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THESIS

GIS-BASED HYDROLOGICAL DATABASE FOR SITE SELECTION OF DAM PROJECTS IN PAKISTAN

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A Thesis Submitted in Partial Fulfilment of
the Requirements for the Degree of
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The present study presents an approach for management of the hydrological data of Indus River in Pakistan with an aid of Geographic Information System (GIS). The Indus River is the biggest river in Pakistan in terms of its catchment area and discharge carrying capacity. Proper management of hydrological data, which include daily inflows and water levels of the Indus River, is imperative for taming its full potential and the development of the water sector mega projects such as dams. Nevertheless, most of hydrological data are currently maintained in hardcopy format thus making it difficult to be accessed by dam designers, hydrologists, engineers, scientists and researchers. With the availability of today information technology, the data can be converted to digital format and systematically stored in the database management system. The primary goal of this study is to develop the web-based GIS hydrological database system for the Indus River that offers easy accessibility of hydrological data to the data users. The system provides the historical inflows of the river at different gauging sites on daily, monthly and yearly basis as well as the statistical summary including maximum, minimum, average and standard deviation. The system also helps to determine the suitability of site for construction of dam based on the hydrology of Indus River. The system is developed by free and open source software which is a cost effective approach for the developing countries like Pakistan.

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Faris Qazi
April 2009

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

Appendix Table

LIST OF TABLES (Continued)

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure

LIST OF ABBREVIATIONS

AJK	=	Azad Jammu & Kashmir
CSS	=	Cascading Style Sheet
CIDA	=	Canadian International Development Agency
DEM	=	Digital Elevation Model
ERD	=	Entity Relational Diagram
EPSG	=	European Petroleum Survey Group
FOSS	=	Free and Open Source Software
GIS	=	Geographic Information System
GIF	=	Graphic Interchange Format
G & D	=	Gauge and Discharge Data
GML	=	Geography Markup Language
GTZ	=	German Agency for Technical Cooperation
GOP	=	Government of Pakistan
HTML	=	Hypertext Markup Language
IBIS	=	Indus Basin Irrigation System
IIS	=	Internet Information Server
JDBC	=	Java Database Connectivity
JPEG	=	Joint Photographic Expert Group
KDP	=	Kalabagh Dam Project
KML	=	Keyhole Markup Language
MAF	=	Million Acre Feet
MIS	=	Management Information System
MSL	=	Mean Sea Level
NWFP	=	North West Frontier Province
OGC	=	Open Geospatial Consortium
PHP	=	Hypertext Preprocessor
PNG	=	Portable Network Graphics
PMF	=	Probable Maximum Flood
UML	=	Unified Modeling language

LIST OF ABBREVIATIONS (Continued)

RSS	=	Really Simple Syndicate
RDBMS	=	Relational Database Management System
SPD	=	Survey of Pakistan datum
SQL	=	Structural Query Language
SRS	=	Spatial Reference System
SVG	=	Scalable Vector Graphics
SHYDO	=	Sarhad Hydel Development Organization
WAPDA	=	Water and Power Development Agency
WGS		World Geodetic System
WMS	=	Web Map Service
WFS	=	Web Feature Service
WebCGM	=	Web Computer Graphics Metafile
WRPs	=	Water Resource Projects
XML	=	Extensible Markup Language.

GIS-BASED HYDROLOGICAL DATABASE FOR SITE SELECTION OF DAM PROJECTS IN PAKISTAN

INTRODUCTION

Pakistan is located in South Asia with an area of 340,403 square miles (881,640 km²) and the population is about 172 million. Figure 1 shows the location map of Pakistan.

Figure 1 Location Map of Pakistan

Source: Asia Society (2007)

Water resources in Pakistan are unevenly distributed spatially and temporally. Idiosyncrasies of monsoon and diverse physiographic conditions lead to unequal distribution of water. Over the years, increasing population, urbanization and expansion in agriculture has accentuated the situation. The country is near the conditions of chronic water stress. Per capita availability of surface water has been gradually dwindling in Pakistan from 5,300 m^3 in 1951 to 1,300 m^3 in 2002. It is projected that by 2012 per capita availability of surface water may hit 1000 m^3, which puts Pakistan in the category of a high stress country. Presently, the available water from surface water resources can meet only less than 40% of the requirements.

The agrarian economy of Pakistan pre-dominantly depends on availability of water. Since agriculture is the major user of water, therefore sustainability of agriculture depends on the timely and adequate availability of water. Rainfall, glacier and snow-melts resulting in river flows and groundwater are the major sources of available water in Pakistan. Historically, the high aridity index of the country is adding further to the significance of water in developmental activities in Pakistan. Although about 88 per cent of water is used in the agriculture sector, the industry, commerce and public health are also greatly affected by the quantity and quality of the available water. Pakistan's economy mainly depends upon agriculture. It is the single largest sector and accounts for 24 percent of the GDP and employs 48.4 per cent of the total workforce. Water sector industry of Pakistan is the largest enterprise accounting for approximately $300 billion of infrastructural investment and contributing about 25% to the country’s GDP. As a result, Pakistan now has the largest contiguous irrigated area of the world developed over the past 140 years. The Indus River Basin System in Pakistan has three multi-purpose dams, nineteen barrages, twelve link canals and forty-five independent main canal commands.

The population on the other hand is increasing rapidly with a growth rate of 2.7% and was reported 148.72 million in 2004 and may reach up to 208.06 million in year 2025. Food grain production in the country shows shortfall with respect to its requirements. A recent study shows that food grain requirement will increase to 40 million tons in the year 2025 against a current supply of about 20 million tons. Major factors limiting the yield are considered to be inadequate availability of irrigation water at farm gate, unreliability and inequity in water supplies. The extended drought during recent years reduced fresh-water supplies of the country, which has highlighted the importance of development of new sources and adopting water conservation measures for extremely sensible use of the finite quantity of water. Thus efficient management/utilization of water resources is indispensable for the sustained development of agriculture in Pakistan.

Hydropower is the cheapest and environmentally cleanest way for generating electricity. Its abundant potential in Pakistan can provide great opportunity to generate low cost electrical energy, hence lowering the oil import bills of Pakistan.

Statement of the problem

The Indus River is the lifeblood for most of the economic activity in Pakistan. A continually increasing population and demand to grow more food is forcing the Government of Pakistan (GOP) to construct new dams on the Indus River on sustainable bases. Therefore, GOP is planning to undertake new construction of dams to meet the need.

The water availability plays an important role in the selection of suitable sites for the construction of dams. Hydrologists, dam designers and engineers use the water availability data including water level and discharge, to support their decision makings in designing various structural elements of dam including height of dam, spillway gates, energy dissipation arrangement, turbines and power house.

The discharge in the river is usually measured with the help of the water level gauge. The gauge is placed in the river closed to the bank. The gauge meter personnel records the readings usually around six in the morning on daily basis. The discharge in the river is then calculated depending on water level by using a rating curve, which represents the relationship between water level and discharge in the river. The gauge as well as rating curve is calibrated regularly by hydrologists corresponding with the change in cross section of the river and its water velocity. The data compiled in this way is commonly known in Pakistan as the gauge and discharge (G & D) data.

The upper catchment of the Indus River, which is mostly hilly terrain, has a huge potential for the development of many dams. Furthermore there are a number of

G & D sites along the river, which collect G & D data on daily bases. Nevertheless, the G & D data is currently not compiled in a digital form. Most historical G & D data are available in hard copy, which makes it difficult to access the information. With the availability of today information technology, the data can be converted to digital format and systematically stored in database management system. The dam designers, hydrologists, engineers, researchers as well as other people can easily use the information to support their decision makings for the development of dams on Indus River in Pakistan. In addition the system can also help to tackle other water resources issues like controlling flood and drought conditions in Pakistan.

OBJECTIVES

The primary goal of this study is to develop the GIS-based hydrological database system for the G & D data of the Indus River. The objective of this study includes:

1. Convert historical G & D data to digitalized format.

2. Design and develop G & D database.

3. Design and develop web based GIS system to publish G & D data.

Scope

The study focuses on the existing G & D sites in the upper catchment area of the Indus River in Pakistan. The database includes historical daily water level and discharge data for the past two years.

LITERATURE REVIEW

1 Water Resources of Pakistan

1.1 Introduction

Water is essential for sustaining quality of life on earth. The agrarian economy of Pakistan pre-dominantly depends on availability of water. Since agriculture is the major user of water, therefore sustainability of agriculture depends on the timely and adequate availability of water. Rainfall, glacier and snow-melts resulting in river flows and groundwater are the major sources of available water in Pakistan. Historically, the high aridity index of the country is adding further to the significance of water in developmental activities in Pakistan. The situation indicates that the country is near the conditions of chronic water stress. Presently, the available water from surface water resources can meet only less than 40% of the requirements. Crop yields in Pakistan are much lower than that of many parts of the world with similar agro-climatic conditions. For example, the cereal production per m^3 of irrigation water at 0.13 kg is lower as compared to 0.39 kg in India, 0.82 kg in China, 1.56 kg in USA and 8.22 kg in Canada.

The extended drought during recent years reduced fresh-water supplies of the country, which has highlighted the importance of development of new sources and adopting water conservation measures for extremely sensible use of the finite quantity of water. Thus efficient management/utilization of water resources is indispensable for the sustained development of agriculture in Pakistan.

1.2 Water Resources Potential

The water resources of Pakistan include surface water, rainfall, and groundwater. The extent of availability of these resources is location specific. A brief description of water resources of Pakistan is given in the following paragraphs.

1.2.1 Rainfall

Rainfall in Pakistan is markedly variable in magnitude, time of occurrence and its aerial distribution. However, almost two-thirds of the rainfall is concentrated in the three summer months of July-September. The mean annual precipitation ranges from less than 100 mm in parts of the lower Indus plain to over 750 mm near the foothills in the upper Indus plain and even up to 2000 mm in some northern areas of the country.

There are two major sources of rainfall in Pakistan: the monsoons and the western disturbances. The relative contribution of rainfall in most of the canal commands is lower compared with the two other sources of irrigation water i.e. canal water and groundwater. More than 60% of the kharif season (summer or monsoon season) rainfall is concentrated in the month of July for almost all of the canal commands. The monsoons originate in the Bay of Bengal and usually reach Pakistan, after passing over India, in early July. They continue till September. The Indus plains receive most of their rainfall from the monsoons. There are two periods of thunderstorms in Pakistan (1) April- June (2) October-November. These periods are the driest parts of the year, particularly October and November. During this time, thunderstorms caused by convection bring sporadic and localized rainfall.

As Pakistan lies in an arid and semi-arid climate zone, the entire Indus plains (canal command areas) receive an average seasonal rainfall of 212 mm and 53 mm in the kharif (summer) and rabi (winter) seasons, respectively. The rainfall varies as it moves from the north and northeast to the south of the country.

It is only the canal command areas in the North-West Frontier Province (NWFP) and the northern canal commands of the Punjab province that receives some appreciable amount of rainfall during the summer as well as in the winter season. The canal commands upstream of the rim stations (i.e. in the NWFP) receive almost 55% of their annual rainfall during the kharif season. The canal commands in the upper and lower Indus plains receive 75% and 85-90% of the annual rainfall respectively, during the kharif season. The annual variability of rainfall increases as one move towards South. The canal command areas of Guddu and Sukkur barrages fall in an area where variability is the highest. Contribution of rainwater to crops in the Indus Basin Irrigation System (IBIS) is about 13.36 Million Acre Feet (MAF), which is around 10% of the mean annual river flows.

1.2.2 Glacier

The catchment area of the Indus Basin contains some of the largest glaciers in the world, outside the polar regions. The glacial area of the upper Indus catchment is about 2,250 km^2 and accounts for most of the river runoff in summer. The Kabul River, which is mainly snow-fed, originates from the Unai pass of the southern Hindukush at an elevation of 3,000 m above mean sea level (msl). It drains eastern Afghanistan and then enters Pakistan just north of the Khyber pass. The Jhelum River rises in Kashmir at a much lower elevation than the source of the Indus River. It falls much less rapidly than the Indus River after entering Pakistani territory. The Chenab River originates in the Himachal Pardesh in India, at an elevation of over 4,900 msl. It flows through Jammu in Indian-held Kashmir and enters Pakistani territory upstream of the Marala barrage. The snow and ice melt from the glacial area of the upper Indus catchment supply approximately 80% of the total flow of the Indus River in the summer season.

The annual flows in the Kabul River are less than one-third of that in the Indus River. However, the Kabul River starts to rise approximately a month earlier than the main stem of the Indus. Its flows are of significance for fulfilling the late-rabi early-kharif (March to May) irrigation requirements of the canals. Snow-melt accounts for more than 50% of the flow in the Jhelum River. However, the Jhelum is much more dependent than the Indus on the variable monsoon runoff. Both, the Jhelum and Chenab River catchments can simultaneously be influenced by the monsoons. Since the Chenab River rises at higher altitudes, snow-melt accounts for a considerable proportion of its runoff.

1.2.3 Surface water

Incident precipitation and river flows are two major sources of surface water used to meet requirement of agriculture and other sectors. The surface water resources of Pakistan are based on Indus River and its tributaries. As Pakistan possesses the world's largest contiguous irrigation system commonly called as Indus Basin Irrigation System (IBIS). It commands about 14.3 million-hectare (Mha) and encompasses the Indus River (with its eastern tributaries of Jhelum, Chenab, Ravi and Sutlej and northern/western tributaries of Kabul, Swat, Haro and Soan). Three large reservoirs (Tarbela, Mangla and Chashma), 23 barrages/headworks/siphons, 12 inter-river links and 44 canal commands extending for about 60,800 km to serve over 140,000 farmer operated watercourses. The inflow to these rivers is mainly derived from snow and glaciers melting and rainfall in the catchment areas of the Himalayan mountains and the Hidukush. Presently, the available water from surface water resources can meet only less than 40% of the requirements. As a result of the Indus Water Treaty in 1960, Pakistan was constrained to the right of the waters of the Indus, Jhelum and Chenab, while the rights of Ravi, Sutlej and Bias were given to India. Pakistan remodeled its irrigation system through construction of reservoirs, barrages and link canals. As a result of the Indus basin development, the river water diversions for irrigation were increased by 15-20% and cropping intensity almost doubled.

Pakistan's land resources are more than the available water resources. Of the total area of about 79.61 Mha of land nearly 31.16 Mha are culturable. The total cultivated area for agriculture is about 21.1 Mha. Out of this, 16.2 Mha are irrigated through canal and groundwater resources.

Average annual budget of water in Pakistan is given in Table 1. At present, average annual river flows is 144 MAF (177.624 billion cubic meters) but due to lack of storage structures and seasonal variability only 104.7 MAF are being diverted at canal headworks to irrigate over 14.6 Mha. Thus more than 25% river water flows to sea annually. Of this, 67.11 MAF on an average are diverted during the kharif period, while 37.63 MAF are diverted during the rabi period. During the kharif periods of the last ten years, Punjab used 34.3 MAF annually; while Sindh and Baluchistan used 31.4 MAF and NWFP used 2.35 MAF. During the rabi periods of the last ten years, average .Withdrawals by Punjab, Sindh/Baluchistan and NWFP were 19.87 MAF, 16.06 MAF and 1.46 MAF, respectively. A further 49 MAF is pumped annually from the groundwater reservoirs, of which more than 90% is used for irrigation.

Table 1 Average Annual Budget of Water in Pakistan (Cheema, 2006)

		Water Budget of Pakistan (MAF)
River inflow		144
Escape to sea		39.4
Canal water diversion		104.7
Transmission losses		25
Delivery at water course		
	Surface water	79.7
	Ground water	49
Total		128.7
Distribution losses in water courses		22.25
Delivery at farm gate		106.45

Flows of the Indus and its tributaries vary widely from year to year and within the year. As is the case with the water availability, there is significant variation in annual flows to the sea. The average annual flow rates of major rivers has been calculated between 1922-61 to indicate water flows before the Indus Water

Treaty, 1985-1995 to indicate the post-Treaty flows and the 2001-02 flows to present the current situation. These are presented in Table 2.

Table 2 Average Annual Flow-Rates of Major Rivers (Cheema, 2006)

River	Average Annual Flow (1922-61) MAF	Average Annual Flow (1985-95) MAF	Average Annual Flow (2001-02) MAF
Indus	93	62.7	48.0
Jhelum	23	26.6	11.85
Chenab	26	27.5	12.38
Ravi	7	5.0	1.47
Sutlej	14	3.6	0.02
Kabul	26	23.4	18.9
Total	189.0	148.8	92.62

Outside the Indus Basin, there are smaller river basins. One is the Mekran coast in Baluchistan, drains directly into the sea and a closed basin (Kharan). The total inflow of these basins is less than 4 MAF annually. The Khirthar and Pat Feeder canals of the Indus Basin System and Lasbella canal feed the major area under irrigated agriculture from the Hub dam. Another important source of surface water is the floodwater that flows through the streams. Around 30% of the floodwater is harnessed for agriculture through Sailaba diversions, storage dams and minor perennial irrigation schemes.

1.2.4 Rainfall

The cropped area of Pakistan consists of 20.9 Mha, of which 4.8 Mha (24.4%) is rainfed and concentrated in Pothwar uplands, salt range, northern mountains and northeastern plains.

Mean monthly rainfall varies from 85-200 mm in summer and 30-50 mm in winter (Jan-Feb). The Pothwar Plateau mainly comprises of districts Attock, Rawalpindi, Chakwal, Jhelum and Mianwali. This zone is entirely dependant on rainfall and is characterized by diverse and complex agriculture, reflecting the interaction of land type, soil type, rainfall variability, and socio-economic factors in farmers' management. In these rainfed areas almost 60% of the total rain is received during summer (June- September) and 40% during winter (October-May). Cropping intensity is considerably low during the summer season because most land is left fallow as a soil water storage measure for winter crops.

Most of the agricultural soils have developed from wind and water transported material comprising of loess, old alluvial deposits, mountain outwash and recent stream valley deposits. Their texture mostly varies from sandy to silt loam and clay loam comprising from poor to fertile lands. The plateau has a flat to gently undulating surface broken by gullies and low hill ranges. About 60 % of the land area has been highly eroded leaving the rest as a flat land which constitutes the main cultivated area. Only 4% of cultivated area is irrigated, while 96% is under rainfed agriculture. The irrigated farming system is currently practiced on a relatively much smaller scale from small and mini dams and tube-wells. A natural lake namely Namal lake is located in the extreme southwest of Pothwar. Part of water from this lake is pumped for irrigation of adjacent areas but most of it is conveyed through a tunnel through the Salt range to irrigate lands near Mianwali. The major rainfed crops grown in Pothwar are wheat, gram, groundnut, millets, sorghum, oilseeds and fodders. Maize and sunflower are grown on higher rainfall areas. Vegetables and orchards are grown where access to cities and irrigation water from dams and tube-wells are available.

Very little of natural vegetation remains except at a few protected and inaccessible areas while most of the area is prone to unchecked grazing.

1.2.5 Groundwater

Because of scarce canal water supplies in most of the irrigated areas, groundwater has become an additional and indispensable source of irrigation water. Since the introduction of tube-well pumping in 1960, the use of groundwater has been consistently increasing. The number of tubewells in Pakistan has increased from 32,524 in 1965 to over 700,000 in 2004. From the perspective of groundwater use, it is estimated that about 49 MAF of groundwater is annually abstracted for irrigation use and for domestic water supplies from the total ground water potential of 55 MAF. Thus the groundwater is contributing to the irrigation system as a supplement source of water. The total province-wise available ground water potential and withdrawal is given in Table 3.

Table 3 Ground Water Potential and Withdrawal in Pakistan (Chaudhry *et al*., 2002)

Total groundwater potential (MAF)	55.0
Withdrawals (MAF)	
Punjab	44.0
Sindh	2.5
NWFP	2.0
Baluchistan	1.0
Present groundwater withdrawal (MAF)	49.0

In Baluchistan, groundwater, extracted through dug wells, tube wells, springs and karezes (underground channels), is the main dependable source of water for irrigation of orchards and other cash crops. This is because almost all the rivers and natural streams are ephemeral in nature, with seasonal flows only. It is estimated that, out of a total available potential of about 0.9 MAF, 0.5 MAF is already being utilized, thereby leaving a balance of 0.4 MAF that can still be utilized.

1.3. Future Water Needs and Availability

Future water needs for irrigation and non-irrigation sectors were computed for 2010. The irrigation sector includes water needs for agriculture, farm forestry, aquaculture, livestock, and wetlands. The non-irrigation sector includes largely the domestic and industrial water needs. Present and future water needs and availability is presented in Table 4.

Table 4 Pakistan Water Requirements and Availability, 2000 and 2010 (Chaudhry *et al*., 2002)

Requirement/Availability (MAF)	Year	
	2000	2010
Net water requirement		
Net irrigation water requirement	81.01	91.79
Net non-irrigation water requirement	5.91	8.67
Total net water requirement	86.92	100.46
Net water availability		
Mean annual canal diversions	104.7	104.7
Canal water availability for consumptive use	36.37*	41.56**
Groundwater availability for consumptive use	40.51	40.51
Total surface and groundwater availability	76.88	82.07
Shortfall	10.04	18.39

*Based on 79, 60 and 75% of canal, watercourse and field application efficiencies.

**Based on 85, 65 and 80% of canal, watercourse and field application efficiencies.

1.3.1 Irrigation water needs

Net irrigation water requirement for crops in Pakistan is about 81.01 MAF for the year 2000. Rainfall was disregarded in estimating net irrigation water requirements, but it was assumed that a 10% contribution of rainfall in the basin is required for leaching to maintain the salt balance in the root zone. The agriculture growth rate targeted by Ministry of Food, Agriculture and Livestock for the next decade (2000-2010) is estimated as 5% per annum. This would be achieved through increasing the cropped area by 0.5% per annum and raising productivity by 4.5% per annum for the next decade. The increase in cropped area of 0.5% per annum can be achieved by providing additional water to increase cropping intensity in irrigated area of the Indus basin. Increased availability of additional water will be mainly through saving water from existing losses; new storage reservoirs will not be available during the next decade, even if the construction started now. Instead there will be reduced available storage capacity in the basin due to continuous sedimentation of the Tarbela and Mangla reservoirs. The storage loss by the year 2002 due to sedimentation of the Trebela dam was 3.03 MAF, the Mangla dam 1.18 MAF and the Chashma barrage 0.37 MAF with a total loss of 4.58 MAF which is 25 % of the original storage capacity of 18.37 MAF. This may further decline by 6 MAF by the year 2010 which is virtually equal to the original storage capacity of 5.9 MAF of the Mangla dam constructed in 1967 and nearly equal to the storage capacity of 6.1 MAF of the purposed Kalabagh dam. Increased productivity of 4.5% per annum would also require more reliable and adequate availability of water. Additional water requirement will be about 1% (1.02 MAF) of existing canal supplies per annum. Current mean annual canal diversions to the Indus command area is 104.7 MAF. Additional canal supplies required to meet 5 percent growth in agriculture and to meet annual loss of live storage capacity of existing reservoirs due to sedimentation comes to 1.56 MAF.

For the next decade, the additional irrigation water required to achieve required growth in agricultural production is 10.8 MAF (based on 1.02 MAF per annum), which is a considerable amount of water. Systematic efforts are needed to find new resources of water through improved management of water in the Indus basin and areas outside the basin. The future net irrigation water requirement for crops for the year 2010 is 91.8 MAF (Table 4). It can be assumed that no additional storage will be available for the year 2010 compared to the year 2000. Construction of large storage reservoirs would require a period of 10 to 12 years. Water management will be the only workable option for the next decade.

1.3.2 Non-irrigation water needs

The gross water requirement for non-irrigation needs was 5.9 MAF for the year 2000 (Table 4). This will increase to 8.67 MAF for the year 2010, based on a growth rate of 4% per annum for increased non-water needs due to a growth in population and coverage of domestic and industrial water supplies.

1.4 Future Water Vision

Shortfall in water use would increase from 10.04 MAF to 18.39 MAF in the next decade (2000-2010) even with an increase in overall irrigation efficiency of 44% compared to the current efficiency of 36%. Thus water resources development and management in the next decade will not make the country self-sufficient in irrigation and non-irrigation water needs. On the one-hand, demand for additional water is increasing rapidly while on the other, opportunities for further development of water resources or maintaining their use to existing levels are diminishing faster than the expected pace. Thus the challenge for the next decade will be the effective implementation of a state of the art management cum development strategy. Approach encompassing the development of additional reservoirs, integrated water management and use, introduction of water efficient techniques, implementation of water conservation practices and containment of environmental degradation will have to be implemented.

1.5 Efficient Utilization of Available Resources

Now the major concern is how Pakistan can efficiently utilize the available resources. Here some future options are outlined in order to improve water situation of the country.

1.5.1 Construction of new storage reservoirs

About 35-40 MAF water is being lost without utilization and escapes to Arabian sea while requirement of water flow below Kotri barrage for fish culture and controlling water logging problem in the area is estimated from 9-14 MAF. Thus a huge amount of precious water (24-30 MAF) is wasting, in the water scarce country. Thus instead of creating conflicts among the provinces Pakistan should have a national approach and construction of new storage facilities should be the priority. Especially Kalabagh, Bhasha, Satpara dams whose feasibility studies have been almost completed should start without further delay. These large dams will not only store the extra water, thus improving supplies in the rabi season which is water stress season in Pakistan but also will be the cheapest source of power production.

1.5.2 Raising the level of the Mangla dam

Mangla raising project will increase the storage capacity of the dam thus more reliable water supplies will be available in stress periods.

1.5.3 Desiltation of the Tarbela/Mangla dam

The storage loss by the year 2002 due to sedimentation of the Tarbela dam was 3.03 MAF, the Mangla dam 1.18 MAF and the Chashma barrage 0.37 MAF with a total loss of 4.58 MAF which is about 25% of the original storage capacity of 18.37 MAF. Hence desiltation of these dams is very much necessary to improve the storage capacity and thus life of the dams.

1.5.4 Watershed management

In order to check inflow of sedimentation in the dams and rivers, afforestation of watersheds and catchment areas is the key. As trees and vegetation help to reduce erosion and thus siltation in the dams can be reduced.

1.5.5 Construction of carry-over/delay action dams

This technique consists of constructing dams across streams to store floodwater for recharging of groundwater. The dams delay the passage of floodwater by retaining it behind an impoundment structure. Recharge then takes place by infiltration behind the structures through the bed of reservoir. These dams can be built in the province of Baluchistan especially in district Zhob, Kharan, Barkhan and Kachhi Plains as well as Quetta and Ziarat valley as they are facing scarcity of groundwater resources and it will be a real source for recharging the underlain aquifer. In Sindh province, Kohistan and Thar are prone areas for such intervention.

