasonal changes in the extent of Hab dam reservoir on NDWI maps of the study area are also clearly validating the fact Figure **6 a-d**.

CONCLUSION

Water is a very serious concern in Karachi because all economic activities including barani agriculture is heavily dependent on rainwater. The evaluation of rainwater for current use and future potential is an important aspect for the life of Karachiites. In this paper attempt is made to explore the water potential for the city and it is observed that western and northern sections of Karachi has great water potential but it is heavily associated with proper water management schemes.

This Study clearly proved the potential of Landsat-7 ETM+ data for delineating pixel based surface moisture. Wavelength of Infrared and Near Infrared bands of Landsat-7 sensor is ideal for detecting and differentiating water pixels on satellite image for mapping the variations in extent of water bodies such as Dam, Lake, River etc. Regular monitoring and mapping of surface water at different administrative units is helpful for planning purpose. Quantification in percentage can be based on any administrative unit to assess the past and current availability of water thus future scenario can also be projected.

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