1.5.6 Rain water harvesting

The Pothwar plateau and Hazara division in north, while Suleiman and Kirthar ranges in south western part of the country have the potential to harness rain water. Rainfalls in the upper parts flow as run off which can be controlled and collected by constructing small/medium size dams check structures and dikes that can ultimately be utilized for agricultural purposes.

1.5.7 Exploitation of remaining groundwater potential

Farmers of the areas where groundwater quality is considerably good for irrigation should be encouraged to adopt tube-well technology to explore the groundwater resources so that excess water may be available in the stress periods.

1.5.8 Lining of canals/watercourses to improve conveyance efficiency

Considerable wastage of water occurs in canals and watercourses. The main causes of operational losses are: seepage; overflow; vegetation; and rodent holes. Lining of canals and water courses can improve conveyance efficiency and thus over all irrigation efficiency can be improved.

IBIS comprises of 48 canal systems with a length of 60800 km while the tertiary level irrigation system in Pakistan consists of about 140,500 watercourses (58,110 in the Punjab). A significant percentage of irrigation water is being lost (about 40%) from these century old community watercourses because of their poor maintenance and aging. This is resulting in severe water shortage at the farm level that has been further aggravated due to persistent drought.

Now government has realized the situation and under different schemes 22,971 (39.5%) of 58,110 water courses in Punjab have so far been improved leaving a balance of 35,139 (60.5%) still to be improved. Now a mega project entitled “National Program for Improvement of Watercourses in Pakistan” has, accordingly, been formulated by the Federal government to improve remaining 87,000 watercourses overall (28,000 in the Punjab). By the virtue of this effort, 243 acre-feet water per watercourse will be saved annually as well as water delivery efficiency would be increased by 38.5%, that would result in 13.4% increase in cropped area and 14.8% increase in cropping intensity thus ultimately the crop yield will be increased by 17%. It is also the duty of the farmers to take active part in this program and get all the watercourses improved under the scheme.

2 The Indus River

The Indus River which is the biggest river in Pakistan in terms of its catchment area and discharge carrying capacity is the lifeblood for most of the socio-economic activities in Pakistan. The Indus River originates from the Karakoram, Hindukush, and the Himalayan regions along the north and north eastern borders of Pakistan. The rivers flow south towards the Arabian Sea with a combined annual average volume of 178 bcm (for all major rivers) discharged into the Indus Plains. The Indus River system forms a link between two large natural reservoirs, the snow and glaciers in the mountains and the groundwater contained by the alluvium in the Indus Plains of the Sindh and Punjab Provinces of Pakistan.

Figure 2 Satellite Imagery of Indus River

Source: European Space Agency (2009)

Climate is not uniform over the Indus Basin. It varies from subtropical arid and semi-arid to temperate sub-humid in the plains of the Sindh and Punjab

Provinces, and alpine in the mountainous highlands of the north. Annual precipitation ranges between 100 mm and 500 mm in the lowlands to a maximum of 2000 mm (water equivalent) on mountain slopes. Snowfall at higher altitudes (above 2500 m) accounts for most of the river runoff.

3 Hydropower Developments in Pakistan

Dams are viewed as engines of economic progress and centerpieces of efforts to develop modern and industrial societies. They are also among the largest single investments in development infrastructure and are among the largest structures built by humans. Since the late 1940's, the number of large dams worldwide has grown enormously on every continent.

Dams in arid and semi-arid climates are considered food machines and insurance against starvation and large-scale poverty reduction. Large dams have the direct benefits, which are generally considered for economic development of water resources. Canal irrigation leads to a general expansion of secondary and tertiary channels in the areas to be irrigated. Irrigation with respect to large dams strengthens the activities and facilitates growth of larger units in terms of investment, employment, and other opportunities. It is a fact that the farmers and public are aware of the benefits of water development projects and pressure the local leaders to obtain sanction, construct and develop large dams projects. However the development and economic objectives of dams are often not fully compatible with an equitable distribution of the benefits among different stakeholder and community groups. For example, with dams for hydropower generation or drinking water supply, the beneficiaries may be hundreds of kilometres away in urban centres, while the local and downstream communities may suffer from the adverse health effects, environmental changes and social disruption.

Today, most of the world's large rivers have dams. Among those, irrigation and hydropower generation purposes consist of the very first reason of building dams, amounting to approximately 48 percent of all. A considerable proportion, approximately 15 percent, serves for domestic and industrial water supply. Construction of water resources development projects creates very large employment potential for the skilled and semi-skilled categories of workers. It is observed that labor component comprises nearly 25% of the project cost. Besides the employment created on account of construction of projects, canal irrigation is a direct source of livelihood for millions of agricultural labour in the developing countries where automatic and pressurized irrigation is not common.

The hydroelectric power development in Pakistan started in the year 1925 when 1 MW Renala Hydropower Station in the Okara district of Punjab was constructed. Thereafter a number of low head small/medium hydropower schemes in NWFP and Punjab were completed in the fifties and the sixties. 240 MW Warsak Hydropower Project was the first major project in this sector and its first phase was completed in 1960. The signing of Indus Waters Treaty between Pakistan and India in 1960 heralded an era of construction of large multipurpose dams and mega hydropower projects of Mangla (1000 MW) and Terbela (3478 MW). After these large projects, the main efforts for hydropower projects planning have been undertaken as follows.

The first comprehensive effort to inventory the hydropower potential was undertaken in 1980-82 with the assistance of Canadian International Development Agency (CIDA). The study called Hydropower Inventory and Ranking of Pakistan covered 26 sites mainly for large dams on the Indus River and its main tributaries. Thereafter planning studies for some individual projects were taken up. In mid eighties, the process of systematic investigations to identify the hydropower potential of Pakistan outside the high dam projects on the main rivers was started by WAPDA with the assistance of German Agency for Technical Cooperation (GTZ). The inventory of low head hydropower potential on barrages and canals falls within the irrigation system of Indus basin was carried out.

The planning for the development of high head hydropower was undertaken again in the late eighties and early nineties by SHYDO for the development of such projects in NWFP. In parallel, WAPDA commenced the effort for the areas of AJK and the Northern Areas of Pakistan. In early first decade of twenty first century WAPDA has prepared Vision 2025 for the development of Hydropower and now vision 2016 for short, medium, and long term plans for the development of projects.

4 Types of Hydropower projects

Hydropower projects can be classified by type of operation, which is in turn a function of the amount of storage available for the regulation of power output. The major types of conventional hydro power projects are run-of-river, pondage, storage, reregulating and pumped-storage projects.

4.1 THE WATER POWER EQUATION

4.1.1 MECHANICAL POWER (HP)

The amount of power that a hydraulic turbine can develop is a function of the quantity of water available, the net hydraulic head across the turbine, and the efficiency of the turbine. This relationship is expressed by the water power equation.

$$Hp = Q*H*et / 8.815$$

Where: Hp = the theoretical horsepower available
Q= the discharge in cubic feet per second
H= the net available head in feet
et = the turbine efficiency

4.1.2 ELECTRICAL POWER

The above equation can also be expressed in terms of kilowatts of electrical power

$$K W= Q*H*e / 11.81$$

In this equation, the turbine efficiency (et) has been replaced by overall efficiency (e) which is the product of the generator efficiency (e), and the turbine efficiency (et). For preliminary studies, a turbine and generator efficiency of 80 to 85 percent is sometimes used. Above equation can be simplified by incorporating an 85 percent overall efficiency as follows:

$$K W= 0.072 *Q*H$$

5 Gauge and Discharge Data in Pakistan

The water availability plays an important role in the selection of suitable sites for the construction of dams. Hydrologists, dam designers and engineers use the water availability data including water level and discharge to support their decision makings in designing various structural elements of dam including height of dam, spillway gates, energy dissipation arrangement, turbines and power house. The water level in the river is measured daily by a water level gauge by gauge meter personnel as illustrated in the Figure 3.

Figure 3 Gauge Recorded by Personnel
Source: Irrigation and Power Department, Punjab (2009)

The discharge in the river is then calculated depending on water level by using a rating curve, which represents the relationship between water level and river discharge as demonstrated in the Figure 4.

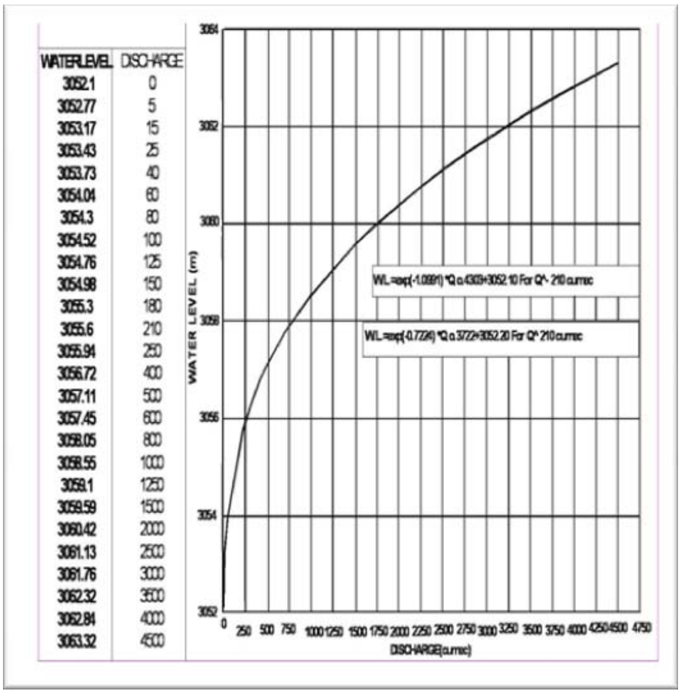


Figure 4 Rating Curve Showing Gauge and Discharge

Source: Office of Pakistan Commissioner for Indus Waters (2009).

The gauge as well as rating curve is calibrated regularly by hydrologists corresponding with the change in cross section of the river and its water velocity. The data compiled in this way is commonly known in Pakistan as the gauge and discharge (G & D) data.

The upper catchment of the Indus River, which is mostly hilly terrain, has a huge potential for the development of many dams. Furthermore there are more than 200 gauging sites along the river. The current practice is to measure the G & D data on daily basis and then store them mostly in hardcopy formats likes books, reports and journals. In this way, millions of the historical data were compiled for the past couple of decades in the hardcopy format and are lying in cupboards or racks thus occupying large spaces. The number of G & D data keeps on increasing day by day demanding more space to store them. The data compiled in the hardcopy format make it tedious to be accessed and utilized by the data users like dam designers, hydrologists, engineers, researchers as well as other people.

With the availability of today information technology, the data can be converted to digital format and systematically stored in database management system. Geographic Information System (GIS) technology provides suitable alternatives for efficient management of large and complex databases to solve hydrological problems. The data users can easily use the information to support their decision makings for the development of dams on the Indus River in Pakistan. In addition, the system can also help to tackle other water resources issues like controlling flood and drought in Pakistan.

The primary goal of this study is to develop the web–based GIS hydrological database system for the Indus River. The objective can be achieved by converting the historical data to digitalized format, designing and development of the database and designing and developing of web-based GIS system to publish the data.

6 Geographic Information System

A geographic information system (GIS) captures, stores, analyzes, manages, and presents data that is linked to location. In the strictest sense, the term describes any information system that integrates stores, edits, analyzes, shares, and displays geographic information. In a more generic sense, GIS applications are tools that allow users to create interactive queries (user created searches), analyze spatial information, edit data, maps, and present the results of all these operations. It is the combination of skilled persons, spatial and descriptive data, analysis methods, and computer software and hardware, all organized to automate, manage and deliver information through geographic presentation as shown in Figure 5.

The way maps and other data have been stored or filed as layers of information in a GIS makes it possible to perform complex analyses: Information retrieval, Topological modeling, Networks Overlay, and Data output as shown in Figure 5.

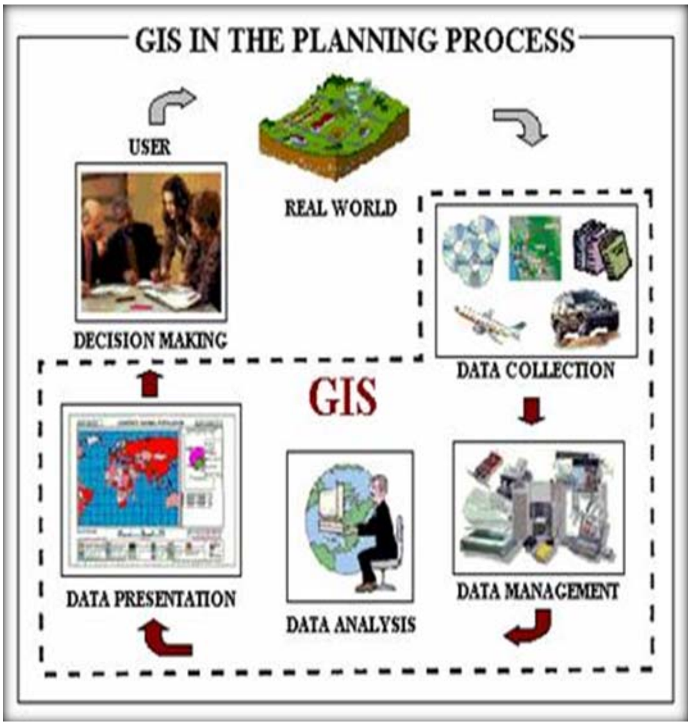


Figure 5 GIS in Planning Process

Source: Environmental Systems Research Institute (2009)

A GIS's ability lays strongly in its high capability in relating information from different sources, data capture, data integration, projection and registration, data structures and data modelling. Geographic information system technology can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, geographic history, marketing, and logistics to name a few.

6.1 Data Representation

GIS data represents real world objects (roads, land use, elevation) with digital data. Real world objects can be divided into two abstractions, discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two board methods used to store data in a GIS for both abstractions, Raster and Vector.

6.1.1 Raster

A raster data type is, in essence, any type of digital image represented in grids. Just like the digital photography which is made of pixel as the smallest individual unit of an image. A combination of these pixels will create an image. Aerial photos are one commonly used form of raster data, with only one purpose, to display a detailed image on a map or for the purposes of digitization. Other raster data sets will contain information regarding elevation, a DEM, or reflectance of a particular wavelength of light, LANDSAT.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG, etc. to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly-sized records.

6.1.2 Vector

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different geographical features are expressed by different types of geometry:

6.1.2.1 Points

Zero-dimensional points are used for geographical features that can best be expressed by a single point reference; in other words, simple location. For example, the location of wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world would be represented by points rather than polygons. No measurements are possible with point features.

6.1.2.2 Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

6.1.2.3 Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

6.2 Database Normalization

Databases are designed to offer an organized mechanism for storing, managing and retrieving information by using the tables. A table in a relational database is a predefined format of rows and columns that define an entity. Each column contains a different type of attribute and each row corresponds to a single record.

Normalization is the process of efficiently organizing data in a database. There are two goals of the normalization process: eliminating redundant data (for example, storing the same data in more than one table) and ensuring data dependencies make sense (only storing related data in a table). Both of these are worthy goals as they reduce the amount of space a database consumes and ensure that data is logically stored.

6.2.1 The Normal Forms

The database community has developed a series of guidelines for ensuring that databases are normalized. These are referred to as normal forms and are numbered from one (the lowest form of normalization, referred to as first normal form or 1NF) through five (fifth normal form or 5NF). However mostly the database are normalized up to 3NF. The normal forms are explained as under

6.2.2. First Normal Form (1NF)

First normal form (1NF) sets the very basic rules for an organized database:

1 Eliminate duplicative columns from the same table.

2. Create separate tables for each group of related data and identify each row with a unique column or set of columns (the primary key).

The primary key of a relational table uniquely identifies each record in the table. It can either be a normal attribute that is guaranteed to be unique (such as Social Security Number in a table with no more than one record per person) or it can be generated by the DBMS. Primary keys may consist of a single attribute or multiple attributes in combination.

The first rule dictates that data must not be duplicate within the same row of a table. Within the database community, this concept is referred to as the atomicity of a table. Tables that comply with this rule are said to be atomic. This is explained with an example of human resources database that stores the manager-subordinate relationship. For the purposes of the example, the rule that each manager may have one or more subordinates while each subordinate may have only one manager.

Intuitively, when creating a list or spreadsheet to track this information, a table is developed with the following fields:

1. Manager
2. Subordinate1
3. Subordinate2
4. Subordinate3
5. Subordinate4

However, first rule imposed by 1NF: requires eliminating duplicative columns from the same table. Clearly, the subordinate1 to subordinate4 columns are duplicative. The problems rose by this scenario is that if a manager only has one subordinate then the subordinate 2 to subordinate 4 columns are simply wasted storage space. Furthermore, imagine the case where a manager already has 4 subordinates and what happens if the manager takes on another employee? The whole table structure would require modification.

At this point, a second bright idea usually occurs to database a novice that allows having a flexible amount of data storage and also one column can solve this issue as mentioned below.

1 Manager

2 Subordinates

Where the Subordinates field contains multiple entries in the form "Mary, Bill, Joe". This solution is closer, but it also falls short of the mark. The subordinates' column is still duplicative and non-atomic. What happens if something is added or removed from the subordinates' columns. Then the entire table needs to be read and write. But it requires enormous efforts if the manager has more than hundred employee. Also, it complicates the process of selecting data from the database in future queries.

Here's a table that satisfies the first rule of 1NF:

1. Manager
2. Subordinate

In this case, each subordinate has a single entry, but managers may have multiple entries.

Now, second rule states that there must be primary key that identify each row with a unique column or set of columns. A close look on the table above shows that subordinate column is best suitable as a primary key because business rule specify that each subordinate may have one manager. It's best to use a truly unique identifier (such as an employee ID) as a primary key. Then the final table would look like this:

1 Manager ID

2 Subordinate ID

6.2.3 Second Normal Form (2NF)

Second normal form (2NF) further addresses the concept of removing duplicative data:

1 Meet all the requirements of the first normal form.

2. Remove subsets of data that apply to multiple rows of a table and place them in separate tables.

3. Create relationships between these new tables and their predecessors through the use of foreign keys.

A foreign key is a field in a relational table that matches the primary key column of another table. These keys are used to create relationships between tables. Natural relationships exist between tables in most database structures.

The rule is elaborated by means of the following example. Imagine an online store that maintains customer information in a database. They might have a single table called Customers with the following elements:

1 CustNum
2 FirstName
3 LastName
4 Address
5 City
6 State
7 ZIP

A brief look at this table reveals a small amount of redundant data about storing the "Sea Cliff, NY 11579" and "Miami, FL 33157" entries twice each. Now, that might not seem like too much added storage in the simple example, but imagine the wasted space if we had thousands of rows in our table. Additionally, if the ZIP code for Sea Cliff were to change, we'd need to make that change in many places throughout the database.

In a 2NF-compliant database structure, this redundant information is extracted and stored in a separate table. The new table (let's call it ZIPs) might have the following fields:

1 ZIP

2 City

3 State

Now that the duplicative data from the Customers table is removed and it satisfies the first rule of second normal form. But a foreign key is needed to tie the two tables together. Therefore, ZIP code (the primary key from the ZIPs table) is used to create that relationship. Here's the new Customers table becomes as shown below:

1 CustNum

2 FirstName

3 LastName

4 Address

5 ZIP

This will minimized the amount of redundant information stored within the database and the structure is said to be in a second normal form.

6.2.4 Third Normal Form (3NF)

Third normal form (3NF) goes one large step further:

1 Meet all the requirements of the second normal form.

2. Remove columns that are not dependent upon the primary key.

As an example consider a table of widget orders that contains the following attributes:

1 Order Number

2 Customer Number

3 Unit Price

4 Quantity

5 Total

Remember, the first requirement is that the table must satisfy the requirements of 1NF and 2NF. There should not be duplicative columns in a database design. And also there must be a primary key mentioned as the order number in the above table. Therefore, the requirement of 1NF is satisfied. And also the requirement of 2NF should be satisfied which is about the subset of data that can be applied to multiple rows.

Now, all of the columns are fully dependent upon the primary key. The customer number varies with the order number and it doesn't appear to depend upon any of the other fields. But the unit price could be dependent upon the customer number in a situation charged each customer is charged with a set price. However, looking at the data above, it appears that sometimes same customer is charged with different prices. Therefore, the unit price is fully dependent upon the order number. The quantity of items also varies from order to order.

Now about the total there is a trouble here. The total can be derived by multiplying the unit price by the quantity; therefore it's not fully dependent upon the primary key. Therefore it is better to remove it from the table to comply with the third normal form by using the following attributes:

1 Order Number

2 Customer Number

3 Unit Price

4 Quantity

Now the table is in 3NF and the total is a derived field and its best not to store it in the database at all. And it can be computed while database queries.

6.3 Entity Relationship Modeling for Spatial Data

GIS design (planning, design and implementing a geographic information system) consists of several activities: feasibility analysis, requirements determination, conceptual and detailed database design, and hardware and software selection. Over the past several years, GIS analysts have been interested in, and have used, system design techniques adopted from software engineering, including the software life-cycle model which defines the above mentioned system design tasks. Specific GIS life-cycle models have been developed for GIS by Calkins (1982) and Tomlinson (1994). Figure 6 is an example of a typical life-cycle model.

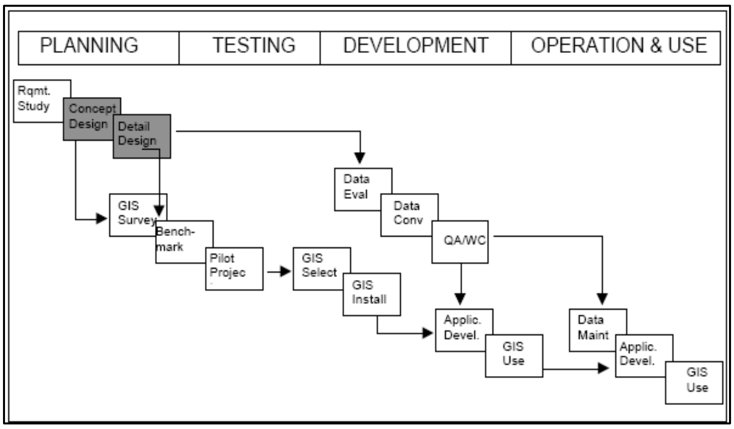


Figure 6 GIS Life-Cycle

Source: Calkins (1982**)** and Tomlinson (1994)

6.3.1 Conceptual Modeling and Database Design

Database design is the information system planning activity where the contents of the intended database are identified and described. Database design is usually divided into three major activities:

1 Conceptual data modeling: identify data content and describe data at an abstract, or conceptual, level;

2 Logical database design: translation of the conceptual database design into the data model of a specific software system; and

3 Physical design: representation of the data model in the schema of the software.

For most GIS implementations, a commercial GIS software package is used, often in conjunction with a commercial database system. In these instances, the basic structure of the logical schema (e.g., a relational data schema) and the entire physical schema are already predetermined. The task of the GIS designer is to prepare a conceptual schema that properly describes the entire GIS database and is suitable for translation into the logical schema of the proposed GIS and database software.

The programmer/analyst needs precise information about the data to set-up the database and necessary computer processes. Descriptions of data and algorithms using normal language (such as English) are not usually adequate for implementing a system. Thus, tools allowing greater precision in description are needed for the task of conceptual data modeling and database design. Such tools provide a means to identify and describe the intended database in terms that facilitate two critical activities: user verification and detailed database design.

6.3.2 Tools for Database Modeling

Various tools to support the database modeling activity have been developed. One widely accepted and used technique is the entity-relationship modeling technique developed by Chen (Chen, 1976). The entity-relationship (E-R) technique has been applied to many disciplines and has been revised and extended by many researchers to meet a variety of specialized needs. The E-R technique is a graphical method of representing objects (or entities) of a database, all important relationships between the entities, and all attributes of either entities or relationships which must be captured in the database. The set of rules controls the definition of entities, relationships, and attributes and the manner in which they are portrayed in diagrammatic form. All items are names and additional information is appended to the diagram indicating the nature of each relationship, i.e. the cardinality of each relationship (one-to-one, one-to-many, or many-many).

6.3.2.1 Basic Entity-Relationship Modeling

The basic entity-relationship modeling approach is based on describing data in terms of the three parts noted above (Chen 1976):

1. Entities

2. Relationships between entitles

3. Attributes of entitles or relationships

Each component has a graphic symbol and there exists a set of rules for building a graph (i.e., an ER model) of a database using the three basic symbols.

The implementation rules for identifying entities, relationships, and attributes include an English language sentence structure analogy where the nouns of a descriptive sentence identify entities, verbs identify relationships, and adjectives identify attributes. These rules have been defined by Chen (1983) as follows:

Rule 1: A common noun (such as person, chair), in English corresponds to an entity type on an E-R diagram.

Rule 2: A transitive verb in English corresponds to a relationship type in an E-R diagram.

Rule 3: An adjective in English corresponds to an attribute of an entity in an E-R diagram.

As an example the english statement: A person may own a car and may belong to a political party.

Analysis: “person,” “car,” and “political party” are nouns and therefore correspond to entity types. “own” and “belong to” are transitive verbs (or verb phases) and therefore define relationships.

7 GIS Based Hydrological Models

The researchers in the field of hydrology are cognizant of the benefits of GIS applications towards hydrology and hydrological modeling. The application of GIS in the field of hydrology has enabled the planners of WRPs to address various conflicting issues by taking into consideration the spatial dimension and temporal variations on a regional scale.

Hydrological and water resource projects (WRPs) will always present a realm of issues both technical and non-technical. The technical issues include but are not limited to upstream watershed management, downstream flow management, loss of reservoir capacity, and even dam stability. The non-technical issues include but are not limited to ecological, environmental, socio-economic problems, and other political, religious, legal, and international disputes (M. Ravichandran and N. Indrasenan, 2001).

GIS has become a particularly useful and important tool in hydrology and to hydrologists in the scientific study and management of water resources. Climate change and greater demands on water resources require a more knowledgeable disposition of arguably one of our most vital resources. As every hydrologist knows, water is constantly in motion. Because water in its occurrence varies spatially and temporally throughout the hydrologic cycle, its study using GIS is especially practical. GIS systems previously were mostly static in their geospatial representation of hydrologic features. Today, GIS platforms have become increasingly dynamic, narrowing the gap between historical data and current hydrologic reality.

Modeling the hydrological and other pertinent issues of a WRP can be done with a GIS and many earlier studies identified GIS's potential benefits in constructing WRPs models with total hydrological orientation.

Modelling surface and subsurface flow using a GIS can be done with a comprehensive setting for both surface and groundwater scenario instead of individual models. When the transport of pollutants and contaminants is considered, the scenario is very complicated. When the pollutants are carried away by runoff, the groundwater specialists feel relieved, as the pollutant is to be considered as a part of the river. When the pollutants go into the groundwater, the hydrologists feel that they are not affected. Instead both the hydrologists and the groundwater specialists should identify ways to reduce the contaminant content in a comprehensive manner. GIS based hydrological project models can be effectively used to resolve such conflicting issues (David R. Maidment, 1993).

The presence of an integrated and a reliable GIS database with quality control to maintain positional, attribute, and logical accuracies are needed to provide quality data to plan effective WRPs. When such accuracy of data is maintained, the data can be considered to be complete in all respects and can be used for planning purposes (Sindre Langaas, 2001). GIS-based Hydrological Database can help the planners make perpetual decisions for better engineering and even non-engineering decisions to ensure the success of the projects.

8 GIS in Surface Water

It is possible to access historical and real time stream flow data via the Internet. Embedded within a GIS are layers with stream locations and gage or measuring/monitoring sites. It's also possible to link radio transmitted and remotely sensed (Remote Sensing) data in GIS. Within a GIS, it's possible to direct link via the Internet to real time data. All these data are available for analysis within GIS, providing a spatial representation of what would otherwise be data in a table type format.

GIS is much more capable of displaying data spatially than temporally. Within one GIS, ESRI's ArcGIS for example, is it possible to delineate a watershed. Digital Elevation Model (DEM) data are layered with hydrographic data so that the boundaries of a watershed may be determined. Watershed delineation aids the hydrologist or water resource manager in understanding where runoff from precipitation or snowmelt will eventually drain. In the case of snowmelt, snowpack coverage may be determined from ground stations or remotely sensed observers and input into GIS to determine or predict how much water can be counted on to be available for use by cities, agriculture, and environmental habitat.

Geographic information systems (GIS) have been proved to be very useful in handling point, vector data, and raster data. GISs provide the means to geo-referenced data which enables the overlaying, merging and visualization of the data. These are key tasks that simplify distributed hydrological modelling. There is, however, a problem in simulating hydrological processes at the time scale shorter than that of the surface water process. At this time scale, the linkage of GIS and hydrological models becomes difficult because simulation of channel flow depends on the structure of channel network heavily; processing cannot be done pixel by pixel. Physically, the channel routing should be done only from upstream to downstream. A channel routing scheme is needed which takes into account the structure of channel network.

Even though the concept of GIS based hydrological modelling is of recent origin, a number of studies and researches were done in the recent past. However, an attempt is made to highlight a few of them in the following paragraphs.

A preliminary study in South Africa identified GIS as a viable tool to mitigate issues arising out of complex geopolitical, socio-political, and international agreement bound water-sharing problem to optimize the water utilization (J. J. Oliver and D. R. McPherson, 1993).

GIS was used for developing a hydrological model for River Nile to address the issues such as water demand, geopolitical, and socio-political disputes and litigation. It was found that the spatial orientation was well addressed by using commercial GIS software such as ArcView. The study further highlighted the fact that with the advent of multimedia, hypertext, development in computer science in the fields of expert systems, and decision support systems will enhance the applications of GIS particularly to hydrological modelling (John Schaake, Robert Ragan, and Edward J. VanBlargan, 1993).

GIS can provide a framework for the integration of data from different and disparate data sources. This will enable the planners to integrate data from satellite imagery, aerial photographs, historical map, raster format data, fine DEM grids, and other point data from hydrological and environment monitoring agencies (Angela Gurnell and David Montgomery, 1998).

The GIS can permit the modelling of the data from varied sources highlighting their importance in an intuitive form otherwise unavailable. The research also warns hydrologists of potential error amplifications, which would be hard to detect by the use of the GIS framework (Angel Gurnell and David Montgomery, 1998).

Integrating complex systems such as ARC/INFO GIS, a product of Environmental Systems Research Institute Inc.(ESRI) and Hydrological Modelling Systems (HMS) was found to be useful in improving water resources planning, land management to minimize pollution from agricultural land and informal settlements. This helped the planners in effectively translating the spatial features into meaningful hydrological parameters (Stefan W. Kienzle, 1993).

Another study found that the absence of temporal variations in GIS tools presented an incomplete modelling scenario and the research concluded that future GIS tools would allow temporal variations in GIS modelling of hydrological modelling (M. Brilly, M. Smith, and A. Vidmar, 1993).

A recent research concluded that the implementation of GIS modelling to solve hydrological problems will suffer an inevitable paradigm shift. The study further indicated that the paradigm shift would equip researchers and planners with new computational models and implementation strategies that are platform independent to perform better modelling (D. Z. Sui and R. C. Maggio, 1999).

GIS and Landsat Thematic Mapper (TM) were used in a research that concluded with a correlation of human presence and their interaction with the environment and its relevance to a watershed were found in Kickapoo watershed and two other watersheds (Tracy K. Kuczenski et. al., 2000).

GIS as a tool will soon be the preferred environment for hydrological modelling as more GIS vendors are adapting to open standards for data models and customization using different programming languages and tools (Neil Stuart and Christopher Stocks, 1993).

Nguyen and Van Dai (2004) presents remote sensing and GIS integration for terrain evaluation and land resources assessment in north western Vietnam. He focuses on the study of the terrain and major land features in northwestern Vietnam using remote sensing and GIS to assist in the manipulation and interpretation of spatial data. Representation of the terrain is based on the digital elevation model (DEM) of northwest Vietnam generated from radar interferometry and interpretation of Landsat images. The Landsat TM and ETM images of the study area were processed and interpreted to extract information about the major landforms (fault lines, geo-dynamic zones) and land-resources delineation (forest-vegetation cover, water resources, and agricultural and residential areas) in the region. Vegetation cover was characterized by vegetation index (NDVl). The integration of remote sensing methodologies with GIS provides a powerful way of extracting land features inherent in satellite images. The information provided in this study has many areas of application, including in environmental management and planning, hydrological watershed analysis and modeling, landform and natural resource evaluations, geological structural study, and hydropower infrastructure planning and construction.

Ershadi, Ali (2005) gives the applications of remote sensing, GIS and river basin modelling in integrated water resource management of Kabul river basin. He describes an Integrated Water Resources Management Project in the Kabul River Basin that is located in the South-East of Afghanistan. In order to be able to prepare proper IWRM plans for the basin, the available resources in the basin need to be determined. For this purpose an approach involving combined application of remote sensing, GIS and river basin modelling was used. All the prepared information on water demands and observed discharge was then organized in the Mike Basin model. Based on the data and estimated water uses during the 1961-78 periods, the true water availability, i. e. the naturalized flow, in the basin was assessed. Integrated water resources management plans will then be prepared for the basin based on the estimated naturalized flow and the projected future water uses.

M. Davis. Kimberley (2000) presents object-oriented modeling of rivers and watersheds in geographic information systems. It is possible to take advantage of object-oriented programming and modeling techniques to build a data model of custom features for GIS that supports hydrography and hydrology. The unifying structure that ties river maps to river analysis is the network built from rivers themselves. The result describes the design process for the ArcGIS Hydro data model, discusses object-oriented programming concepts, UML and CASE tools, and shows how to apply data from the National Hydrography Dataset. The result is a data structure, not a process-based engineering model, which can be used as-is for most situations, and extended to represent unique conditions if needed.

Daene C. McKinney (2005) presents arc hydro data model for Ethiopian watersheds. Ethiopia is endowed with a substantial amount of water resources. The country's renewable surface and ground water amounts 123 and 2.6 billion cubic meters per annum, respectively, but its distribution shows high temporal and spatial variation. The Ministry of Water Resources of Ethiopia (MoWR) planned to develop a digital hydrologic data model that supports management of country's water resources. The purpose of that project is to use the Arc Hydro data model to organize and manage water resource data Ethiopia. To accomplish this, raw Shuttle Radar Topographic Mission (SRTM) data was processed and a 90mX90m Digital Elevation Model (DEM) was created. Second, drainage lines and watersheds were created using the Arc Hydro tools. Third, six hydro administrative regions were identified based on the flow direction of the streams.

M. Davis. Kimberley (2000) presents object-oriented modeling of rivers and watersheds in geographic information systems. It is possible to take advantage of object-oriented programming and modeling techniques to build a data model of custom features for GIS that supports hydrography and hydrology. The unifying structure that ties river maps to river analysis is the network built from rivers themselves. This thesis describes the design process for the ArcGIS Hydro data model, discusses object-oriented programming concepts, UML and CASE tools, and shows how to apply the ArcGIS Hydro data model from the National Hydrography Dataset. The result is a data structure, not a process based engineering model, which can be used as-is for most situations, and extended to represent unique conditions if needed.

Zoran Micovic in his study presents an approach for calculating the Probable Maximum Flood (PMF) as a hypothetical flood that is considered to be the most severe "reasonably possible" at a particular dam location. The UBC Watershed Model (UBCWM) was used to derive the PMF estimates for several Hydro dams in Southwestern British Columbia. The UBCWM uses the concept of area-elevation bands and point-input precipitation data. This means that a watershed is split into several elevation bands and the precipitation measured at a point (usually at one or two meteorological stations) is distributed to the elevation bands using the orographic precipitation gradients. However, the Probable Maximum Precipitation causing the PMF was provided in a rectangular-grid format of 3.5 km^2 resolution and as such could not be used as the UBCWM input. ArcView 3.2 with the Spatial Analyst extension was utilized to enable the UBCWM to use the gridded precipitation input and derive the corresponding PMF estimates.

Kumar Sinha and Ashok (2003) explain GIS database management for planning of hydel power generation. In that studies he presents a methodology for using GIS database for site location and preparing layout for transmission lines for hydel power system.

From the above studies, it can be seen that GIS, as a tool is finding increasing use in modeling the hydrological, environmental, socio-economic, political, and other issues of WRPs. The researchers could have used data from disparate sources and some of them might be in proprietary formats. If data such as elevation, topography, hydrological flow characteristics, ecological disturbance, foliage, and a variety of demographic information can be stored in a database with geo-codes as their primary keys, the resulting database will be reliable, consistent and with a high level of data integrity. If the database is periodically updated by doing surveys and other studies, and periodically updated by the departments, the resulting database will be a robust and a reliable one. Such a database can be used for planning WRPs to optimize the benefits and reduce the negative outcomes of the projects.

RESEARCH METHODOLOGY

1. Hydrological Data Collection

The hydrological data of the gauging sites on the Indus River were collected from the different organizations which are responsible for the collection and compilation of the hydrological data in Pakistan. The hydrological data was in hard copy format and indicates the name of the gauging sites, the gauge reading which is shown in the feet and corresponding discharge measured in cubic feet per second on the daily basis. The G & D data was collected for the two years period.

There are more than 200 gauging sites on the Indus River but as a case study 36 gauging sites were selected on the upper catchment area of the Indus River. Some of the gauging sites were located on the main stem of the Indus River and while other are on the tributaries of the Indus River.

2 Methodology

Figure 7 illustrates the overall process for the study. The activities include the functional requirement analysis, system design, database design and the system implementation.

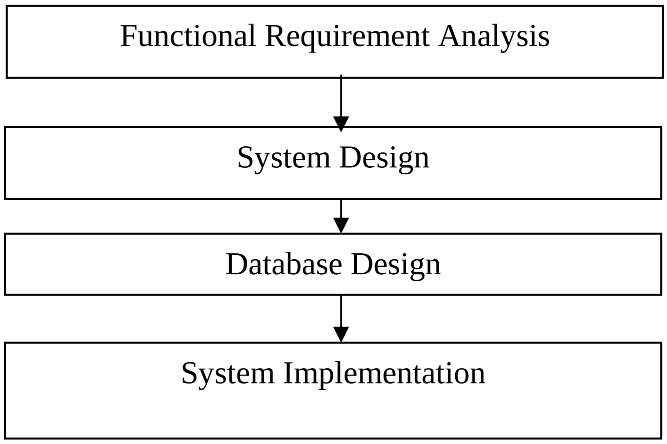


Figure 7 Research Framework

2.1 Functional Requirement Analysis

Functional requirement analysis is critical to the success of development of web-based GIS system. It is a process of determining the requirements of the system which essentially reflects how the system will perform the stated purposes. The requirement of the system must be actionable, measurable, testable related to needs of the system. The functional requirement of the system was assessed after having done detailed literature review and communicating the data users like the engineers, hydrologists, scientists and dam designers in order to determine what were their requirements. After that the analysis of the requirement was done in order to know whether the requirements are clear, complete, unambiguous and consistent in resolving any problem.

2.2 System Design

Free and open source software (FOSS) was used for the development of the hydrological database system of the Indus River. There are many components of the system. The system was designed by using different software including PostgreSQL which was primarily used to develop the database of the system. PostGIS was used to store spatial data in the PostgreSQL database. Geoserver was used to publish the dynamic map of the spatial data on the web. The web application of system was developed in the Apache web server which displayed the web pages stored in the computer to be displayed on the internet.

2.3 Database Design

The data is the core of GIS and the quality of the system and application depends on the quality of the data. The database design is a fundamental component of GIS application design. The primary dataset used to develop the system are the G & D data which was digitalized manually from the hardcopy format and stored initially in the Microsoft Excel. There were more than 26,000 entries of the G & D data in the Microsoft Excel. The second dataset is about the spatial data of the Indus River and the location of the gauging sites on it. The spatial data also shows important features of the Pakistan like the cites, the road and railways network the international boundary and the contour lines of the country.

The database was designed conceptually, logically and physically. Conceptual database design is a process of constructing a model of information used in an enterprise and is independent of all physical considerations. Conceptual design of the system is carried out by synthesising information from the requirement analysis and it describes entities, attributes and relations among entities. The logical database design is the process of constructing a model of information used in an enterprise based on a specific data model (e.g. relational) but is independent of particular DBMS and other physical consideration. The logical design involves the transformation of the conceptual data model into an internal model- schema that can be processed by a particular Database Management System (DBMS). The physical database design is a process of producing a description of the implementation of the database on secondary storage. It describes the base relation, file organisations and indexes design to achieve efficient access to the data and any associated integrity constraints and security measures. PostgreSQL is used to develop the database of the Indus River. It is a Relational Database Management System (RDBMS) that means it is a system for managing data stored in relations.

2.4 System Implementation

The source code of the system is written by using different scripting languages like the PHP (Hypertext Preprocessor), JavaScript, HTML and SQL. The different languages are used for developing the web application; retrieving the data from the database and publishing the results on the internet. PHP is a widely used open source general-purpose scripting language that is especially suited for web development and can be embedded into HTML. PHP is executed on the server; generating HTML which is then sent to the client. The system is fully complying with the functional requirement of the system. The system displays the statistical summary and historical inflows of the river at different gauging sites. Moreover system displayed the maps in a nice and presentable manner and support basic GIS functionalities. The modification of the database is easy and also the system helped to select suitable site of the construction of the dams on the Indus River. The site selection for the dams is based on the average inflow of the river.

RESULTS AND DISCUSSION

1. Functional Requirement Analysis

Functional requirement analysis is the process of determining the requirements of the system which essentially reflects how the system will perform the stated purposes. After extensive literature review and thorough discussion with the individuals who are data users, the functional requirement of the system was assessed. The system is expected to display the historical inflows of the river at different sites on daily, monthly, and yearly basis as well as the statistical summary like maximum, minimum, average, and standard deviation.

In order to visualize the gauging sites on the Indus River, the system should display the maps, which show geographic location of the gauging sites along the river and other pertinent features of the country like cities, roads, railways and international boundary. The system should be capable to support basic GIS functionalities such as zoom in, zoom out, panning and display the results in a nice and presentable manner.

The data importing process should be easy. The system should be capable enough to prohibit the unauthorized access. The system should support the database management functions which are needed to modify the tables in the database. The database management functions include different operations like the retrieving, adding, updating, and deleting the data.

The use case diagram depicts the functional requirement of the system as shown in Figure 8. A use case diagram in the Unified Modeling language (UML) is a type of behavioral diagram which identify the requirement of a system. It presents a graphical overview of the functionality provided by the system in terms of actors (represented by stick figure), their goal (use cases represented by ovals), and any dependencies between those use cases.

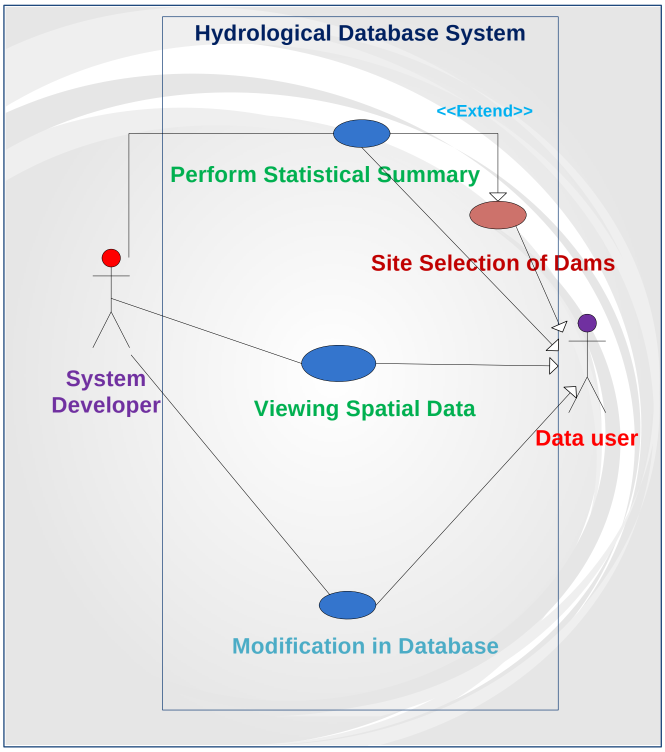


Figure 8 Use Case Diagram

2. System Design

Free and open source software (FOSS) is used for the development of the hydrological database system of the Indus River. The main advantage of FOSS is that it provides full accessibility to the source code, which can be legally modified and used. Moreover, it is free to access and no cost incurs for the development of the applications. Figure 9 illustrates the overview of the system. Following are necessary components for completing the objectives. The details of each component are explained as follows.

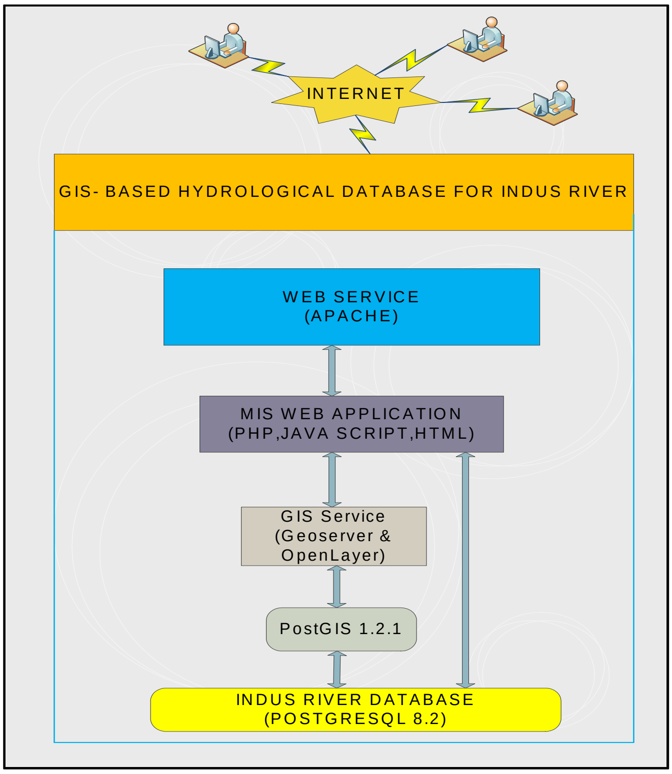


Figure 9 Overview of System

2.1 PostgreSQL/PostGIS

PostgreSQL is used to develop the database of the Indus River because it is robust database system and runs on many operating system platforms (Linux, Mac OS/X and Microsoft Windows). PostgreSQL is a Relational Database Management System (RDBMS) that means it is a system for managing data stored in relations. A relation is essentially a mathematical term for tables and tables are grouped into databases. The main advantage of PostgreSQL is that it is free software with complete source code available and there is no upfront fee to use it. As it is free therefore its development is faster than any commercial DBMS because many users who quickly test it and report bugs which get fixed quickly. Moreover, the training for personnel remain minimal because PostgreSQL functions is similar to other database system. Therefore, it can be easily used for any purpose whether it is private, commercial or academic in nature and it can be used by any engineer who has some experience in any database system. Moreover it supports standard SQL language and supports all the modern features like complex queries foreign keys, triggers, views, transactional integrity and multiversion concurrency. Many languages like PL/pgSQL, C, C++ and Java can be used to write functions of PostgreSQL. The primary front end for PostgreSQL is the “psql” command-line program which is used to enter any queries directly or execute them from a file. It also facilitates in writing scripts and carrying out wide variety of tasks. The graphical front end administration tool for the PostgreSQL is “pgAdmin”.

In comparison with other MySQL which is also a database management system, the PostgreSQL is found to be faster for querying large databases. Also it has a complete journaling system which ensures data consistency. In order words it means that even if the computer is crashed, the database will still be consistent and work correctly [Made to Order Software Corporation, 2006]. Moreover MySQL cannot utilize more than one index per query but PostgreSQL has the ability to combine multiple indexes to handle cases that cannot be implemented by single index scans. It means that system can form AND and OR conditions across several index scans.

PostGIS is a spatial language extension module to the PostgreSQL backend server that spatially enables it for storing GIS content and it adds supports for the geographic objects in the PostgreSQL. PostGIS is also an open source software program and follows the simple features, which specify about the digital storage of geographical data (point, line, polygon, multi-point) for the SQL specification. PostGIS also includes geometry types for points, line strings, polygons and multipoint. It also includes spatial operators which can determine geospatial measurements like area, distance, length and perimeter.

2.2 Geoserver

Spatial data of the Indus River and other pertinent features of Pakistan are published on web by using the Geoserver which is an open source server and allows users to view and edit geographic data. Geoserver connects geographically referenced information to the GeoSpatial Web by using open standards set forth by the Open Geospatial Consortium (OGC), the leading standards organization in the geospatial arena. Geoserver is java-based server and conforms to Web Feature Service (WFS). WFS communicate real geographic data (roads, rivers) to and from users in the form of Geography Markup Language (GML) which is a brand of XML that describes geographic data. The WFS defines a standard protocol for querying and retrieving vector features over the web. Therefore, users can view and edit geospatial data with greater freedom. Moreover, it allows users a greater flexibility in terms of creating maps and sharing data because it implements the Web Map Service (WMS) which displays geographic data as raster images (maps), therefore maps are produced dynamically from spatially referenced data. The WMS specifications define a standard protocol for generating cartographic maps over the web. A map is a portrayal of geographical information as digital image file suitable for display on a computer screen as defined by the international standard. A map is not the data itself. Map produced by WMS are generally rendered in a “picture” or “graphic element” format. Picture formats constitute a rectangular pixel array of fixed size. Picture formats include file types such as Portable Network Graphics (PNG), Graphic Interchange Format (GIF) or Joint Photographic Expert Group (JPEG) all of which can be displayed by common Web browsers for display. Graphical element format constitute graphic elements (point, line, curve, text and image) to be displayed. Graphical element formats include Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (WebCGM) format.

Geoserver is also integrated with OpenLayer which make it easy to put a dynamic map in any web page. OpenLayer is a pure JavaScript library for displaying map data in the web browsers, with no server-side dependencies. OpenLayer is also free software.

In comparison with Mapserver, the Geoserver is found to be faster and also has capability to display output in vector super-overlays, which is the form of Keyhole Markup Language (KML) allowing data to be broken up into regions. Super-overlays are used to efficiently publish large sets of data.

Geoserver is free software and reduces significantly the financial cost in comparison with other commercially available GIS products. The other advantage of using the open source software is that bug fixing and features improvement which is greatly accelerated.

Geoserver can read data in many format including PostGIS, Oracle Spatial, ArcSDE, DB2, MySQL and Shapefiles. The data can be easily edited in Geoserver served through Web Feature Service.

Geoserver supports Google Earth by providing KML as a Web Map Service (WMS) output format. Earth is a 3-D virtual globe program. It allows the user to virtually view, pan, and fly around Earth imagery. The imagery on Google Earth is obtained from a variety of sources, mainly from commercial satellite and aerial photography providers.

This means that adding data published by GeoServer is as simple as constructing a standard WMS request and specifying "application/vnd.google-earth.kml+xml" as the output Format. Since generating KML is just a WMS call, it fully supports styling via the SLD standard. A user can even load their own SLD file and GeoServer will render the data as the user wants. GeoServer also supports the WFS and WCS standards for access to the raw data, the 'source code' of the maps, for further analysis, modifications, and modeling.

2.3 Apache HTTP Server

Web application was developed by Apache HTTP server commonly known as Apache and it is an important web server, which plays a key role in growth of the World Wide Web. Web server is the application running on a computer and thus making available the WebPages stored on the computer to internet users. Web server can also be integrated with databases to make available the information stored in database to internet users. Apache is suitable for the projects that are heavily Java based because Apache offers superior handling of Java Database Connectivity (JDBC) application program interface (a program which allows Java-based services to access information stored in SQL-compliant database). Apache is also free and open source software and is constantly being updated and supports many features ranging from the server-side programming language to the authentication schemes.

In comparison with Microsoft Internet Information Server (IIS) which is only limited to new Technology (NT)-based system and it is closed source, Apache primarily serve both static content and dynamic web pages on the World Wide Web. Apache can also be used to share information from a personal computer over the internet in a more secure and reliable way by putting any information file in Apache's document root which can then be shared. Many programmers develop and test the code of the web application by locally installing Apache in their personal computers.

3. Database Design and Development

Database design is the process of producing a detailed data model of database. The data model is an abstract model that describes how data is represented and accessed basically. It is the representation of the world in simplified term. It defines the data elements and relationships among data elements. The procedure for designing the database for Indus River is explained as under.

3.1 Conceptual Database Design

To achieve a good database design and the desired GIS, the conceptual data model must be complete. It must contain all data needed to meet the system's objectives, and must be directly translatable into the logical and physical database schema. Data identification and description includes defining the objects (entities), the relationships between the objects and the attributes of objects (or relationships) that will be represented in the database. The data description activity also includes assembly of information about the data objects, i.e., metadata (definition, data type, valid values, data quality, etc.). The purpose of the conceptual data modeling process is to prepare an unambiguous and rigorous description of the data to be included in the database in a form that is understandable by the proposed users of the database or system and it is sufficiently structured for a programmer or an analyst to design the data files and implement data processing routines to operate on the data. The conceptual database of the system is shown in Figure 10.

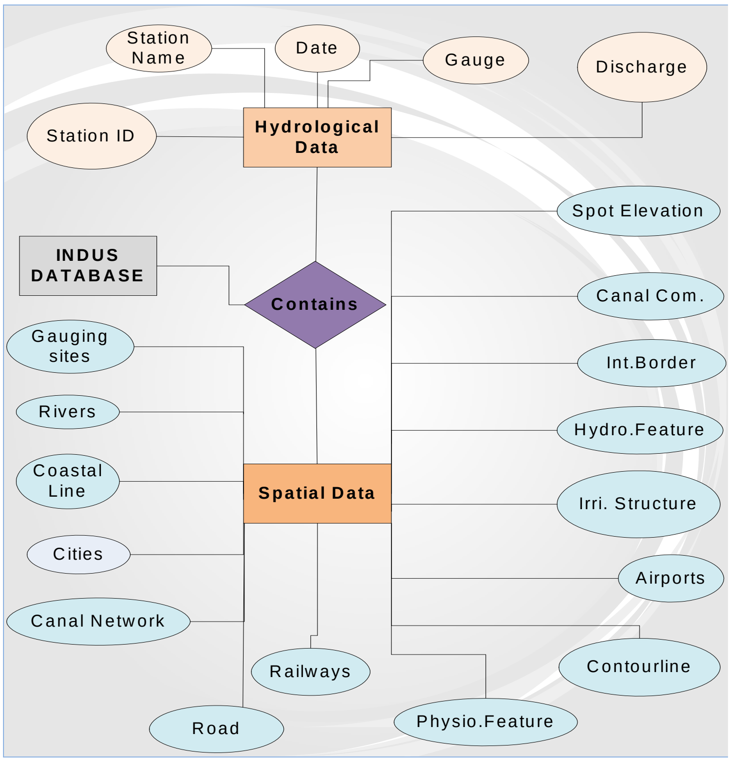


Figure 10 Conceptual Database Diagram

3.2 Logical database design

The conceptual design can then be translated into a relational model. Every entity becomes a separate entity relation. A relationship is represented either by a foreign key (for a one-to-many relationship) or a separate relation (for a many-to-many relation). The main purpose of logical database design is to structure the data in stable structures which called normalized tables with minimal redundancy. It reflects the requirement of the data users and can be used to develop the physical database. Logical database design account for every data element on a system and the normalized relations are the primary outcome of the logical database design. The normalization is a process of converting complex data structures into simple and stable data structures. In order to refine the conceptual data model it is important to remove features that are not compatible with the relational model. After that the Entity Relational Diagram (ERD) is converted into relations by transforming regular entity into relations by means of primary key. The primary key must be uniquely identifying every row in the relation.

The database of system was normalized to the third normal form (3NF) by removing all the redundancy in the database and defining the primary keys into the database. The logical database of system is shown in Figure 11.

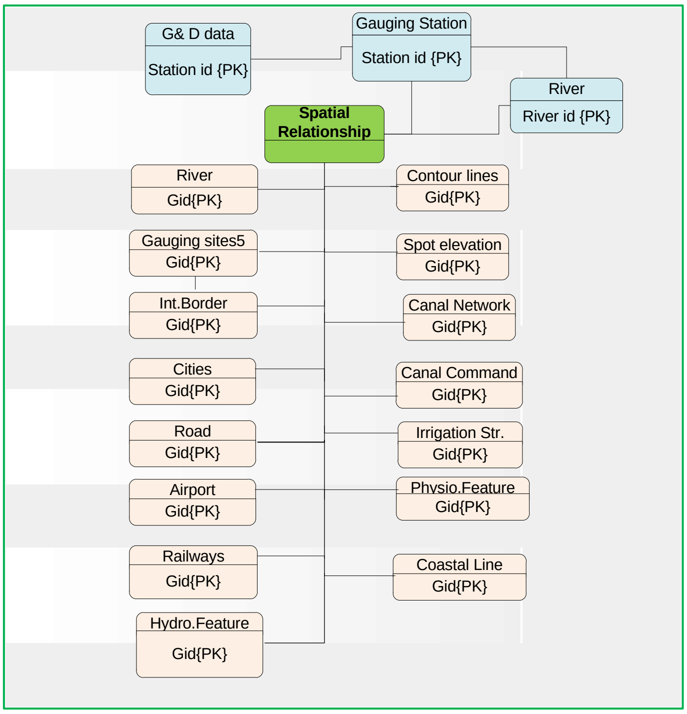


Figure 11 Logical Database Diagram

3.3 Physical database design

Physical database design is process of producing a description of the implementation of the database on secondary storage. It describes the base relations, files organizations and indexes used to achieve efficient access to the data and its associated integrity constraints and security measures. The logical database model is translated into target DBMS in order to produce a relational database schema that can be implemented in the target DBMS. The important consideration in this regard are to exactly know the functionalities of DBMS in order to create a base relations by defining the name of the relation, the list of simple attributes and the primary key.

3.3.1 Entity-Relationship Model

An Entity Relational Diagram (ERD) is a model that identifies the concepts or entities that exist in a system and the relationships between those entities. An ERD is used to visualize a relational database in which each entity represents a database table and each row of the table representing an instance of that entity, while the relationship lines represent the keys in one table that point to specific records in related tables. Entities are concepts within the data model. Each entity is represented by a box within the ERD. An entity might be considered a container that holds all of the instances of a particular thing in a system. The Entity Relational Diagram (ERD) of database is shown in the Figure 12

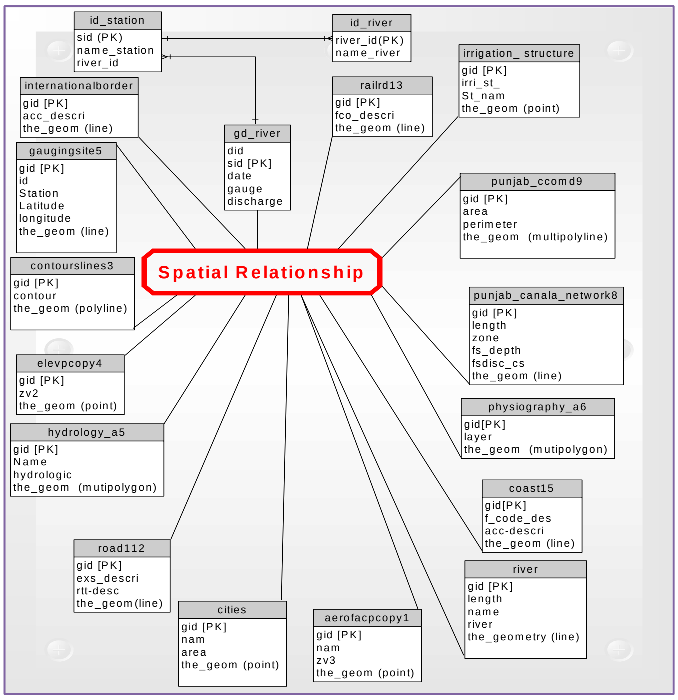


Figure 12 Entity Relational Diagram

3.3.2 Data Dictionary

A data dictionary is a collection of descriptions about the data objects or items in a data model which benefits the programmers as well as other who need to refer to the data. In order to analyze a system of data object which allows the data user to interact, it is important to identify each data object and its relationship with other data object. This process is called data modeling and it will results in a picture of relationships of data. After each data object or item is given a descriptive name, its relationship is described, the type of data (such as text or image or binary value) is described, and possible predefined values are listed along with a brief textual description. This collection can be organized for reference purpose into a tabular form called a data dictionary. The data dictionary for the table used in the database were attached Appendix A.

4 Database Development

After designing the conceptual, logical and physical database then PostgreSQL is used to develop the database of the Indus River. It is Relational Database Management System and it is used to manage the data that is stored in relations.

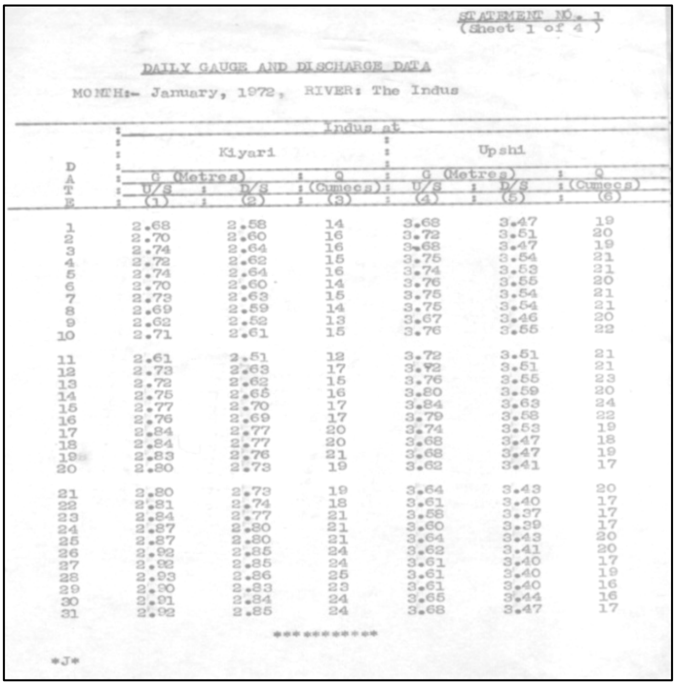
4.1 Digitalizing Historical Data

The first objective of the study is to convert the daily historical G & D data from the hard copy format to the digitalized form. The current practice of data management is conventional meaning that daily G & D data are compiled in the shape of books and reports as shown in Figure 13.

Figure 13 Picture Showing G & D data Compiled in Books and Reports

Source: Office of Pakistan Commissioner for Indus Waters (2009).

The G & D data sheet scanned from the reports is shown in the Figure 14. The data sheet shows the tabulated form of G & D data in which the gauge are measured in feet and the discharge are measured in cubic feet per second.



STATEMENT NO. 1
(Sheet 1 of 4)

DAILY GAUGE AND DISCHARGE DATA

MONTH:- January, 1972, RIVER: The Indus

DATE	Indus at Kiyari G (Metres) U/S (1)	Kiyari G (Metres) D/S (2)	Kiyari Q (Cumecs) (3)	Upshi G (Metres) U/S (4)	Upshi G (Metres) D/S (5)	Upshi Q (Cumecs) (6)
1	2.68	2.58	14	3.68	3.47	19
2	2.70	2.60	16	3.72	3.51	20
3	2.74	2.64	16	3.68	3.47	19
4	2.72	2.62	15	3.75	3.54	21
5	2.74	2.64	16	3.74	3.53	21
6	2.70	2.60	14	3.76	3.55	20
7	2.73	2.63	15	3.75	3.54	21
8	2.69	2.59	14	3.75	3.54	21
9	2.62	2.52	13	3.67	3.46	20
10	2.71	2.61	15	3.76	3.55	22
11	2.61	2.51	12	3.72	3.51	21
12	2.73	2.63	17	3.72	3.51	21
13	2.72	2.62	15	3.76	3.55	23
14	2.75	2.65	16	3.80	3.59	20
15	2.77	2.70	17	3.84	3.63	24
16	2.76	2.69	17	3.79	3.58	22
17	2.84	2.77	20	3.74	3.53	19
18	2.84	2.77	20	3.68	3.47	18
19	2.83	2.76	21	3.68	3.47	19
20	2.80	2.73	19	3.62	3.41	17
21	2.80	2.73	19	3.64	3.43	20
22	2.81	2.74	18	3.61	3.40	17
23	2.84	2.77	21	3.58	3.37	17
24	2.87	2.80	21	3.60	3.39	17
25	2.87	2.80	21	3.64	3.43	20
26	2.92	2.85	24	3.62	3.41	20
27	2.92	2.85	24	3.61	3.40	17
28	2.93	2.86	25	3.61	3.40	19
29	2.90	2.83	23	3.61	3.40	16
30	2.91	2.84	24	3.65	3.44	16
31	2.92	2.85	24	3.68	3.47	17

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Figure 14 Picture Showing Scanned Copy of G & D Data Sheet from Report

Source: Office of Pakistan Commissioner for Indus Waters (2009).

The upper catchment area of the River Indus is mostly a hilly terrain and lies in the north and north western part of Pakistan. The daily G & D data of the River Indus are measured by the gauging sites. There are more than 200 gauging sites which are located on the main stem and on the tributaries or nallahs (streams) of the River Indus. But as a case study, 36 gauging sites were selected in the upper catchment of the River Indus. The IDs of gauging site located on the main stem of River Indus is "IM" while the IDs of gauging sites located on the tributaries of River Indus is "IT". Table 5 shows 36 gauging sites selected on River Indus.

Table 5 Location map of Gauging Sites on River Indus

ID	Station	Latitude	Longitude
IM1	Indus at Kharmong	34.903	76.236
IT2	Shyok at Yugo	35.181	76.076
IM3	Indus at Kachura	35.428	75.46
IT4	Gilgit at Gilgit	35.951	74.342
IT5	Gilgit at Alam Bridge	35.808	74.607
IM6	Indus at Bunji Bridge	35.725	74.643
IT7	Astore at Doyian	35.545	74.727
IM8	Indus at Besham Qila	34.988	72.901
IT9	Brandu at Daggar	34.398	72.5007
IT10	Siran at Phulra	34.2399	73.1152
IT11	Chitral at Chitral	35.782	71.825
IT12	Swat at Kalam	35.507	72.619
IT13	Swat at Chakdara	34.722	72.141
IT14	Bara at Jhansi Post	33.898	71.25
IT15	Kabul at Nowshera	34.0474	71.9604
IM16	Indus at Mandori	33.8316	72.2258
IT17	Haro at Garriala	33.74324	72.27854
IT18	Soan at Chirah	33.57281	73.25411
IT19	Soan at Gorakhpur Bridge	33.47923	72.88017
IT20	Sil at Chohan	33.6798	73.3372
IT21	Soan at Dhoke Pattan	33.1226	72.2028
IM22	Indus at Massan	33.7911	71.9947
IT23	Kurram at Thal	33.7307	70.7615
IT24	Swat at Munda Headworks	34.57953	71.6637
IT25	Siran at Shinkari	34.4974	73.580783

Table 5 (Continued)

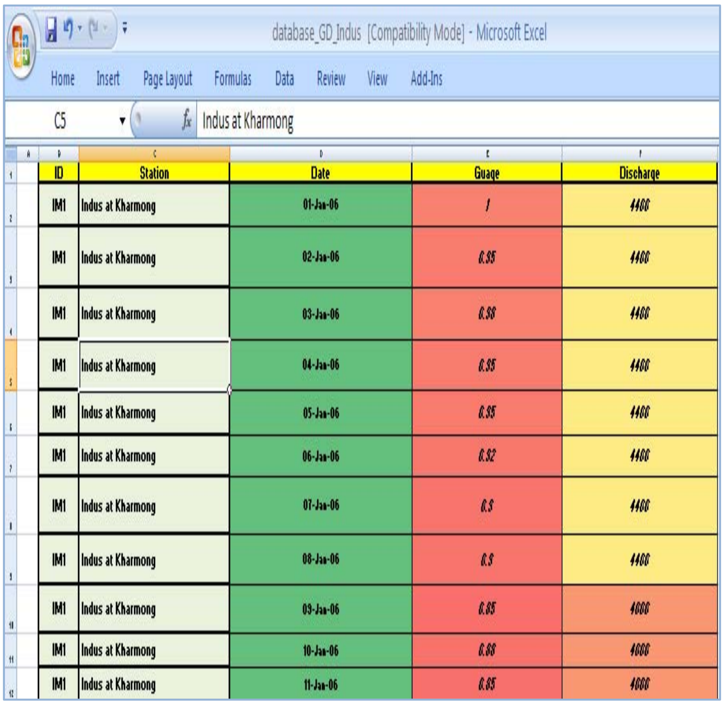
ID	Station	Latitude	Longitude
IT26	Daur at Makhan	34.1591	73.1192
IT27	Daur River at Rajoya	34.065	72.951
IT28	Siran River at Daryal	34.23229	73.08581
IT29	Khiali River at Charsada Road	34.166	71.7658
IT30	Kurram Headwork U/S	33.689	71.697
IT31	Kurram Headworks D/S	33.698	71.729
IM32	Indus at Attock	33.9393	72.2628
IM33	Indus at Kalabagh Above	32.95	71.53
IM34	Indus at Kaalabagh Below (Khudazai)	32.8311	71.4247
IT35	Soan at Dhok Chiniot	33.7357	73.3487
IT36	Soan at Makhad	33.008	71.777

The daily G & D data of the sites mentioned in Table 1 were collected for the past two years (2006 and 2007) from the following agencies:

1. Office of Pakistan Commissioner for Indus Waters

2. Surface Water Hydrology Project (SWHP) data, WAPDA.

More than 26,000 entities of the daily G & D data along with the date, station name and station’s ID were entered manually in Microsoft Excel as illustrated in Figure 15. Microsoft Excel is used because it can handle massive amounts of data in worksheets; moreover it offers an easy connectivity with the database.



ID	Station	Date	Guage	Discharge
IM1	Indus at Kharmong	01-Jan-06	1	4400
IM1	Indus at Kharmong	02-Jan-06	0.95	4400
IM1	Indus at Kharmong	03-Jan-06	0.98	4400
IM1	Indus at Kharmong	04-Jan-06	0.95	4400
IM1	Indus at Kharmong	05-Jan-06	0.95	4400
IM1	Indus at Kharmong	06-Jan-06	0.92	4400
IM1	Indus at Kharmong	07-Jan-06	0.9	4400
IM1	Indus at Kharmong	08-Jan-06	0.9	4400
IM1	Indus at Kharmong	09-Jan-06	0.85	4000
IM1	Indus at Kharmong	10-Jan-06	0.88	4000
IM1	Indus at Kharmong	11-Jan-06	0.85	4000

Figure 15 Screen Output Showing G & D Data in Microsoft Excel

The Spatial data about the location of the gauging sites on the Indus River and other pertinent features about the Pakistan were also developed. The location map of gauging sites on the Indus River is illustrated in Figure 16

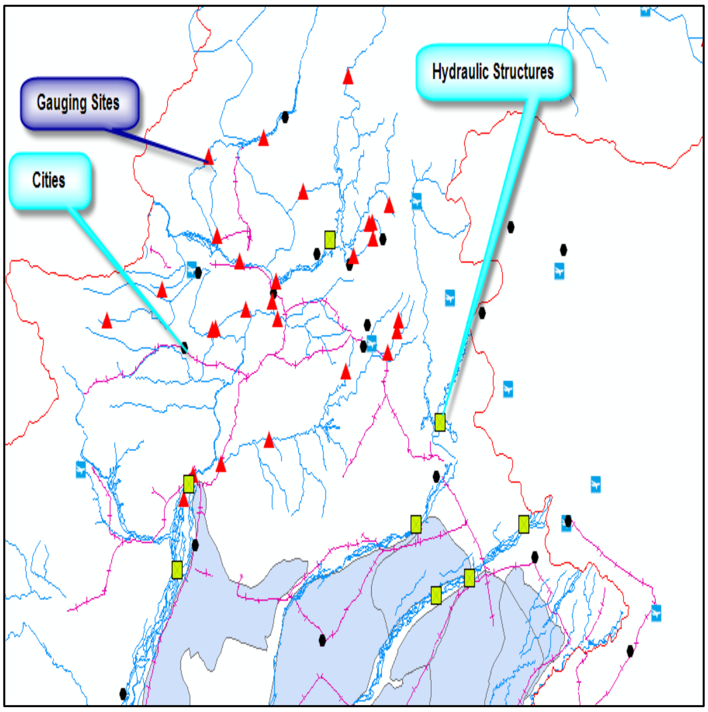


Figure 16 Screen Output Showing Gauging Sites on Indus River

A new database named as RIVERINDUS was created in PostgreSQL by using the "pgAdminIII". A total number of 25 tables were created in pgadmin III for storing the G & D data and the spatial data about the location of gauging sites, road network, airports, railway network, cities, contours lines, spot elevations, international border, canal networks, canal command area, location of hydraulic structures on the rivers, hydrological features of the area, physiographical features of land and coastal lines.

The G & D data was imported into the pgAdminIII by using the "EMS Data Import" program, which can import quickly import data from Microsoft Excel to the table of pgAdminIII as shown in Figure 17.

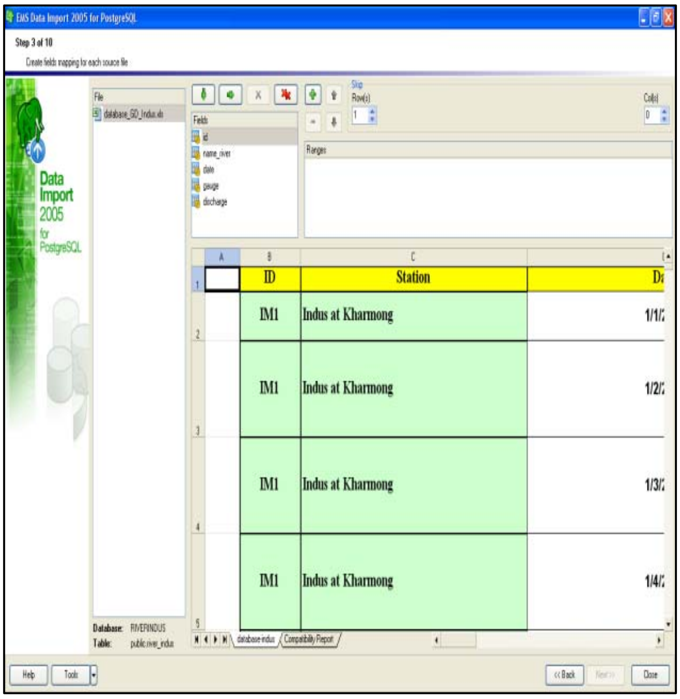


Figure 17 Screen Output Showing Data Import for PostgreSQL

The spatial data about the Indus River, the location of the gauging site and other features of Pakistan were also loaded in pgAdminIII and stored separately in tables. The spatial data was loaded into the database by using the "shp2pgsql" command line which is also called the Loader utility as illustrated in Figure 18. This utility convert spatial data into SQL files which then can be loaded into the database of pgAdminIII.

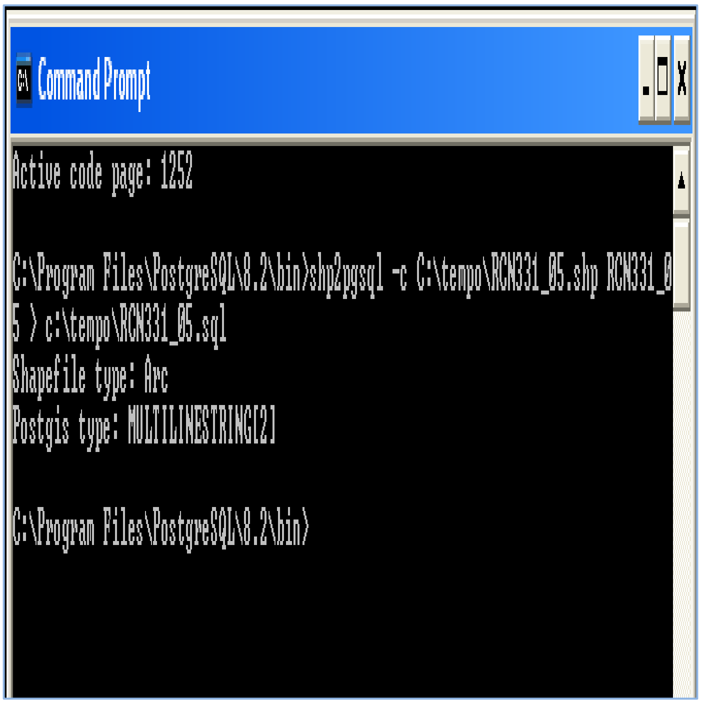


Figure 18 Screen Output Showing “shp2pgsql” Command Line

The data stored in the table of the pgAdminIII is illustrated in Figure 19.

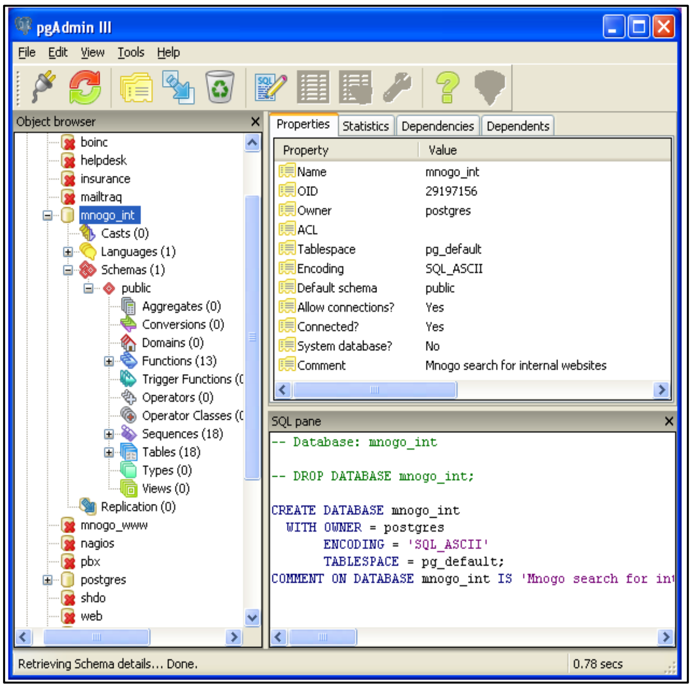


Figure 19 Screen Output Showing Tables in pgAdminIII

4.2 Publishing Data on Web

The spatial data stored in the PostGIS were published on web by using Geoserver as explained in following steps.

4.2.1 Start Geoserver and Login

In order to start Geoserver, click on ‘ start Geoserver’ in the Geoserver folder and then directing the internet browser to the Geoserver start page by opening http://localhost:8080/geoserver in a new browser. Log in with the username ‘admin’ and the password ‘Geoserver’ and click on ‘Submit’ button and Geoserver is ready to be used as shown in the Figure 20.

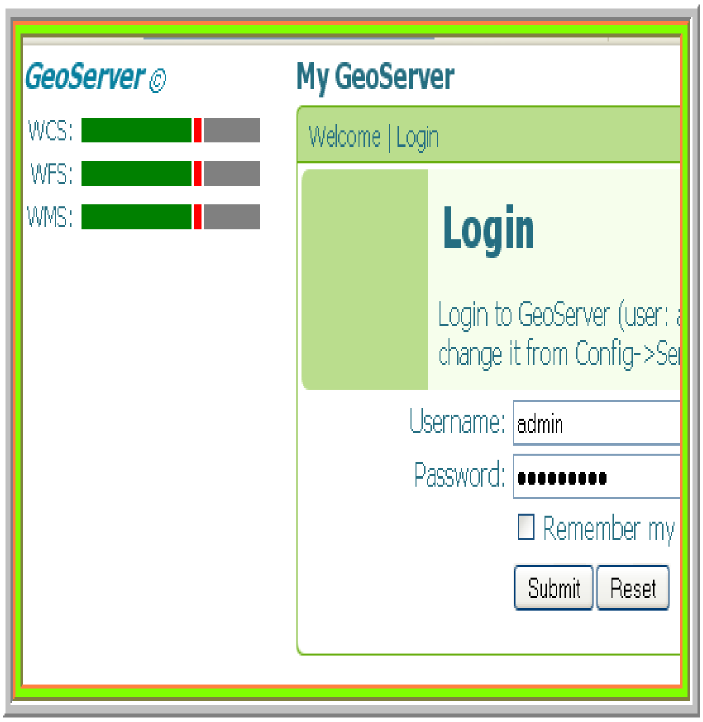


Figure 20 Screen Output Showing Login Geoserver

4.2.2 Create a Datastore

Now Geoserver was pointed out towards the data and its store by clicking the “config” buttons as shown in Figure 21.

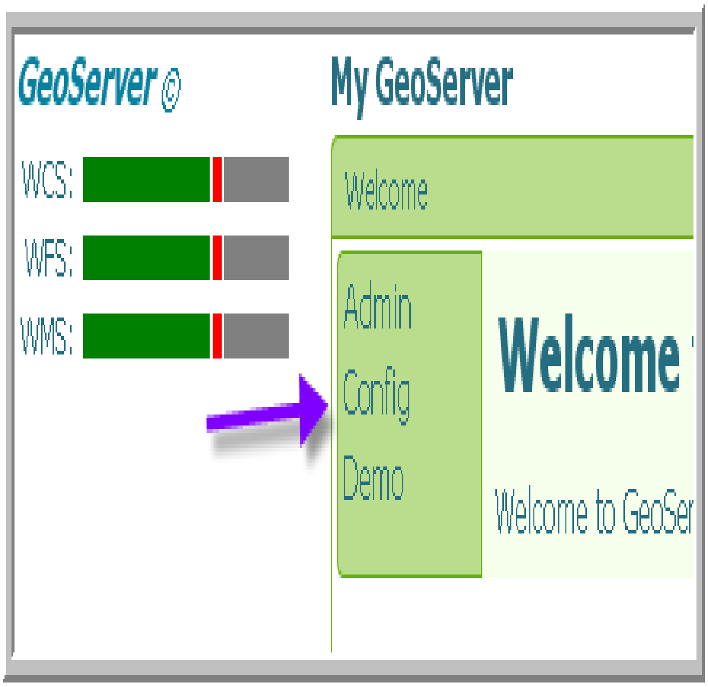


Figure 21 Screen Output Showing "Config" Button

Next click on the "data" button as shown in Figure 22

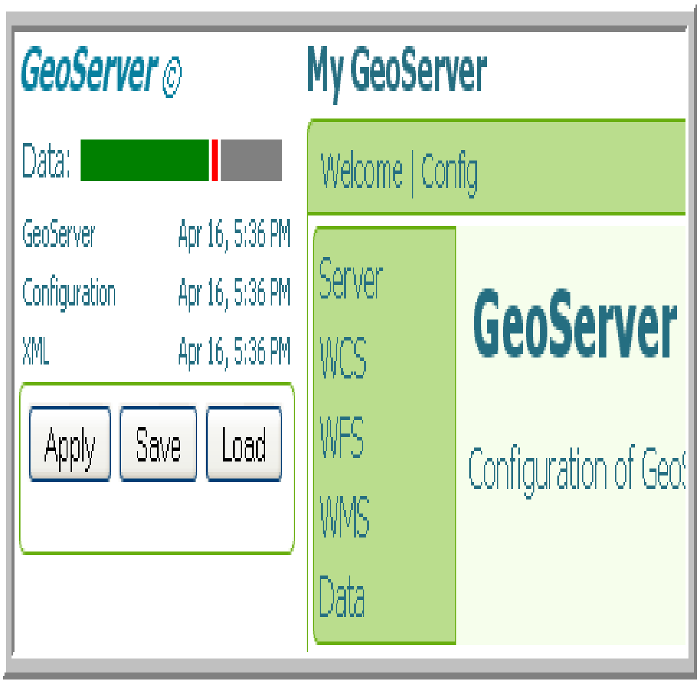


Figure 22 Screen Output Showing "data" Button

Then click on the “DataStores” button as shown in Figure 23

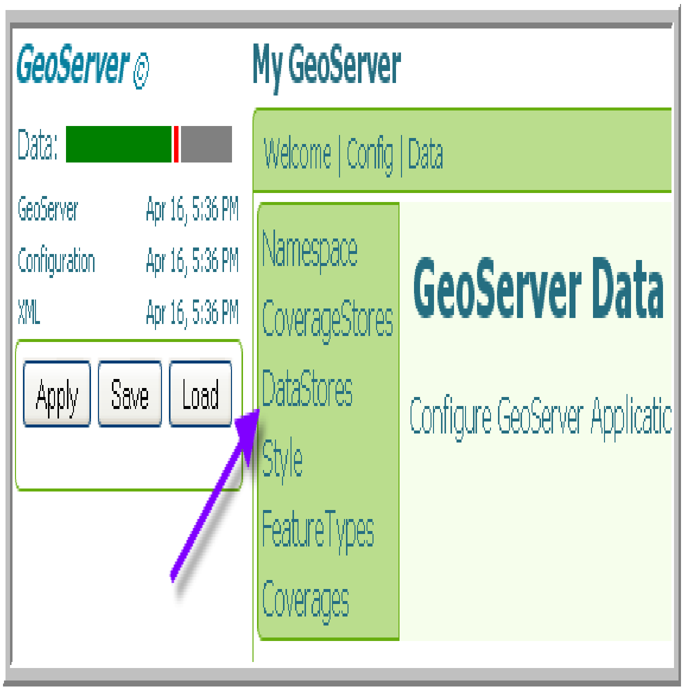


Figure 23 Screen Output Showing “DataStore” Button

Finally click on “New” Button as shown in Figure 24.

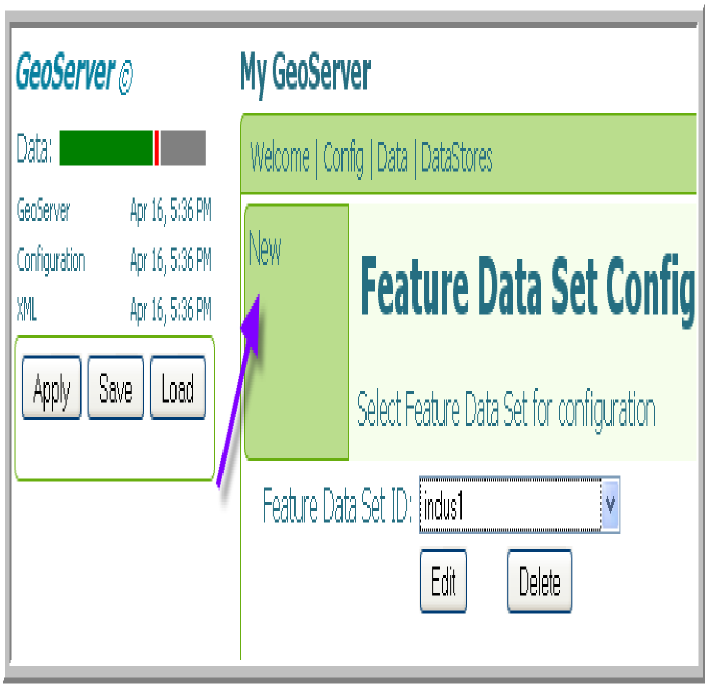


Figure 24 Screen Output Showing “New” Button

Type and source of spatial data was added in Geoserver by selecting “Postgis” from Feature Data Set Description drop- down menu. Then picking the name of data set and enters it in the Feature Data Set ID box (Indus). After that click “New” as shown in Figure 25.

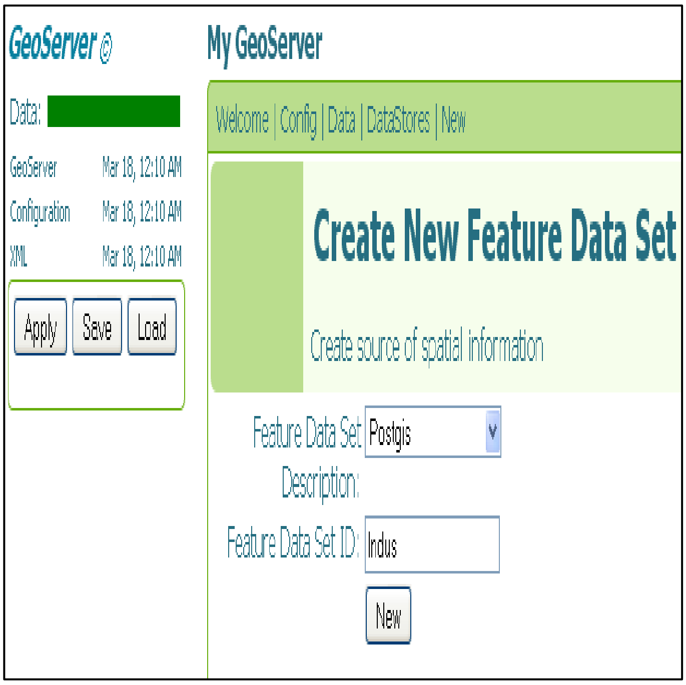


Figure 25 Screen Output Showing Selection of Source and Type of Data

Create connection with the database which is developed in the PostgreSQL. In the Feature Data Set Editor Dialog box enter the name of database, user name and password and then hit the “submit” button as shown in Figure 26.

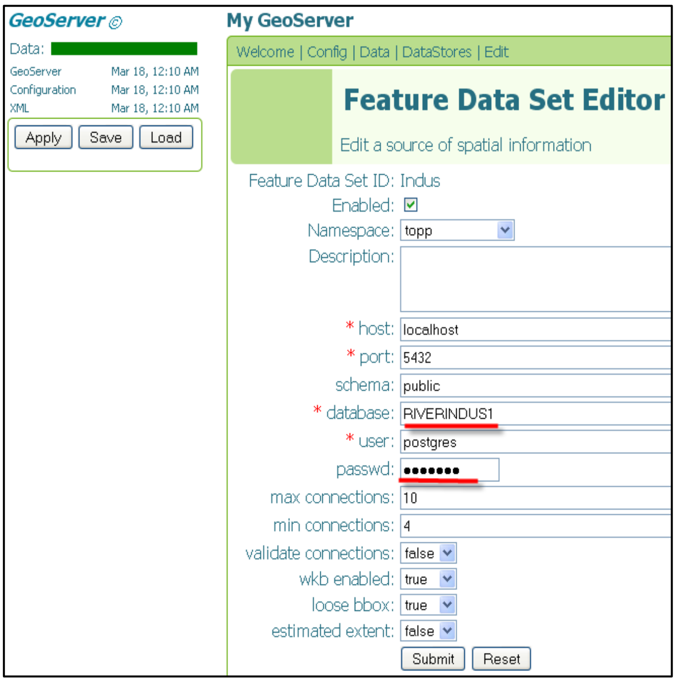


Figure 26 Screen Output Creating Connection with Database in PostGIS

Select the spatial data from the Database and hit "New" button as shown in Figure 27

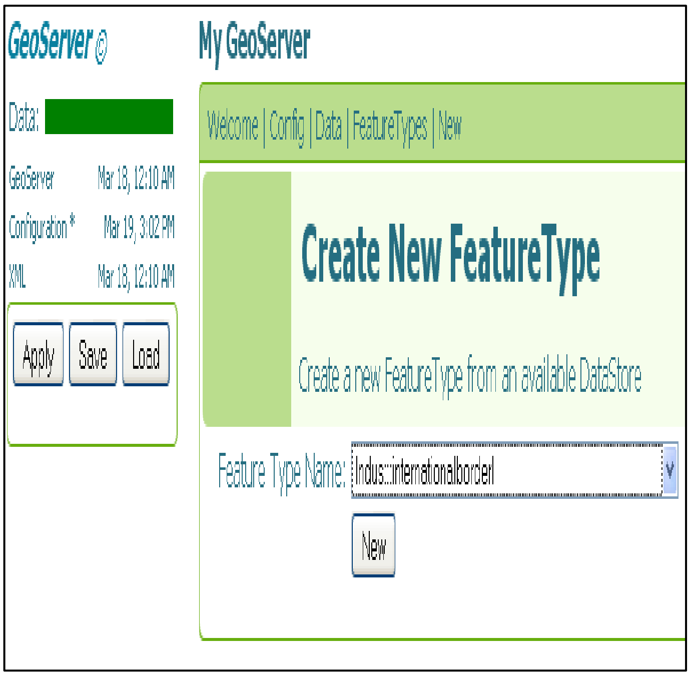


Figure 27 Screen Output Showing Selection of Spatial Data

4.2.3 Create Feature Type

In order to customize the spatial data to be presented on a map (text and polygon color, line thickness) in a Feature type Editor Dialog box find the " Style" field as shown in Figure 28.

Figure 28 Screen Output Showing Adding Style to Spatial Data

For creating new style to spatial data, click on "Create New SLD". A new Screen as shown in Figure 29 appears which help to customize data that appears on a map. Click the squares next to "Text Color" and "color of the lines" to select a color. Also select the width of line in pixel. Click "Apply Style" and then "Finished"

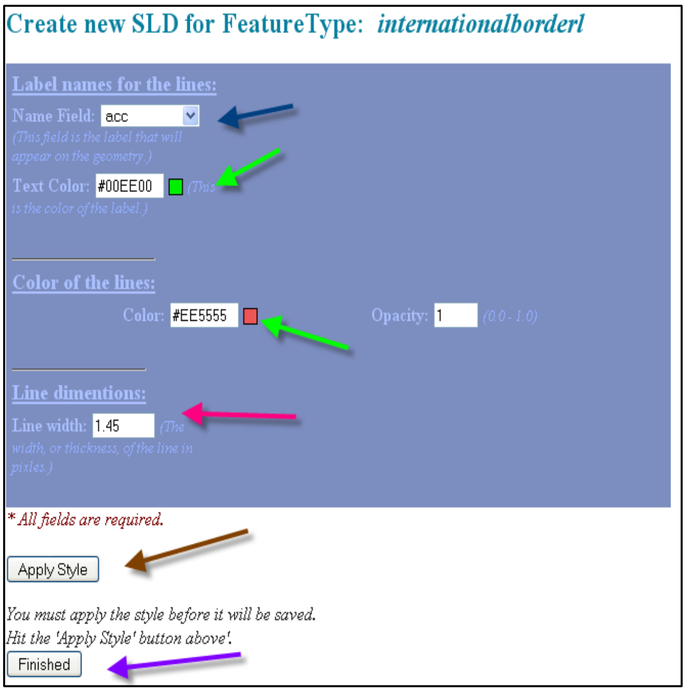


Figure 29 Screen Output Creating New SLD for Spatial Data

Spatial reference system (SRS) is a coordinate-based local, regional or global system used to locate geographical entities. World Geodetic System (WGS) is a standard for use in cartography, geodesy and navigation. It comprises a standard reference coordinate frame for the Earth, a standard spheroid reference surface for raw altitude data and gravitational equipotential surface (geoid) that defines the "nominal sea level." The latest version is WGS 84 (dating from 1984 and last revised in 2004), which is valid up to about 2010. The European Petroleum Survey Group (EPSG) defines numeric identifiers (EPSG code) for many common projections and associate projection for each identifier. EPSG: 4326 is a common coordinate system that refers to WGS 84 as (latitude, longitude) pair coordinates in degrees with Greenwich as the central meridian.

Find the "SRS" box and type "4326" in the box and click "Generate" button and after that click "Submit" button at the bottom of page as shown in Figure 30.

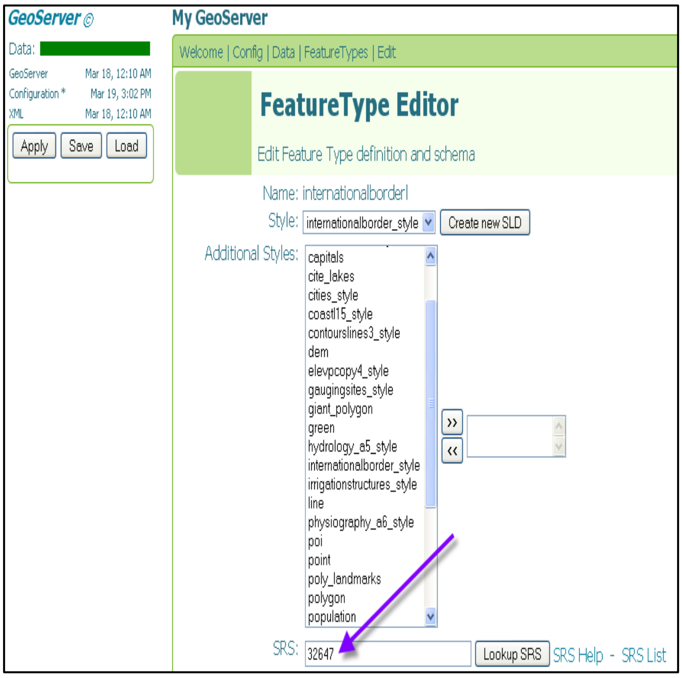


Figure 30 Screen Output Showing SRS box in Feature Type Editor

Finally click “Apply” and then “Save” at the top left of the screen which will store the spatial data as shown in Figure 31.

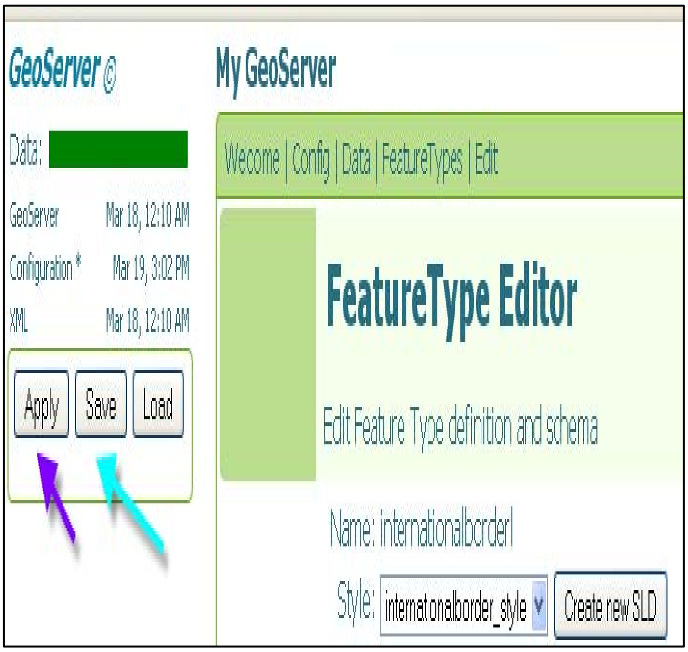


Figure 31 Screen Output Showing Spatial Data in Feature Type Editor

4.2.4 Viewing Data in Geoserver Homepage

In the Geoserver Homepage the spatial data can be viewed first by clicking the “Demo” button and then click “Map Preview” as shown in Figure 32.

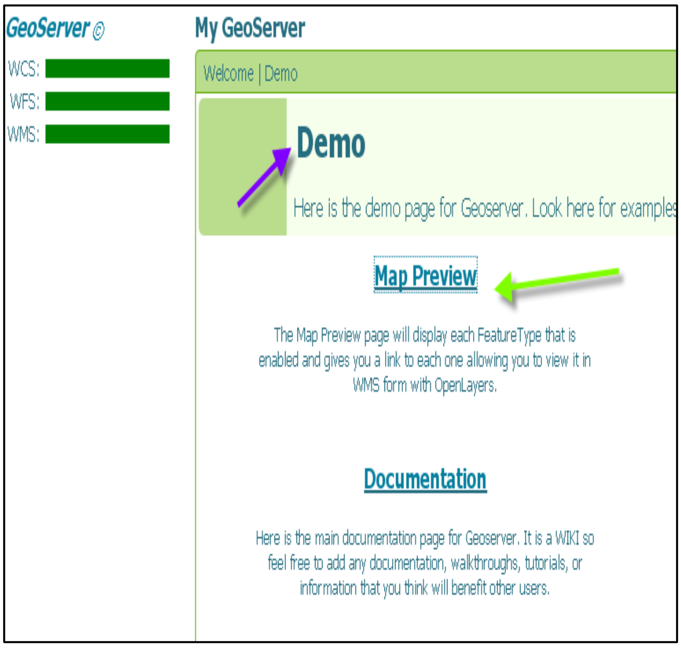


Figure 32 Screen Output Showing Demos and Map Preview in Geoserver

Then click on the “Preview” button located near the DataStore name as shown in the Figure 33.

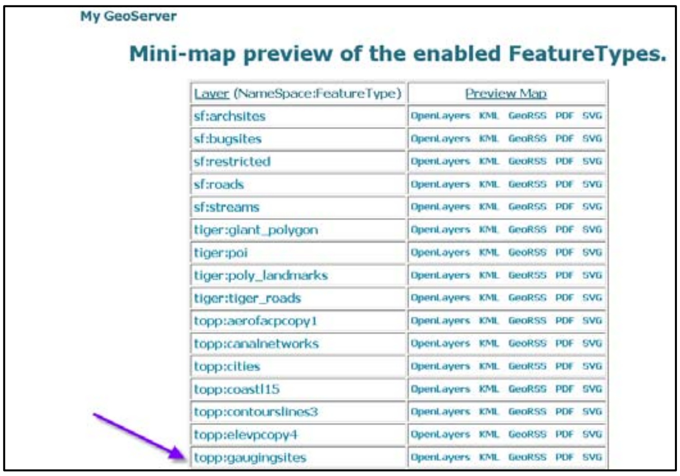


Figure 33 Screen Output Showing Mini-Map preview in Geoserver

The map preview is displayed in the OpenLayer as shown in Figure 34.

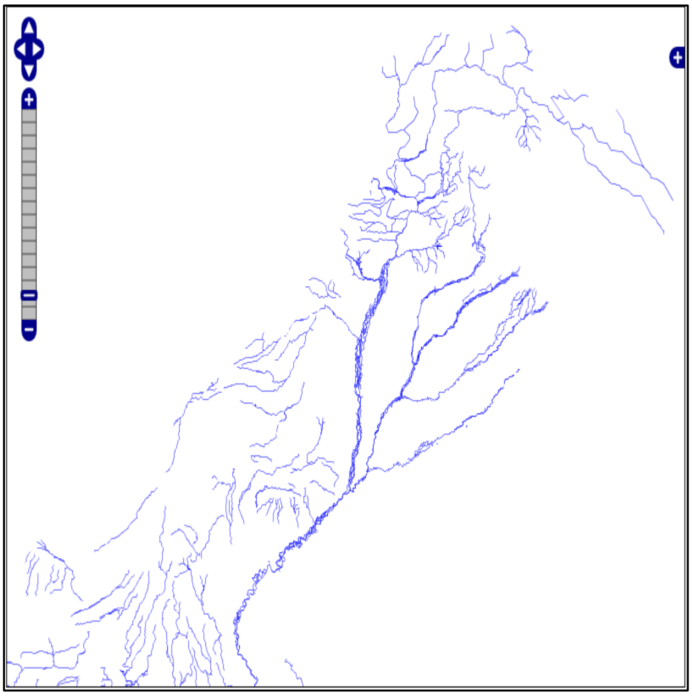


Figure 34 Screen Output of OpenLayers Preview

The map can be viewed in the Google Earth also by navigating the map preview page. A list of currently configured layers (Feature Types) in the Geoserver is available. Then click the "KML" link. A new dialog box asking how to open the file appeared. Then Select "open with" Google Earth and click ok. After that Google Earth start loading the layer as shown in Figure 35.

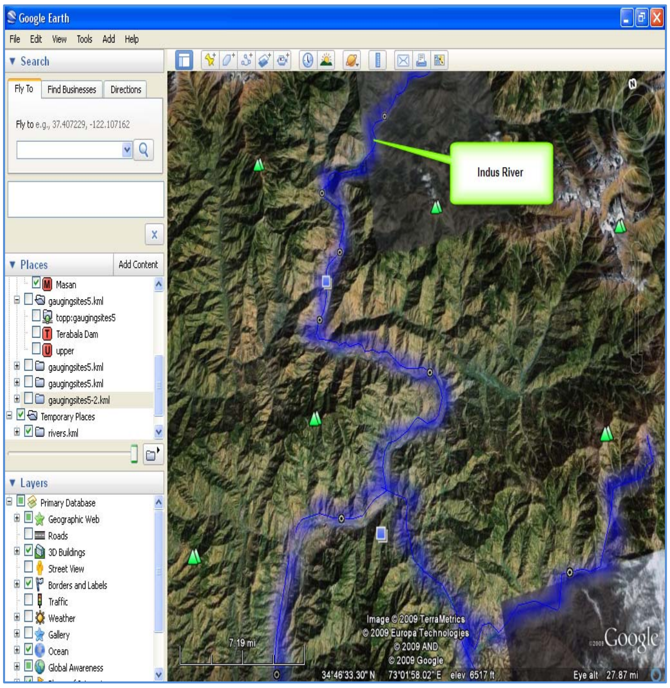


Figure 35 Screen Output of Layer Rendered in Google Earth

5. **System Implementation**

The source code for the system is written in PHP, which is a server side scripting language and is mainly used for creating dynamic and interactive websites and can be embedded into HTML.

PHP generally runs on the webserver by taking PHP as its input code and the output is in the form of the webpages. It is also available free with complete source code for the users. In order to access and generate the queries from the PostgreSQL database, SQL (Structured Query Language) is used. SQL is a programming language used for querying, modifying and managing the database. In order to add interactivity to HyperText Markup Language (HTML) pages the JavaScript is used which is a scripting langauge and is usually embedded directly into HTML pages. JavaScript is also free to use without purchasing a license and various commands of HTML. PHP, SQL, JavaScript and HTML are used to generate the source code of the web application of the system. The different languages are used for developing the web application; retrieving the data from the database and publishing the results on the internet. The source code of system is written in Macromedia Dreamweaver which is a web development application and is shown in Figure 36. The source code of the system is attached as Appendix B.

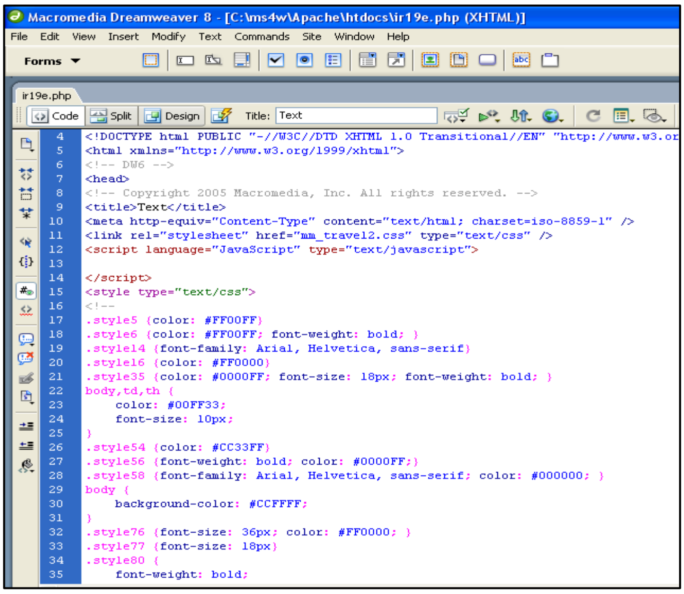


Figure 36 Screen Output Showing Source Code of System

The main interface of the system was developed in Geoserver is illustrated in Figure 37

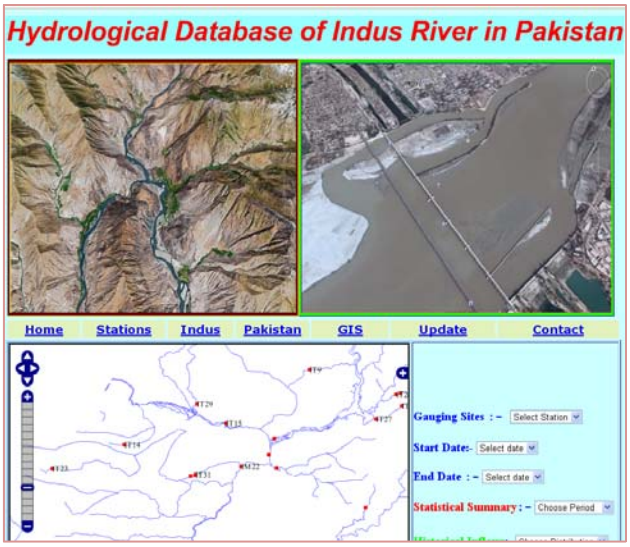


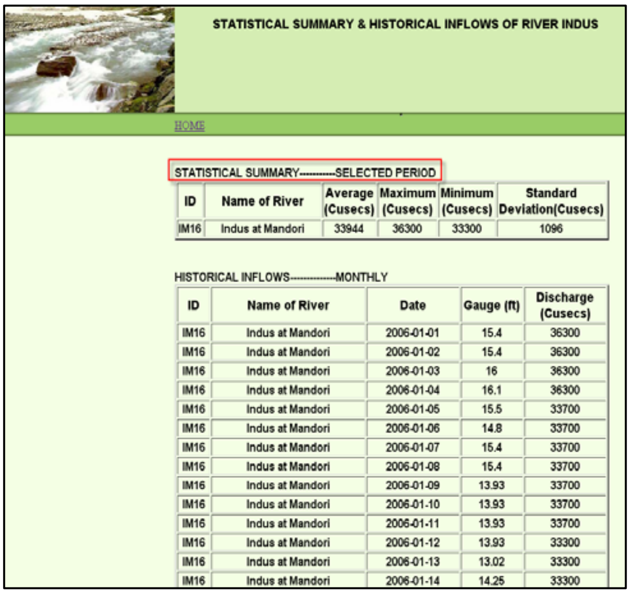
Figure 37 Screen Output Showing Interface of System

The system capabilites are explained as under.

5.1 Statistical Summary and Historical

One of the functional requirement of the system is to display the historical inflows of the river at different sites on daily, monthly and yearly basis as well as the statistical summary like maximum, minimum, average and standard deviation of the inflows.

The system was designed with a capability to display the statistical summary and historical inflows. The IDs of sites are selected from the drop down buttons provided on the main interface of the system. After selecting the period from the “start date” and “end date” buttons provided on the main interface of the system. The system generates the statistical summary such as maximum, minimum, average, standard deviation and also the historical inflows on daily, monthly and yearly basis as illustrated in Figure 38. Moreover, the system can generates statistical summary for the entire two year period along with the historical inflows for any selected site on the Indus River.



ID	Name of River	Average (Cusecs)	Maximum (Cusecs)	Minimum (Cusecs)	Standard Deviation(Cusecs)
IM16	Indus at Mandori	33944	36300	33300	1096

HISTORICAL INFLOWS-------------MONTHLY

ID	Name of River	Date	Gauge (ft)	Discharge (Cusecs)
IM16	Indus at Mandori	2006-01-01	15.4	36300
IM16	Indus at Mandori	2006-01-02	15.4	36300
IM16	Indus at Mandori	2006-01-03	16	36300
IM16	Indus at Mandori	2006-01-04	16.1	36300
IM16	Indus at Mandori	2006-01-05	15.5	33700
IM16	Indus at Mandori	2006-01-06	14.8	33700
IM16	Indus at Mandori	2006-01-07	15.4	33700
IM16	Indus at Mandori	2006-01-08	15.4	33700
IM16	Indus at Mandori	2006-01-09	13.93	33700
IM16	Indus at Mandori	2006-01-10	13.93	33700
IM16	Indus at Mandori	2006-01-11	13.93	33700
IM16	Indus at Mandori	2006-01-12	13.93	33300
IM16	Indus at Mandori	2006-01-13	13.02	33300
IM16	Indus at Mandori	2006-01-14	14.25	33300

Figure 38 Screen Output Showing Statistical Summary and Historical Inflows

5.2 Mapping, Visualizating and Navigating with Maps

The other functional requirement of system to visualize the gauging sites on the Indus River in the form of maps showing the geographic location of the gauging sites on the River Indus and other pertinent features of the Pakistan like cities, roads, railways and international boundary in nice and presentable way. The system supports the basic GIS functionalities like zoom in, zoom out and panning of the map.

In the light of functional requirement , the system was designed to visualize the maps in the forms of the different layers. The base layer shows the "Rivers", while there are overlayers which can be switch off and on. The overlayers shows the geographic location of gauging sites labelled with reference to their IDs, road network, location of airports, railway network, location of cities, contours lines, spot elevations of country, international border, canal network, canal command, location of hydraulic structures, hydrological features of the area, physiographical features of land and coastal lines. The maps can be navigated by means of zooming and panning functionalities of GIS as demonstrated in Figure 39.

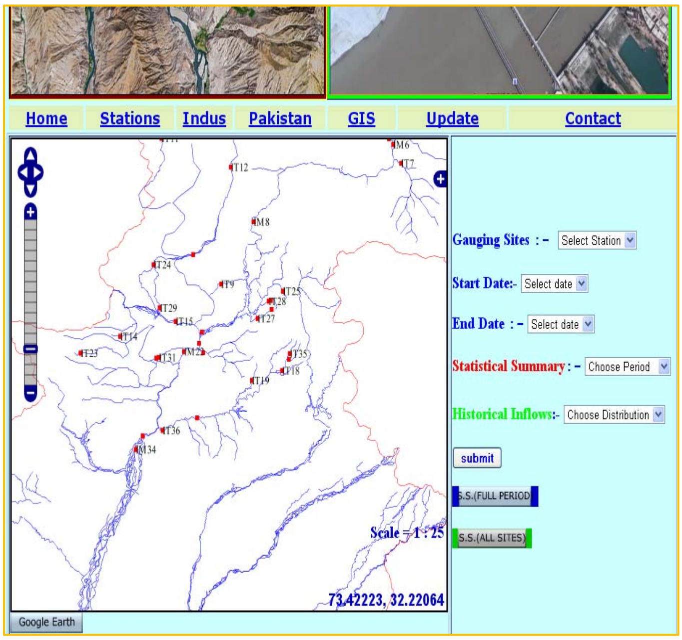


Figure 39 Screen Output Showing River and Gauging Sites

The Indus River and the gauging sites can also be visualized in the Google earth, which is a 3-D virtual globe program. Google Earth displays satellite images of varying resolution of the Earth's surface, allowing users to visually see things like cities and houses looking perpendicularly down or at an oblique angle, with perspective. It allows virtually viewing, panning, and flying around Earth imagery as shown in Figure 40. The Google Earth offers a number of tools that can be used to measure distance and estimate sizes.

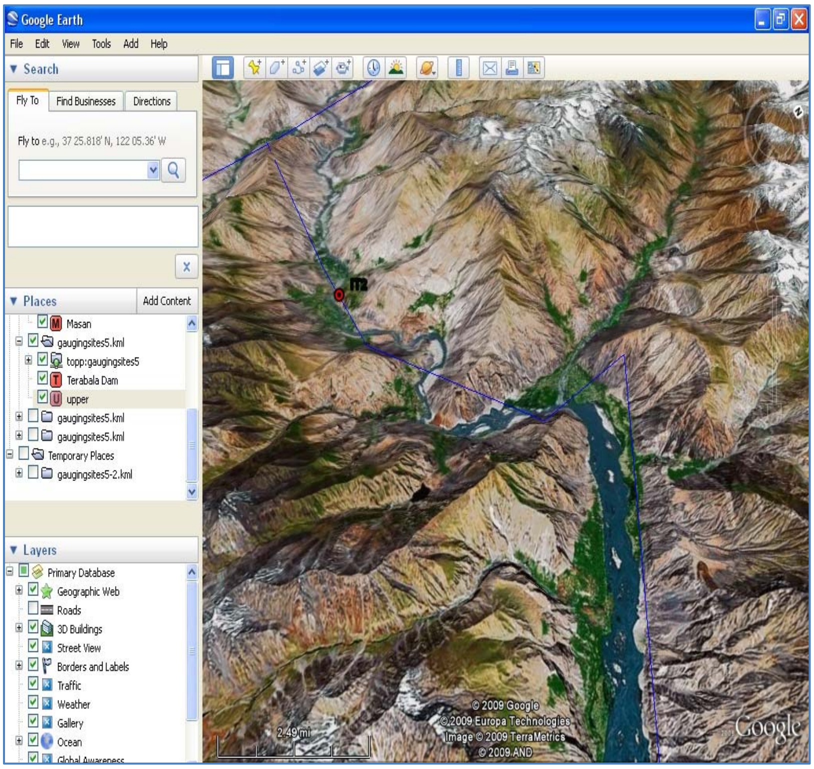


Figure 40 Screen Output Showing River and Gauging Sites in Google Earth

5.3 Database Management

Another functional requirement of the system is to support the database management functions which include different operations like the retrieving, adding, updating and deleting the data.

The system has the capability to modify the historical G & D database developed in PostgreSQL. There is “update” link available on the main interface of the system which allows data users to perform different operations like viewing, editing and deleting the database as shown in the Figure 41. However, the system check against the unauthorized modification of the database by allowing first to enter the login and the password.

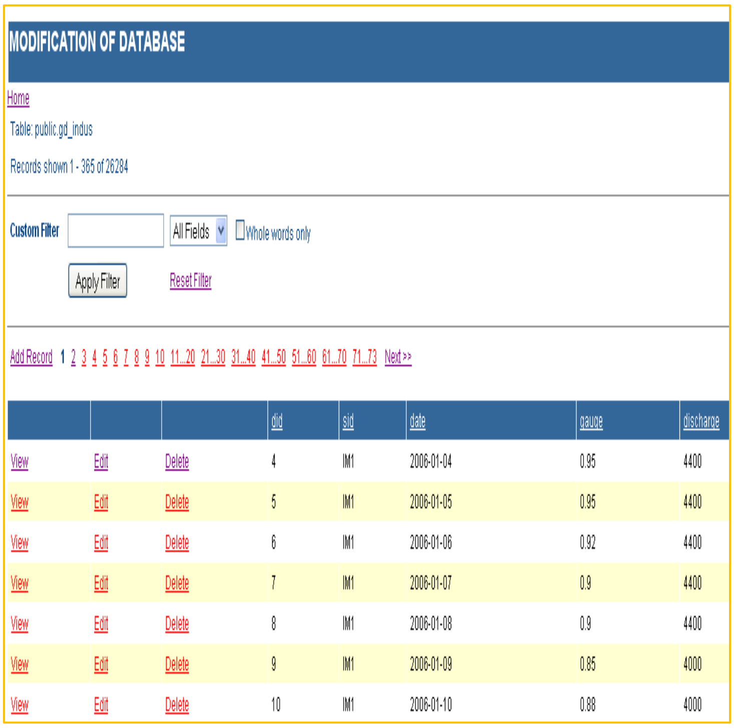


Figure 41 Screen Output Showing Modification in Database

6 Site Selection for Dam Construction

A satisfactory site for a dam must fulfill certain functional and technical requirements. Functional suitability of a site is governed by the balance between its natural physical characteristics and the purpose of the dam. The hydrology of the river, available head and storage volume must be matched by the operational parameters set by the nature and the scale of the project served. Technical suitability is dictated by the presence of a site (or sites) for a dam, the availability of material suitable for dam construction and by the integrity of the reservoir basin with respect to leakage. The hydrological and geological or geotechnical characteristics of catchment and site are the principal determinants establishing the technical suitability of a reservoir site. The principal stages involved in site appraisal and leading to selection of the optimum dam site and type of dam are indicated schematically in Figure 42.

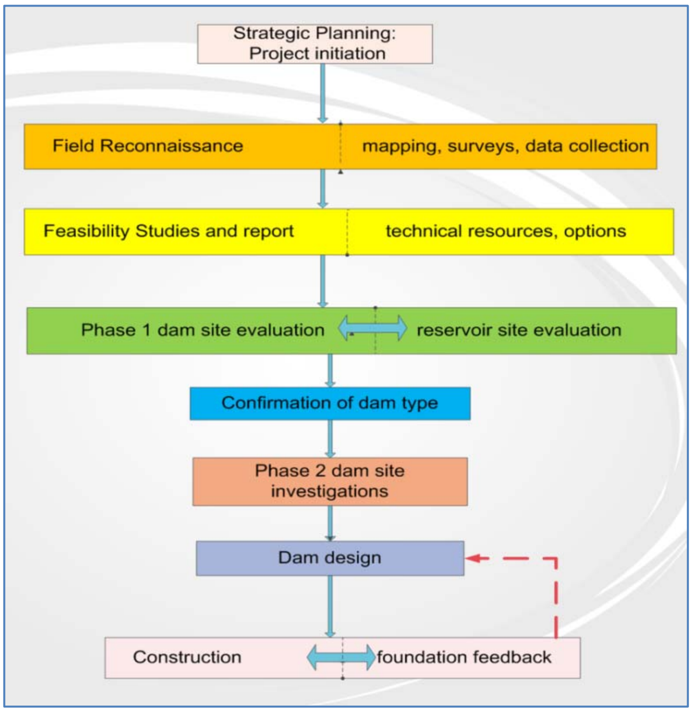


Figure 42 Stages in Dam Site Appraisal and Project Development

The considerable time is elapsed between initial strategic planning, with identification of the project requirment and commencement of construction on site. A significant proportion of that time may be attributable to the 'political' decision-making processes and do arranging project funding.

In the reconnaissance phase, the principal objective is to collect extensive topographical, geological and hydrological survey data. Large-scale maps and any records already available provide the starting point, but much more detailed surveys will inevitably be required. Aerial reconnaissance, employing modern sensors in addition to the traditional photogrammetic survey techniques has a particular role to play in the preparation of accurate and large-scale site plans. In the hands of a skilled interpreter, aerial surveys also provide valuable information on geology, on possible dam sites and on the likely availabiliy of construction materails. Hydrological surverys are directed to determining rainfall and run-off characteristics and historical evidence of floods.

The feasibilty report prepared at the conclusion of the reconnaissance phase assembles and interprets all available information, data and records and makes initial recommendations with respect to the technical and economic viability of the reservoir. Options with regards to the location, height and type of dam are set out, and comparions drawn in terms of estimated cost and construction programmes. On the strength of this report a decision can be made with respect to the further detailed investigations required to confirm the suitability of the reservoir basin and preferred dam site(or sites).

6.1 Physical Factors Govering Site Selection of Dam

6.1.1 Hydrology of River

Hydrology of river is the most important parameter that governs the suitability of site for the construction of dam. The hydrologic investigations primarily include the determination of the yield of streamflow, water requirements for project purpose, flood flows, ground flow water condition and sediment which will be deposited in the reservoir.

The most accurate estimate must be prepared of the portion of the streamflow yield that is surplus to senior water rights as the basis of the justifiable storage. Reservoir storage will supplement natural yield of streamflow during low-water periods. Safe reservoir yield will be the quantity of water which can be delivered on a firm basis through a critical low-water period with a given reservoir capacity. Reservoir evaporation and other incidental losses should be accounted for before computation of net reservoir yield. The critical low-water period may be 1 drought year or a series of dry years during the period of recorded water history. Water shortage should not be contemplated when considering municipal and industrial water use. For other uses, such as irrigation, it is usually permissible to assume tolerable water shortages during infrequent drought periods and thereby increase water use during normal periods with consequent greater project development.

Water requirments should be determined for all purpose contemplated in the project studies must include estimates of flood flows, as they are essential to the determination of the spillway capacity. Consideration should also be given to annual minimum and mean discharges and to the magnitudes of relatively common floods of frequencies up to about 10-year recurrence intervals, as this knowledge is essential for construction purposes such as diverting the stream, providing cofferdam protection, and scheduling operations.

Project studies should also include a ground water study which may be limited largely to determining the effect of ground water on construction methods. However, some ground water situation may have an important bearing on the choice of the type of dam to be constructed and on the estimates of the cost of foundations.

The web-based GIS hydrological database system for the Indus River helps the data users to select suitable sites for the construction of dams based on average annaul inflow of the Indus River. This can be done by selecting statistical summary of “all” gauging sites from the main interface of the system. The system then generates the statistical summary of all the gauging sites and then accordingly ranks the sites based on the average annual inflow of the Indus River. The average annual inflow is a commonly accepted criterion used by the hydrologists and the dam designers to access the suitability of site for the construction of dam. In order words it shows that the quantum of water available to be stored behind the dam. Two sites “ Masan” and “Kalabagh”, are identified by the sytem as the potential suitable sites for the construction of dam based on the average annual inflows. Table 6 shows the ranking of 2 suitable sites based on average annual inflow.

Table 6 Suitable Sites on Indus River Based on Average Annual Inflow.

ID	Name of River	Average (Cusecs*)	Maximum (Cusecs*)	Minimum (Cusecs*)	Standard Deviation(Cusecs*)
IM22	Indus at Massan	139,851	420,000	7,830	94,061
IM34	Indus at Kalabagh Below (Khudazai)	112,307	489,606	12,105	81,015

*****Cusecs (cubic feet per second)

The "Masan" gauging site is located on the main stem of the Indus River and it is approximately 15 miles downstream of the Attock a famous city and confluence point of the Indus River and Kabul River. The Location map of site as viewed from the Google Earth is shown in Figure 43. The hydrolgy of Indus River at this site shows the average annual inflow of 139,851 cusecs based on the two years period.

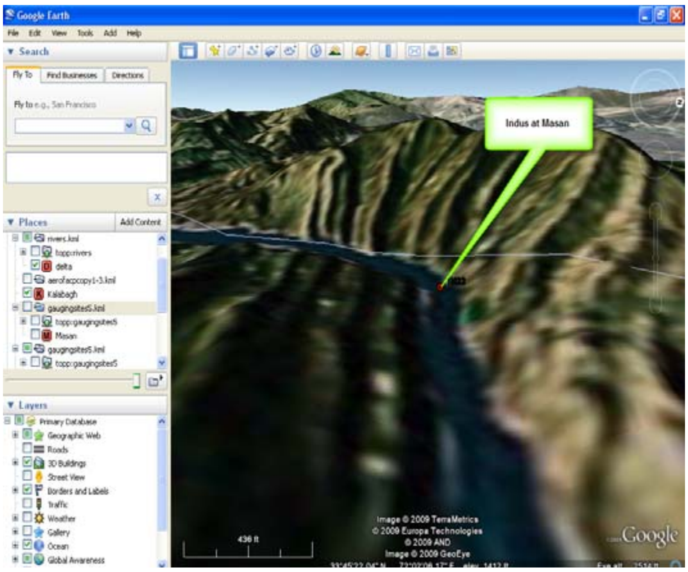


Figure 43 Screen Output Showing Geospatial Location of Indus at Massan

The other site “Kalabagh” is on main stem of the Indus River with average annual inflow of 112,307 cusecs. At this site Government of Pakistan (GOP) has planned to construct a Kalabagh Dam Project (KDP), which is located 16 miles upstream of Jinnah Barrage and about 92 miles downstream of Attock city. The project envisaged construction of 260 feet high dam which create a reservoir with usable storage of 6.1 million acre feet (MAF) for multipurpose utilization of power generation, irrigation supplies and flood control. The annual generation of energy would amount to about 11,200 GWh, generated by hydro power plant of 2400 MW capacity. This capacity may ultimately be increased to 3600 MW, making KBD one of the largest hydro generation dams in Asia. The location map of proposed KDP as viewed from Google Earth is shown in Figure 44.

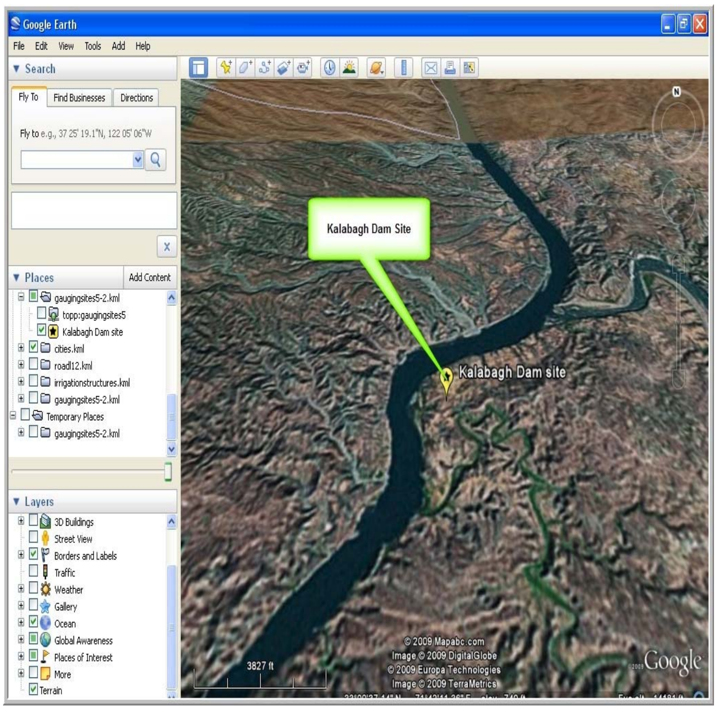


Figure 44 Screen Output Showing Geospatial Location Kalabagh Dam Project

6.1.2 Topography of River Valley

A dam is by nature linked to an environment. The topography of river valley therefore plays a vital role in the choice of dam site and most suitable type of the dam. One of the best places for building a dam is a narrow part of a deep valley. The valley sides can then act as natural walls. A narrow streams flowing between high rocky walls would naturally suggest a concrete overflow dam. The low rolling plains country suggests an earth fill dam with a separate spillway.

From the Google Earth, it appeared that the topography of “Masan” and the “Kalabagh” sites is suitable for dam construction, subject to further investigation, because of the existence of the narrow gorges as shown in Figures 42 and 43 above. The gorge at the site of KDP is only 1,300 feet wide and while there is steep and narrow gorge at “Masan” site. The narrow gorges are most appropraite for the construction of Roller Compacted Concrete (RCC) dam. RCC is a special blend of concrete, having same ingredeints as conventional concrete but it is much drier and has no slump. It has been increasely used to build concrete dams since low cement content cause less heat to be generated while curing.

6.1.3 Geology and Foundation Conditions

Foundation conditions depend upon the geological character and thickness of the strata which are to carry the weight of the dam, their inclination, permeability, and relation to underlying strata, existing faults and fissures. The foundation will limit the choice of type to a certain extent, although such limitation will frequently be modified, considering the height of the proposed dam. The different foundations commonly encountered are discussed below.

6.1.3.1 Solid Rock Foundations

Solid rock foundations have relatively high bearing power and resistance to erosion and percolation and it offers few restrictions as to the type of dam that can built upon them. Economy of materials or overall cost will be ruling factor. The removal of disintegrated rock together with the sealing of seams and fractures by grouting will frequently be necessary.

6.1.3.2 Gravel Foundations

Gravel foundations if well compacted are suitable for earthfill, rockfill and low concrete gravity dams. As gravel foundations are frequently subject to water percolation at high rated special precautions must be taken to provide effective water cutoffs or seal.

6.1.3.3 Silt of fine sand foundations

Silt of fine sand foundations can be used for the support of low concrete gravity dams and earthfill dams if properly designed, but they are not suitable for rockfill dams. The main problems are settlement, the prevention of piping, excessive percolation losses and protection of the foundation at the downstream toe from erosion.

6.1.3.4 Clay foundation

Clay foundations can be used for the support of earthfill dams but require special treatment. Since there may be considerable settlement of the dam if the clay is unconsolidated and the moisture content is high, clay foundations ordinarily are not suitable for the construction of concrete gravity dams, and should not be used for the rockfill dams. Tests of the foundation material in its natural state are usually required to determine the consolidation characteristics of the material and its ability to support the superimposed load.

6.1.3.5 Non uniform foundations

Non uniform foundations occasionally occur where reasonably uniform foundations of any of the foregoing discussion is not found and where a nonuniform foundation of rock and soft material must be used if the dam is to be built. Such unsatisfactory conditions can often be overcome by special design features. Each site however presents a problem for the appropriate treatment by experienced engineers.

The Kalabagh and the Masan sites lies in the harmless geological formation of Pothwar Plateau with salt strata into the shape of bowl as shown in Figure 45. It is believed that about 210 million years ago, the movement of tectonic plates forced the salt formation to fold into the shape of a bowl due to which the northern edge of the bowl appeared close to Kalachita Range while the southern rim in the form of famous salt range. Indus River bifuricates the southern rim so that Kohat range falls on its west side and the Khewra range on its east side. The layer of salt rocks sitting 2000 meters under the KBD site will not allow vertical permeability of water to reach that level. Thus the foundation conditions depict the construction of dam but subject to further detailed geological/ geotechnical investigations.

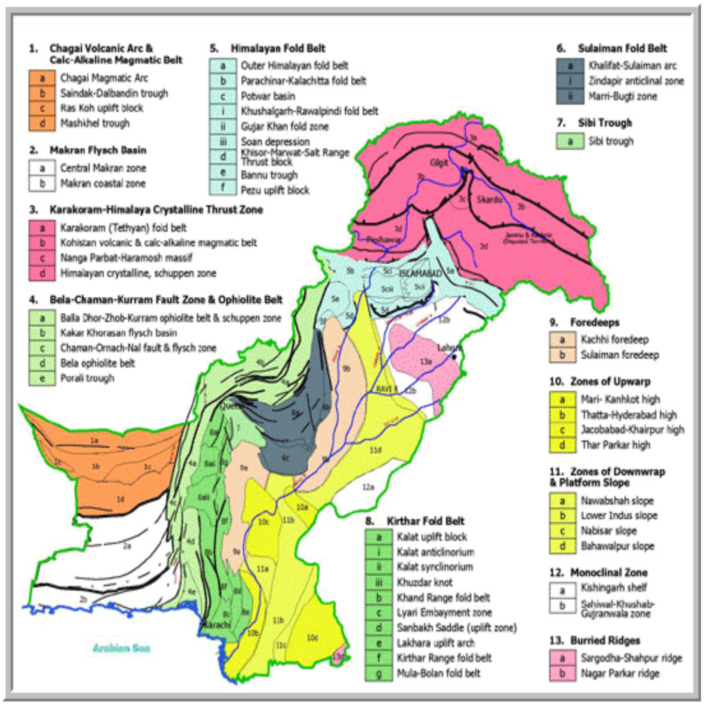


Figure 45 Map Showing Tectonics Zones of Pakistan

Source: Geological Survey of Pakistan (2009)

6.1.4 Availability of Material

Materials for the dams of various types which may sometimes be available at or near the site are

1. Soil for embankment
2. Rock for embankment and riprap
3. Concrete aggregate (sand, gravel, crushed stone)

Elimination or reduction of transportation expenses for construction materials particularly those which are used in great quantity will effect a considerable reduction in the total cost of the project. The most economical type of dam will be found in sufficient quantity within a reasonable distance from the site.

The presence of the rocks as visualized from Google Earth indicates that both sites have enough material available for the construction of the dam. However, further site investigation is needed to carryout to exactly quantify the availability of construction material. For the RCC dams construction the main requirement is the crushed aggregates that can be derived from quarries or excavations. Moreover it is also possible to extract material from the reservoir itself and thus increasing the reservoir storage. This will also keep the cost of the transport and restoring borrows area to a minimum.

Moreover, necessary infrastructure like roads are also available which link both the sites to the nearby cities. Therefore, the transportation of the construction equipments and the materials are easy.

Figure 46 shows the location of Attock city which is approximately 23 miles upstream of the "Masan" site and also nearby road passing close to site.

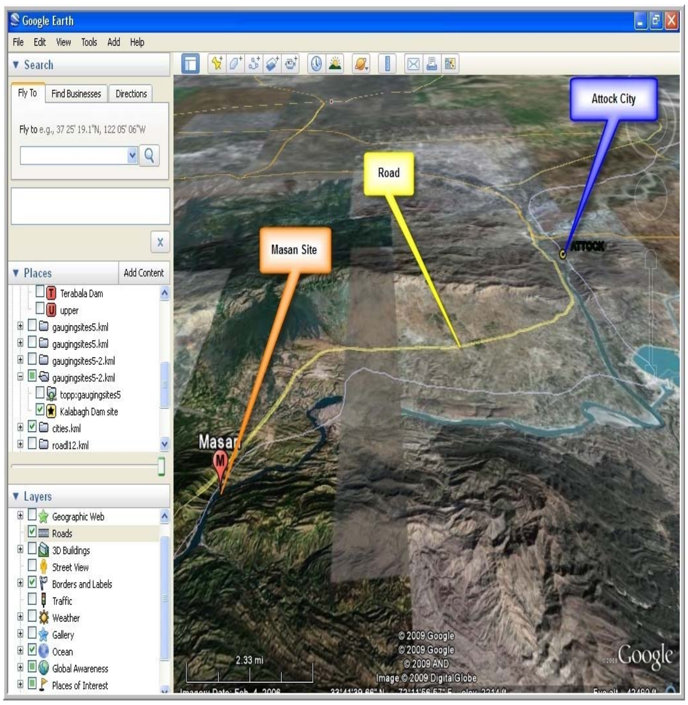


Figure 46 Screen Output Showing locations of City and Road close to Masan

Figure 47 shows the location of Duad Khel city which is approximately 14 miles downstream of the "KDP" site and national highway (N60) which is also close to site.

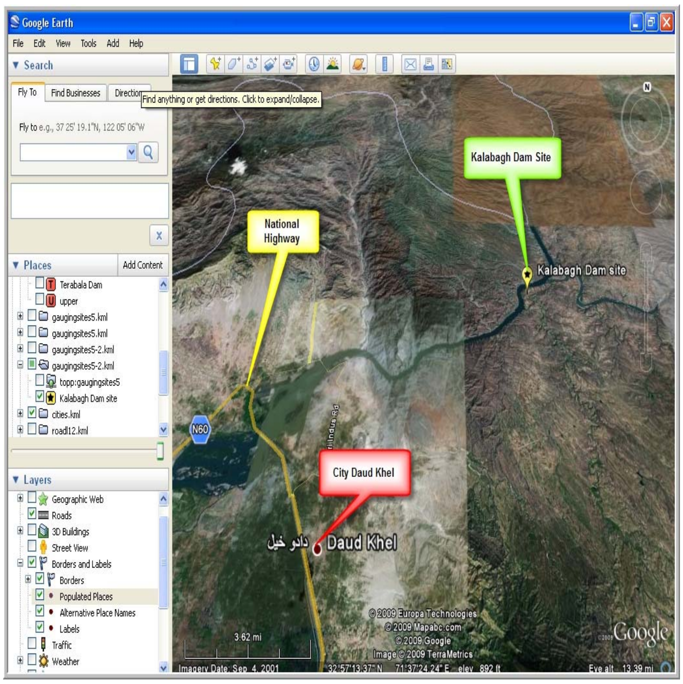


Figure 47 Screen Output Showing locations of City and Road close to KDP

6.1.5 Spillways Size and Location

Dams require certain ancillary structures and facilities to enable them to discharge their operational function safely and effectively. The purpose of the spillway is to pass flood water safely downstream when the reservoir is full. It has two principal components; the controlling spill weir and the spillway channel, the purpose of latter being to conduct flood flows downstream of the dam. The latter may incorporate a stilling basin or other energy-dissipating devices. The spillway capacity must accommodate the maximum design flood, the spill weir level dictating the maximum flood level of the dam.

The cost of constructing a large spillway is frequently a considerable portion of the total cost of the development. In such cases, combining the spillway and dam into one structure may be desirable indicating the adoption of a RCC overflow dam as shown in Figure 48. In certain instances where excavated material from separate spillway channel can be utilized in dam embankment an earthfill dam may be prove to be advantageous. Small spillway requirement often favours the selection of earthfill or rockfill dams, even in narrow dam sites.

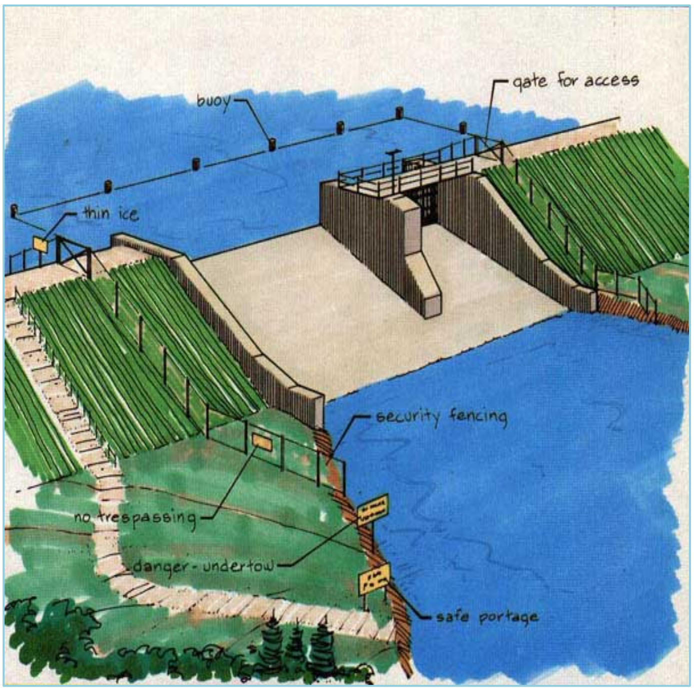


Figure 48 Picture Showing Overflow Spillways in RCC Dam

From the analysis of the statistical summary generated by system, it was found out that maximum flood discharge at "Masan" site is 420,000 cusecs while at the "Kalabagh" site it is 489,606 cusecs. Therefore, it is imperative that spillway must be incorporated in the design of dam to cater for the flood discharges.

The design of KDP envisages the combination of overflow and orifice type of spillways for the KDP. The overflow type spillway can discharge 1,070,000 cusecs of flood water, while the discharging capacity of the orifice spillways is 980,000 cusecs. Some features of Kalabagh reservoir are very favourable for sluicing of sediment. Firstly, the orifice spillway of Kalabagh Dam has its crest elevation 40 ft. below the minimum level of 825 Survey of Pakistan datum (SPD).

Secondly, the operational rules specify the retention of the reservoir at the minimum level of 825 SPD in the months of June and up to 20th July, which shall enable direct sluicing of the silt laden early floods, as well as the removal of the sediment deposited in the preceding months. Thirdly, the long and narrow gorge type reservoir favours flushing of the reservoir by high flows during the flood season. These features allow considerable less sedimentation in the reservoir and in effect, give a perpetual life to Kalabagh reservoir. For “Masan” site orifice type of spillway is appropriate, subject to further investigations, as it can perform dual functions of discharging the maximum flood discharge and the flushing out the sediments from the reservoir.

6.1.6 Earthquakes

If the dam lies in an area that is subject to earthquake shocks the design must include provisions for the added loading and increased stresses. The types of structures best suited to resist earthquake shocks without damage are earthfill and concrete gravity dams.

The Earthquake density map of Pakistan (which indicates the average number of earthquakes with magnitude 5 and greater per year) is shown in Figure 49. Without prejudice to the detailed seismic analysis, it appeared that proposed sites are safe against the earthquakes. However, as measure of the assurance of over seismicity it has been suggested that most well engineered dams on a competent foundation can accept a moderate seismic event, with peak acceleration in excess of 0.2g without fatal damage.

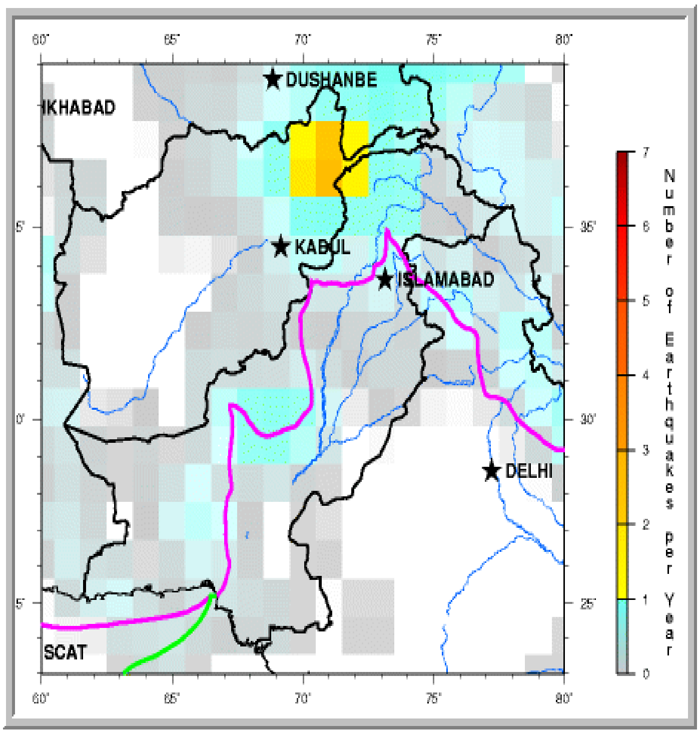


Figure 49 Earthquake Density Map of Pakistan

Source: Geological Survey of Pakistan (2009)

In the light of the above parameters, it is inferred that the proposed sites on Indus River, “Masan” and “Kalabagh”, identified by the web-based system are suitable for the construction of the dams on the Indus River subject to further detailed investigations. Thus the web-based Hydrological Database System for Indus River provide necessary tools that equip the dam designers, hydrologists and engineers to identify suitable sites for the construction of the dam projects on the Indus River.

6.2 Site Selection Using Analytical Hierarchy Process

Physical factors governing the site selection of the dam identify the two sites (Masan and Kalabagh) on the main stem of the Indus which are suitable for the construction of dam. However to rank them based on the physical factors, an analysis using a technique called Analytical Hierarchy Process (AHP) was undertaken.

The Analytical Hierarchy Process (AHP) is a decision-aiding method aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process.

Since a decision-maker bases judgments on knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behavior of a decision-maker. The strength of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structured yet relatively simple solution to the decision-making problems. In addition, by breaking a problem down in a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small to the large.

The hierarchy can be visualized as a diagram shown in Figure 50 with the goal at the top, the alternatives at the bottom, and the criteria in the middle. There are useful terms for describing the parts of such diagrams. Each box is called a node. The boxes descending from any node are called its children. The node from which a child node descends is called its parent. Groups of related children are called comparison groups.

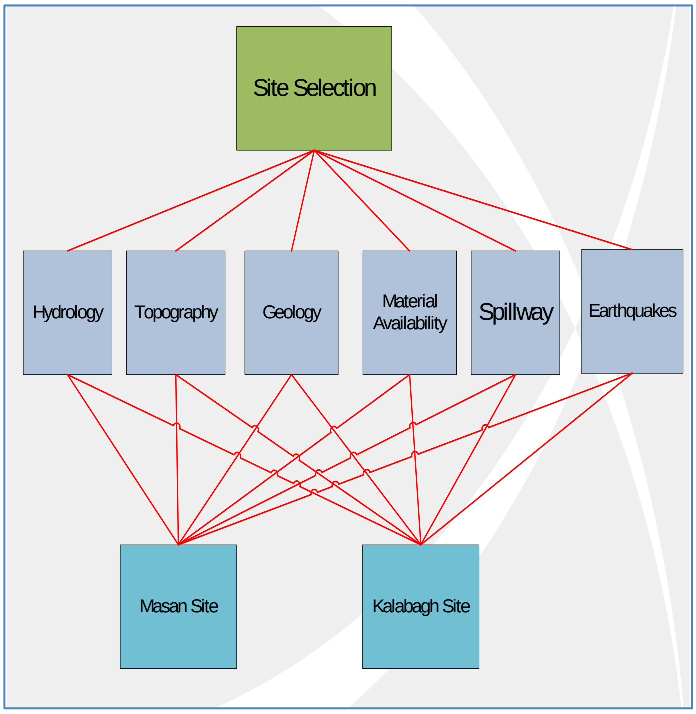


Figure 50 Diagram Showing AHP Hierarchy

After constructing hierarchy, AHP is used to establish the priorities for all its nodes. Priorities are numbers associated with the nodes of AHP hierarchy. They represent the relative weights of the nodes in any group. In order to incorporate the judgment about the various elements in the hierarchy, it is important to undertake pair wise comparison between two physical factors. Each pair of factors was compared, there were total of 15 pairs (hydrology/topography, hydrology/geology, hydrology/material availability, hydrology/spillway, hydrology/earthquakes, topography/geology, topography/material availability, topography/spillway, topography/ earthquakes, geology/material availability, geology/spillway, geology/earthquakes, material availability/spillway, material availability/earthquakes, and spillway/earthquakes). The fundamental scale for the pair wise comparison is shown in Table 7.

Table 7 Fundamental Scale for Pairwise Comparisons

Intensity of Importance	Definition	Explanation
1	Equal importance	Two element contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another
5	Strong importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of highest possible order of affirmation

Keeping in view above criteria the intensity of importance of each pair of the physical factor was judged. It was assessed that hydrology of river has strong importance (5) over the topography of river, moderate importance (3) over geology and foundation conditions, very strong importance (7) over material availability, moderate importance (3) over spillways and location and strong importance (5) over the earthquake. In this way, pair wise comparison matrix for different physical factors was made as attached as Table C1 attached in Appendix C. Synthesizing the pair-wise comparison matrix was performed by dividing each element of the matrix by its column total. The synthesized matrix for physical factors is attached as Table C2 in Appendix C. The weight age for each physical factor was obtained by dividing the sum of the each row by number of physical factors (columns), i.e., 5. After that the weight age of each physical factor was multiplied by the priorities of each decision alternative (Masan and Kalabagh) relative to each physical factor in order to develop an overall priority ranking of the decision alternative which is termed as priority matrix as shown in Table 8.

Table 8 Priority Matrix for Site Selection

Site Selection Criteria	Weight	Masan	Kalabagh
Hydrology	0.394	5.0	4.0
Topography of River Valley	0.227	4.0	5.0
Geology and Foundation Conditions	0.157	3.0	5.0
Availability of Material	0.087	4.0	4.0
Spillways Size & Location	0.093	5.0	5.0
Earthquakes	0.044	5.0	5.0
Summation	1.0	4	5

For selection of suitable sites for the construction of dam projects on the Indus River, the sites were ranked according to their overall priorities, as follows: Kalabagh and Masan, indicating that Kalabagh is best qualified as the site for the construction of dam on the Indus River.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The Indus River is the biggest river in Pakistan and has huge potential for the development of the dam projects in its upper catchment area. There are more than 200 G& D measuring site on the river which measure the data on daily basis nevertheless the data management process is conventional meaning that mostly G & D data are stored in the hard copy format like books, reports and journals. The data compiled in the hardcopy format make it tedious to be accessed and utilized by the data users like dam designers, hydrologists, engineers, researchers as well as other people. But with the availability of today information technology it is possible and convert and store the data in the digitalized format in a database management system. Thus the Web-based GIS system for the hydrological data management of the Indus River provides easy accessibility for the data users to identify suitable sites on Indus River for construction of dam projects in Pakistan. Robust system provides for the historical inflows of the river at different gauging sites on daily, monthly and yearly basis as well as the statistical summary including maximum, minimum, average and standard deviation. The spatial data about the Indus River, the location of gauging sites and other pertinent features of the Pakistan can be visualized easily both in Openlayer and in the Google Earth. Moreover, the hydrological database developed in the system can be modified easily.

The outcome of web-based GIS system helps the data users to select the suitability of site for the construction of dams based on the average annual inflow of Indus River because hydrology plays a decisive role in the selection of the site for the construction of the dam. The average annual inflows of the river determine the storage required and hence the normal full supply level of the reservoir. In order to find the best suitable site, based on physical factors like the hydrology of river, topography of river valley, geological and foundation conditions, availability of material, location and size of spillway and the earthquake, further analysis was carried out by using analytical hierarchy process which ranked Kalabagh site as a best for the construction of the dam on the Indus River subject to the environmental studies.

The web-based GIS system was developed by using different free and open source software rather than purchasing expensive commerical software. The database for historical G & D data for the last two years was developed in PostgreSQL which is an object relational database management system and it is also free and open source software. The spatial data of the Indus River, location of gauging sites and other pertinent features of Pakistan were published both in openlayer and Google Earth, by using Geoserver, which is free and open source web server. The web application was developed by using Apache, which is popular web server. The source code for the system was written in PHP, SQL, JavaScript and HTML which are also free and open source. Thus the use of free and open source software is considered to be cost effective appraoch for the developing countires like Pakistan.

Recommendations

The web-based GIS hydrological database system was developed only for 36 sites gauging sites on the Indus River and it serves as a pilot project. However, there are more than 200 gauging sites on the Indus River, which measures the data on the daily basis. For the effective working of the system, all gauging sites should be incorporated in the hydrological database system. This would results in the development of comprehensive database management system for the entire Indus System of Rivers. The system would generate more accurate results by extending the hydrological database for at least 25 years.

Pakistan lies in the South Asian region, where most of the International Rivers are transboundary in nature, meaning the rivers flow across the international boundary of the countries. If a web-based GIS system is developed at the regional level, it will provide a common platform to integrate hydrological data of the International Rivers and provide cooperation in the development of mega water sector projects. However, it requires proper mechanism, infrastructure and training of human resources to further develop a web-based GIS system at the regional level.

Recommendations for Future Study

The study is limited for the development of hydrological database of the Indus River by using the web-based GIS system. The study can further be extended and following topics are recommended.

1. Development of the web-based GIS system for the other rivers of Pakistan including the Chenab River, Jhelum River and Ravi River.

2. Assessment of Hydropower potential of Indus system of rivers using GIS and Remote sensing techniques.

3. Development of web-based GIS hydrological database for Hindukush, Karakoram and Himalayan region.

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APPENDICES

Appendix A

Data Dictionary

Appendix Table A1 Data Dictionary for gd_river in Database

Field Name	Description	Data type	key
did	serial	Integer	Primary key
sid	ID of stations	Character varying	-
date	date	date	-
gauge	Gauge in feet	Double precision	-
discharge	Discharge in cubic feet per second	Double precision	-

Appendix Table A2 Data Dictionary for id_station in Database

Field Name	Description	Data type	key
sid	ID of stations	Character varying	Primary key
name_station	Station name	Character varying	-
river_id	River ID	Character varying	-

Appendix Table A3 Data Dictionary for id_river in Database

Field Name	Description	Data type	key
river_id	River ID	Character varying	Primary key
name_river	River Name	Character varying	-

Appendix Table A4 Data Dictionary for River in Database

Field Name	Description	Data type	key
gid	Serial number	Integer	Primary key
length	Length of river	Double precision	-
name	Nullah/river	Character varying	-
river	Name of river	Character varying	-
the_geom	Geometry of river	multiline string	-

Appendix Table A5 Data Dictionary for Gauging Sites5 in Database

Field Name	Description	Data type	key
gid	Serial number	Integer	-
id	Station name	Character varying	Primary key
station	Station ID	Character varying	-
latitude	Latitude of station	Double precision	-
Longitude	Longitude of station	Double precision	-
the_geom	Geometry of station	point	-

Appendix Table A6 Data Dictionary for International Border in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
acc_descri	Accurate/approximate	Character varying	-
the_geom	Geometry of boundary	multiline string	-

Appendix Table A7 Data Dictionary for Cities in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
nam	Name of cities	Character varying	-
area	Area of cities	Double precision	-
the_geom	geometry of cities	point	-

Appendix Table A8 Data Dictionary for Road112 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
exs_descri	Operational	Character varying	-
rtt_descri	Secondary Route	Character varying	-
the_geom	geometry of cities	multiline string	-

Appendix Table A9 Data Dictionary for Aerofaccopy1 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
nam	Name of airport	Character varying	-
zv3	Elevation of airport	Character varying	-
the_geom	Airport	point	-

Appendix Table A10 Data Dictionary for Railrd13 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
fco_descri	Type of track	Character varying	-
the_geom	railways	multiline string	-

Appendix Table A11 Data Dictionary for Contourlines3 in Database

Field Name	Description	Data type	key
gid	Serial number	Integer	Primary key
contour	Elevation	integer	-
the_geom	Contour lines	multiline string	-

Appendix Table A12 Data Dictionary for Elevcopy4 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
zv2	Elevation of spot point	Integer	-
the_geom	Spot elevation	point	-

Appendix Table A13 Data Dictionary for Punjab_Canals_Networks8 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
length	length of canal	Double precision	-
zone	zone of canal	Character varying	-
fs_depth	Depth of canal	Double precision	-
fsdisc_cs	Discharge of canal	Double precision	-
the_geom	Spot elevation	multiline string	-

Appendix Table A14 Data Dictionary for Punjab_Ccomd9 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
area	Area of canal	Double precision	-
perimetet	Perimeter of canal	Double precision	-
the_geom	Spot elevation	Multi polygon	-

Appendix Table A15 Data Dictionary for Irrigation Structure in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
st_name	Structure irrigation	Character varying	-
the_geom	Irrigation structure	point	-

Appendix Table A16 Data Dictionary for Hydrology_a5 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
name	Name of feature	Character varying	-
hydrologic	Perennial/Permanent	Character varying	-
the_geom	Hydrologic feature	Multi polygon	-

Appendix Table A17 Data Dictionary for Physiography_a6 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
layer	Snowfield/ice field	Character varying	-
the_geom	physiographic feature	Multi polygon	-

Appendix Table A18 Data Dictionary for Coast15 in Database

Field Name	Description	Data type	key
gid	serial number	Integer	Primary key
f_code_des	Type of coastal	Character varying	-
acc_descri	accuracy of coastal	Character varying	-
the_geom	coastal lines	multiline string	-

Appendix B

Source Code of Web-Based GIS System

SOURCE CODE OF THE WEB PAGE OF MAIN INTERFACE OF SYSTEM

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN" "http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
<!-- DW6 -->
<head>
<!-- Copyright 2005 Macromedia, Inc. All rights reserved. -->
<title>Text</title>
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-1" />
<link rel="stylesheet" href="mm_travel2.css" type="text/css" />
<script language="JavaScript" type="text/javascript">

</script>
<style type="text/css">
<!--
.style5 {color: #FF00FF}
.style6 {color: #FF00FF; font-weight: bold; }
.style16 {color: #FF0000}
.style35 {color: #0000FF; font-size: 18px; font-weight: bold; }
body,td,th {
	color: #00FF33;
	font-size: 10px;
}
.style54 {color: #CC33FF}
.style56 {font-weight: bold; color: #0000FF;}
.style58 {font-family: Arial, Helvetica, sans-serif; color: #000000; }
body {
	background-color: #CCFFFF;
}
```

```
.style77 {font-size: 18px}
.style91 {color: #000000}
.style102 {color: #0000FF}
.style103 {color: #00FF00}
-->
</style>
</head>
<body>


    <th scope="col"><object classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swflash.cab#version=5,0,0,0" width="933" height="57">
     <param name="BGCOLOR" value="#99FFFF" />
     <param name="BGCOLOR" value="#99FFFF" />
     <param name="BGCOLOR" value="#99FFFF" />
     <param name="BGCOLOR" value="#99FFFF" />
     <param name="BGCOLOR" value="#00FF33" />
     <param name="BGCOLOR" value="#0000FF" />
     <param name="movie" value="text6.swf" />
     <param name="quality" value="high" />
     <embed src="text6.swf" width="933" height="57" quality="high"
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
bgcolor="#99FFFF" ></embed>
    </object></th>
    </tr>
  </table>
  <table width="927" border="0">
   <tr>
```

```
          <th width="917" scope="col"><div align="left"><img src="upper-terrian_indus.png" alt="k" width="439" height="381" /><img src="sukkar_barrage.png" alt="k" width="476" height="381" /></div></th>
         </tr>
      </table>
        <table width="928" border="0" cellpadding="0" cellspacing="3" >
         <tr bgcolor="#e3f1bd">
          <td width="109" height="26" align="center" valign="middle"><div align="center"><a href="w5.php" class="style35">Home</a> </div></td>
          <td width="126" align="center" valign="middle"><div align="center"><a href="station.php" class="style35"> Stations </a></div></td>
          <td width="100" align="center" valign="middle"><div align="center"><a href="http://en.wikipedia.org/wiki/Indus_River" class="style35">Indus </a></div></td>
          <td width="111" align="center" valign="middle"><div align="center"><a href="http://en.wikipedia.org/wiki/Pakistan" class="style35">Pakistan </a></div></td>
          <td width="117" align="center" valign="middle"><div align="center"><a href="http://www.gis.com/index.html" class="style35">GIS </a></div></td>
          <td width="157" align="center" valign="middle"><a href="gd1.php" class="style35">Update</a></td>
          <td width="184" align="center" valign="middle"><div align="center"><a href="contact.php?" class="style35"> Contact </a></div></td>
         </tr>
      </table>


              <script language="JavaScript" type="text/javascript">
         document.write(TODAY);      </script>
       </h2></td>
      </tr><tr>
       <td colspan="4" bgcolor="#003366"></tr>
```

```
<table width="928" height="491" border="1">
  <tr>
   <th width="313" height="464" align="left" scope="col"><div id="map"><span class="style54">
    <style type="text/css">
      #map {
        width: 600px;
        height: 500px;
        border: 2px solid black;
      }
      #wrapper {
        width: 500px;
      }
      #location {
        float: right;
      }
    body,td,th {
      color: #0000CC;
      font-size: larger;
}
body {
      background-color: #CCFFFF;
      margin-left: 6px;
      margin-top: 9px;
      margin-right: 6px;
      margin-bottom: 3px;
}
h1,h2,h3,h4,h5,h6 {
      font-family: Times New Roman, Times, serif;
}
h1 {
      font-size: larger;
```

```
}
.style1 {font-family: "Times New Roman", Times, serif}
        </style>
      </span></div>
       <object classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swflash.cab#
version=5,0,0,0" width="100" height="22">
        <param name="BGCOLOR" value="" />
        <param name="movie" value="button8.swf" />
        <param name="quality" value="high" />
        <embed src="button8.swf" quality="high"
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_Prod
_Version=ShockwaveFlash" type="application/x-shockwave-flash" width="100"
height="22" ></embed>
      </object></th>
          <form action="ir20a.php" method="post" name="form101"
id="form101">
      <th width="599" scope="col"><p align="left" class="style56"><span
class="style35">Gauging Sites <tt>:-</tt></span><tt> <strong>
       <select name="station" size="1" class="style58" onfocus =
"changeeg(this);" onchange="aaa()">
        <hr  />

          ;

        <?php
$dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres
password=bangkok") or die("Couldn't Connect");

         $query_stn = "select sid from gd_indus group by sid order by sid ASC
" ;
```

```
$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;

while ( $i_stn < $rows_stn )

        {

            $result_stn1 =pg_fetch_array($result_stn);

            $stn[] = $result_stn1[0];


                            $i_stn++;

        }


pg_close($dbconn_stn);


// put value into combobox

echo "<option value = Select Station>"."Select Station"."</option>";

foreach ($stn as $index => $stn)

{           echo "<option value = $stn>".$stn."</option>";
```

```
}

?>
</select>
</strong></tt></p>
<p align="justify" class="style77"> <span class="style56">
<label class="style35"> Start Date:-</label>
<label class="style35"></label>

<select name="from_date" class="style58" onfocus = "changeeg(this);" onchange="aaa()">
<?php
$dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres password=bangkok") or die("Couldn't Connect");

$query_stn1 = "select date from gd_indus group by date order by date ASC " ;

$result_stn1 = pg_query($query_stn1)or die('Query failed: ' . pg_last_error());

$rows_stn1 = pg_num_rows($result_stn1);

$i_stn1 =0;

while ( $i_stn1 < $rows_stn1 )

{

$result_stn11 =pg_fetch_array($result_stn1);
```

```
                              $stn1[] = $result_stn11[0];

                    $i_stn1++;

                    }

          pg_close($dbconn_stn);

// put value into combobox

          echo "<option date = Select date>"."Select date"."</option>";

          foreach ($stn1 as $index1 => $stn1)

          {                   echo "<option date = $stn1>".$stn1."</option>";
                    }

                                                            ?>
          </select>
          <label class="style5"><br />
          <br />
          </label>
          </span>
          <label       class="style5"><span       class="style35">End
Date</span></label>
          <span class="style35"><tt>:-</tt> </span>
```

```
<label class="style5"></label>
<span class="style56">
<label class="style5"> </label>
<select name="end_date" class="style58" onfocus = "changeeg(this);"
onchange="aaa()">
 <?php
$dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS  user=postgres
password=bangkok") or die("Couldn't Connect");
$query_stn2 = "select date from gd_indus group by date order by date ASC" ;
$result_stn2 = pg_query($query_stn2)or die('Query failed: ' . pg_last_error());

$rows_stn2 = pg_num_rows($result_stn1);

$i_stn2 =0;

while ( $i_stn2 < $rows_stn2 )

        {

    $result_stn12 =pg_fetch_array($result_stn2);

            $stn2[] = $result_stn12[0];



            $i_stn2++;

        }


pg_close($dbconn_stn);
```

```
// put value into combobox

echo "<option value = Select date>"."Select date"."</option>";

foreach ($stn2 as $index2 => $stn2)

{ echo "<option value = $stn2>".$stn2."</option>"; }

?>
</select>
<label class="style5"></label>
</span></p>
<p class="style56">
<label class="style56"></label>
<label class="style5"></label>
<label class="style5"></label>
<label class="style77"> </label>
<label class="style77"></label>
<label class="style77"></label>
<label class="style77"></label>
</p>
<div align="left" class="style56">
<p><span class="style35"><span class="style16">Statistical Summary</span><tt>:-</tt> </span>
<select name="value" class="style58" onchange="oooo()">
<option value="none">Choose Period</option>
<option value="Selected Period">Selected Period</option>
</select>
</p>
</div>
```

```
<p>
  <label class="style77"></label>
  <span class="style56">
  <label class="style5"> </label>
  </span>        </p>
<p align="left" class="style91"> <span class="style56">
  <label class="style77"></label>
  <label class="style35"><span class="style103">Historical
Inflows</span>:- </label>
  <select name="inflow" class="style58" onchange="oooo()">
    <option value="none">Choose Distribution</option>
    <option value="daily">daily</option>
    <option value="monthly">monthly</option>
    <option value="yearly">yearly</option>
  </select>
  <strong>
<!-- From Date   -----------------------------------------------------------------------
--------------------------------------        -->
</strong></span></p>
<p align="left" class="style77"> <span class="style56"><strong>
  <label class="style102"></label>
  </strong>
    <input name="submit2" type="submit" class="style56"
value="submit" />
</span></p>
<p align="left" class="style77">
  <object classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swflash.cab#
version=5,0,0,0" width="119" height="22">
    <param name="BGCOLOR" value="#0000CC" />
    <param name="movie" value="button6.swf" />
    <param name="quality" value="high" />
```

```
<embed src="button6.swf" width="119" height="22" quality="high" pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash" bgcolor="#0000CC" ></embed>
</object>
</p>
<p align="left" class="style77">
<object classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000" codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swflash.cab#version=5,0,0,0" width="110" height="21">
<param name="BGCOLOR" value="#00CC00" />
<param name="movie" value="button7.swf" />
<param name="quality" value="high" />
<embed src="button7.swf" width="110" height="21" quality="high" pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash" bgcolor="#00CC00" ></embed>
</object>
</p>
</form>
</tr>
</table>
<p align="left">
<label class="style6"></label>
</p>
<p align="justify">

<script src="http://localhost:8080/geoserver/openlayers/OpenLayers.js" type="text/javascript">
</script>
<script defer="defer" type="text/javascript">
```

```
        function showMe(it, box) {
    var vis = (box.checked) ? "block" : "none";
    document.getElementById(it).style.display = vis;
    var st_it=new String(it)+"a";
    document.getElementById(st_it).style.display = vis;
        var layername=box.value;
        if(box.checked){//ON
            var st=1;
        }else{//OFF
            var st=0;
        }

        var mapfile=parent.parent.bodygis_1.mapfile;



        exp="makefile.php?status="+st+"&layername="+layername+"&mapfil
e="+mapfile;
        parent.parent.bodygis_1.tempmain.location.href=exp;

    }




      var map;
      var river;
        var city;
                var contour;

      function setHTML(response) {
        document.getElementById('nodelist').innerHTML
response.responseText;
      };
```

```
    OpenLayers.IMAGE_RELOAD_ATTEMPTS = 5;

function init(){
  var bounds = new OpenLayers.Bounds(
    60.851418581581676, 23.17380837674734,
    79.20140191991814, 37.59388498348303
  );
  var options = {
    controls: [],
    maxExtent: bounds,
    maxResolution: 0.07167962241537681,
    projection: "EPSG:4326",
    units: 'm'
  };
  map = new OpenLayers.Map('map', options);

 // =====Rivers==================
  Rivers= new OpenLayers.Layer.WMS(
    "Rivers", "http://localhost:8080/geoserver/wms",
    {
      width: '800',
      styles: '',
      height: '567',
      layers: 'topp:rivers',
      srs: 'EPSG:4326',

      format: 'image/png'



    },
    {singleTile: true ,
                      isBaselayer : false}
```

```
);
// =========Rivers===========
// ==========GuagingSites=======================
GuagingSites = new OpenLayers.Layer.WMS(
    "GuagingSites", "http://localhost:8080/geoserver/wms",
    {
        width: '800',
        srs: 'EPSG:4326',
        styles: '',
        height: '427',
        layers: 'topp:gaugingsites5',


        //format: 'image/png'
                transparent: 'true'
    },
    {
                //singleTile: true,
                isBaseLayer: false,
                visibility: false
            }
)
        ;
// ==========GuagingSites===================
// ==============Roads====================
Roads = new OpenLayers.Layer.WMS(
    "Roads", "http://localhost:8080/geoserver/wms",
    {
        width: '543',
        styles: '',
        height: '550',
        layers: 'topp:roadl12',
```

```
        srs: 'EPSG:4326',

       //format: 'image/png'
                                      transparent: 'true'
    },
    {
                                      //singleTile: true,
                                      isBaseLayer: false,
                                      visibility: false
                               }
  );
  // ===============Roads==================
  // ===========Airports===========================
Airports = new OpenLayers.Layer.WMS(
    "Airports", "http://localhost:8080/geoserver/wms",
    {
         width: '800',
        styles: '',
        height: '749',
        layers: 'topp:aerofacpcopy1',
        srs: 'EPSG:4326',

        //format: 'image/png'
                                      transparent: 'true'
    },
    {
                                      //singleTile: true,
                                      isBaseLayer: false,
                                      visibility: false
                               }
  );
  // =========Airports============================
```

```
// =====================Railways=========
        Railways = new OpenLayers.Layer.WMS(
           "Railways", "http://localhost:8080/geoserver/wms",
           {
               width: '540',
              styles: '',
              height: '550',
              layers: 'topp:railrdl13',
              srs: 'EPSG:4326',

             //format: 'image/png'
                                transparent: 'true'
           },
           {
                                //singleTile: true,
                                isBaseLayer: false,
                                visibility: false
                        }
        );
        // =====================Railways=========
        // =========Cities===========================
        Cities = new OpenLayers.Layer.WMS(
           "Cities", "http://localhost:8080/geoserver/wms",
           {
              width: '800',
              styles: '',
              height: '595',
              layers: 'topp:cities',
              srs: 'EPSG:4326',
```

```
        //format: 'image/png'
                                      transparent: 'true'
    },
    {
                                      //singleTile: true,
                                      isBaseLayer: false,
                                      visibility: false
                              }
);
// ===========Cities=================
// ======Contours================================
Contours = new OpenLayers.Layer.WMS(
    "Contours", "http://localhost:8080/geoserver/wms",
    {
       width: '569',
        styles: '',
        height: '550',
        layers: 'topp:contourslines3',
        srs: 'EPSG:4326',


        //format: 'image/png'
                                      transparent: 'true'
    },
    {
                                      //singleTile: true,
                                      isBaseLayer: false,
                                      visibility: false
                              }
);
// ===Contours=============================
//  =============SpotElevations==============
```

```
SpotElevations = new OpenLayers.Layer.WMS(
    "SpotElevations", "http://localhost:8080/geoserver/wms",
    {
      width: '569',
       styles: '',
       height: '550',
       layers: 'topp:elevpcopy4',
       srs: 'EPSG:4326',

       //format: 'image/png'
                                          transparent: 'true'
    },
    {
                                          //singleTile: true,
                                          isBaseLayer: false,
                                          visibility: false
                              }
);
// ===============SpotElevations===========
// ========InternationalBorder===============
InternationalBorder = new OpenLayers.Layer.WMS(
    "InternationalBorder", "http://localhost:8080/geoserver/wms",
    {width: '800',
       styles: '',
       height: '604',
       layers: 'topp:internationalborder',
       srs: 'EPSG:4326',

       //format: 'image/png'
                                          transparent: 'true'
    },
    {
```

```
                    //singleTile: true,
                    isBaseLayer: false,
                    visibility: false
                }
        );
// ===============InternationalBorder==============================


// ==========CanalNetworks==================
        CanalNetworks = new OpenLayers.Layer.WMS(
          "CanalNetworks", "http://localhost:8080/geoserver/wms",
          {
            width: '800',
            styles: '',
            height: '738',
            layers: 'topp:punjab_canals_network8',
            srs: 'EPSG:4326',



            //format: 'image/png'
                    transparent: 'true'
          },
          {
                    //singleTile: true,
                    isBaseLayer: false,
                    visibility: false
                }
        );
        // =======CanalNetworks==================

    // ======CanalCommand====================
```

```
CanalCommand = new OpenLayers.Layer.WMS(
    "CanalCommand", "http://localhost:8080/geoserver/wms",
    {width: '800',
        styles: '',
        height: '711',
        layers: 'topp:punjab_ccomnd9',
        srs: 'EPSG:4326',

        //format: 'image/png'
                                        transparent: 'true'
    },
    {
                                        //singleTile: true,
                                        isBaseLayer: false,
                                        visibility: false
                              }
);
// ======CanalCommand==============

// ==========IrrigationStructures==============
IrrigationStructures = new OpenLayers.Layer.WMS(
    "IrrigationStructures", "http://localhost:8080/geoserver/wms",
    {
        width: '506',
        styles: '',
        height: '550',
        layers: 'topp:irrigationstructures',
        srs: 'EPSG:4326',

        //format: 'image/png'
                                        transparent: 'true'
    },
```

```
            {
                        //singleTile: true,
                        isBaseLayer: false,
                        visibility: false
                    }
        );
        // =========IrrigationStructures=========
        // ========HydrologicalFeatures===========
        HydrologicalFeatures = new OpenLayers.Layer.WMS(
            "HydrologicalFeatures", "http://localhost:8080/geoserver/wms",
            {
                width: '543',
                styles: '',
                height: '550',
                layers: 'topp:hydrology_a5',
                srs: 'EPSG:4326',

               //format: 'image/png'
                        transparent: 'true'
            },
            {
                        //singleTile: true,
                        isBaseLayer: false,
                        visibility: false
                    }
        );
//  =======HydrologicalFeatures===============
// ================PhysiographicalFeatures===============
        PhysiographicalFeatures = new OpenLayers.Layer.WMS(
            "PhysiographicalFeatures", "http://localhost:8080/geoserver/wms",
            {
                width: '515',
```

```
                styles: '',
                height: '550',
                layers: 'topp:physiography_a6',
                srs: 'EPSG:4326',

                //format: 'image/png'
                                        transparent: 'true'
              },
              {
                                        //singleTile: true,
                                        isBaseLayer: false,
                                        visibility: false
                                  }

           );
// ===============PhysiographicalFeatures==============

// ==================Coastal===============
           Coastal = new OpenLayers.Layer.WMS(
              "Coastal", "http://localhost:8080/geoserver/wms",
              {
               width: '800',
                styles: '',
                height: '300',
                layers: 'topp:coastl15',
                srs: 'EPSG:4326',









                //format: 'image/png'
```

```
                                        transparent: 'true'
          },
          {
                                        //singleTile: true,
                                        isBaseLayer: false,
                                        visibility: false
                                   }
        );
    // ==============Coastal============


map.addLayers([Rivers,GuagingSites,Roads,Airports,Railways,Cities,Contours,SpotElevations,InternationalBorder,CanalNetworks,CanalCommand,IrrigationStructures,HydrologicalFeatures,PhysiographicalFeatures,Coastal]);

          // setup controls and initial zooms

        map.addControl(new OpenLayers.Control.PanZoomBar());
                map.addControl(new OpenLayers.Control.Navigation());
        map.addControl(new OpenLayers.Control.Scale($('')));
        map.addControl(new OpenLayers.Control.MousePosition({element: $('')}));
        map.addControl(new OpenLayers.Control.LayerSwitcher());
                map.addControl(new OpenLayers.Control.NavToolbar());
        map.addControl(new OpenLayers.Control.OverviewMap());
            map.zoomToExtent(bounds);

        // support GetFeatureInfo

        map.events.register('click', map, function (e) {
```

```
                document.getElementById('').innerHTML = "Loading... please wait...";
                AttLayer=window.
Rivers+window.GuagingSites+window.Roads+window.Airports+window.Railways;
                                var url =  map.layers[0].getFullRequestString(
                  {
                    REQUEST: "GetFeatureInfo",
                    EXCEPTIONS: "application/vnd.ogc.se_xml",
                    BBOX: map.getExtent().toBBOX(),
                    X: e.xy.x,
                    Y: e.xy.y,
                    INFO_FORMAT: 'text/html',
                    QUERY_LAYERS: AttLayer,
                    FEATURE_COUNT: 50,
                    srs: 'EPSG:4326',
                    styles: '',
                    layers: 'topp:gaugingsites',

                    WIDTH: map.size.w,
                    HEIGHT: map.size.h
                  },
                  "http://localhost:8080/geoserver/wms"
                );
                OpenLayers.loadURL(url, '', this, setHTML, setHTML);
                OpenLayers.Event.stop(e);
              });
            }
                                </script>
         </head>
        <body onload="init()">

      <div id="wrapper">
```

```
            <div id="location"></div>
            <div id="scale"></div>
        </div>
           </body>
        </html>
            <div class="style16" id="nodelist">Faris Qazi, Master Student,
International Program in Civil Engineering <br />
     Faculty of Engineering , Kasetsart University. Bangkok </div>
        </body>
                    </html>
```

SOURCE CODE OF THE WEB PAGE OF STATISTICAL SUMMARY AND HISTORICAL INFLOW

```
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN">
<html>
<!-- DW6 -->
<head>
<!-- Copyright 2005 Macromedia, Inc. All rights reserved. -->
<title>Text</title>
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-1">
<link rel="stylesheet" href="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configuration/BuiltIn/StarterPages/mm_health_nutr.css" type="text/css">
<script language="javascript">
//--------------- LOCALIZEABLE GLOBALS ---------------
var d=new Date();
var monthname=new Array("January","February","March","April","May","June","July","August","September","October","November","December");
//Ensure correct for language. English is "January 1, 2004"
var TODAY = monthname[d.getMonth()] + " " + d.getDate() + ", " + d.getFullYear();
//---------------   END LOCALIZEABLE   ---------------
</script>
<style type="text/css">
<!--
.style1 {
	font-family: Geneva, Arial, Helvetica, sans-serif;
	font-size: 18px;
```

```
			font-weight: bold;
		}
		.style4 {font-size: 36px}
		.style5 {font-weight: bold; font-family: Geneva, Arial, Helvetica, sans-serif;}
		.style6 {font-size: 36px; font-family: Geneva, Arial, Helvetica, sans-serif;}
		-->
		</style>
		</head>
		<body bgcolor="#F4FFE4">
		<table width="100%" border="0" cellspacing="0" cellpadding="0">
		<tr bgcolor="#D5EDB3">
		 <td width="382" colspan="2" rowspan="2"><div align="left" class="subHeader"><img src="Kaghan2.jpg" alt="Header image" width="278" height="195" border="0"></div></td>
		 <td width="378" height="50" align="center" valign="bottom" class="style1" id="logo"><div align="center" class="style5">
		  <p align="center">STATISTICAL SUMMARY &amp; HISTORICAL INFLOWS OF RIVER INDUS </p>
		  </div></td>
		 <td width="100%" class="style1"> </td>
		</tr>

		 <tr bgcolor="#D5EDB3">
		  <td height="51" align="center" valign="top" class="style1" id="tagline"></td>
			<td width="100%" class="style1"> </td>
		 </tr>

		 <tr>
		  <td colspan="4" bgcolor="#5C743D" class="style4"><div align="center" class="subHeader" id="navigation"><span class="style1"><img src="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configuration/Buil
```

```
tIn/StarterPages/mm_spacer.gif" alt="" width="1" height="2"
border="0"></span></div></td>
        </tr>

        <tr>
         <td colspan="4" bgcolor="#99CC66"
background="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configura
tion/BuiltIn/StarterPages/mm_dashed_line.gif"><div align="center"><span
class="style1"><img
src="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configuration/Buil
tIn/StarterPages/mm_dashed_line.gif" alt="line decor" width="4" height="3"
border="0"></span></div></td>
        </tr>

        <tr bgcolor="#99CC66">
        <td> </td>
              <td height="20" colspan="3" id="dateformat"><a
href="w5.php">HOME<span class="style1"></a>  </a>  
        <tr>
         <td colspan="4" bgcolor="#99CC66"
background="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configura
tion/BuiltIn/StarterPages/mm_dashed_line.gif"><img
src="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configuration/Buil
tIn/StarterPages/mm_dashed_line.gif" alt="line decor" width="4" height="3"
border="0"></td>
        </tr>

        <tr>
         <td colspan="4" bgcolor="#5C743D"><img
src="file:///C|/Program%20Files/Macromedia/Dreamweaver%208/Configuration/Buil
tIn/StarterPages/mm_spacer.gif" alt="" width="1" height="2" border="0"></td>
        </tr>
```

```
<tr>
   <td width="40"> </td>
  <td colspan="2" valign="top" class="style5"> <br>
    <br>
   <table border="0" cellspacing="0" cellpadding="2" width="705">

      <tr class="style4">

          <?php



$id = $_REQUEST["station"];

$v = $_REQUEST["value"];
$all = $_REQUEST["all"];
$vv = $_REQUEST["inflow"];
$dd= $_REQUEST["from_date"];
$ddd = $_REQUEST["end_date"];
//$d = $_REQUEST["gauge"];



//print ("$vd");



          $dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres password=bangkok") or die("Couldn't Connect");



if ($v == 'Selected Period' )
{
```

```
echo "<table width='663' border='2' class='style5'> " ;
echo "<tr> ";
echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
echo "<td width='505000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Average (Cusecs) </div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Maximum (Cusecs)</div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Minimum (Cusecs) </div></td>" ;
echo "<td width='15000' rowspan='1'><big><b><div align='center'>Standard Deviation(Cusecs) </div></td>" ;
echo "</tr>" ;
echo "<tr>" ;
echo " STATISTICAL SUMMARY-----------SELECTED PERIOD";

$query_stn = "SELECT gd_indus.sid, id_station.name_station, ceil (avg(discharge)),ceil (max(discharge)),ceil (min(discharge)),ceil (stddev_pop (discharge)) FROM gd_indus,id_station  WHERE Date BETWEEN '$dd' AND '$ddd' and (gd_indus.sid = '$id') AND gd_indus.sid = id_station.sid   group by gd_indus.sid,id_station.name_station  ";


$result_stn = pg_query($dbconn_stn,$query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;
```

```
while ( $i_stn < $rows_stn )
    {
        $result_stn1 =pg_fetch_array($result_stn);
        $stn[$i_stn] = $result_stn1[0];
        echo "<td><div align='center'>$result_stn1[0]</td>" ;
        echo "<td><div align='center'>$result_stn1[1]</td>" ;
        echo "<td><div align='center'>$result_stn1[2]</td>" ;
        echo "<td><div align='center'>$result_stn1[3]</td>" ;
        echo "<td><div align='center'>$result_stn1[4]</td>" ;
        echo "<td><div align='center'>$result_stn1[5]</td>" ;

$i_stn++;
    }
```

```
pg_close($dbconn_stn);

}

$dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres password=bangkok") or die("Couldn't Connect");

  if ($v == 'Full Period')
{
    echo "<table width='663' border='2' class='style5'> " ;
        echo "<tr> ";
            echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
            echo "<td width='505000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
            echo "<td width='6000' rowspan='1'><big><b><div align='center'>Average (Cusecs) </div></td>" ;
            echo "<td width='6000' rowspan='1'><big><b><div align='center'>Maximum (Cusecs)</div></td>" ;
            echo "<td width='6000' rowspan='1'><big><b><div align='center'>Minimum (Cusecs) </div></td>" ;
            echo "<td width='15000' rowspan='1'><big><b><div align='center'>Standard Deviation(Cusecs) </div></td>" ;
                echo "</tr>" ;
        echo "<tr>" ;
```

```
echo " STATISTICAL SUMMARY-----------FULL PERIOD ";

$query_stn = "SELECT gd_indus.sid, id_station.name_station, ceil (avg(discharge)),ceil (max(discharge)),ceil (min(discharge)),ceil (stddev_pop (discharge)) FROM gd_indus,id_station where (gd_indus.sid = '$id') and gd_indus.sid = id_station.sid group by gd_indus.sid,id_station.name_station ";

$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;

while ( $i_stn < $rows_stn )

{ echo "<tr>" ;

$result_stn1 =pg_fetch_array($result_stn);

//$stn[$i_stn] = $result_stn1[0];

//$stn[$i_stn] = $result_stn1[1];

//$stn[$i_stn] = $result_stn1[2];

//$stn[$i_stn] = $result_stn1[3];
```

```
//print ("$stn[$i_stn] Cusecs <br><br>");

echo "<td><div align='center'>$result_stn1[0]</td>" ;

echo "<td><div align='center'>$result_stn1[1]</td>" ;

echo "<td><div align='center'>$result_stn1[2]</td>" ;

echo "<td><div align='center'>$result_stn1[3]</td>" ;

echo "<td><div align='center'>$result_stn1[4]</td>" ;

echo "<td><div align='center'>$result_stn1[5]</td>" ;

$i_stn++;

}

pg_close($dbconn_stn);
```

```
}
        $dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres password=bangkok") or die("Couldn't Connect");


    if ($all == 'All Sites')
}
        echo "<table width='663' border='2' class='style5'> " ;
            echo "<tr> ";
                echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
                echo "<td width='505000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
                echo "<td width='6000' rowspan='1'><big><b><div align='center'>Average (Cusecs) </div></td>" ;
                echo "<td width='6000' rowspan='1'><big><b><div align='center'>Maximum (Cusecs)</div></td>" ;
                echo "<td width='6000' rowspan='1'><big><b><div align='center'>Minimum (Cusecs) </div></td>" ;
                echo "<td width='15000' rowspan='1'><big><b><div align='center'>Standard Deviation(Cusecs) </div></td>" ;
                    echo "</tr>" ;
            echo "<tr>" ;
                echo " STATISTICAL SUMMARY-----------All Sites ";

            $query_stn = "SELECT gd_indus.sid, id_station.name_station, ceil (avg (discharge)),ceil (max(discharge)),ceil (min(discharge)),ceil (stddev_pop (discharge)) FROM gd_indus,id_station where gd_indus.sid = id_station.sid group by gd_indus.sid,id_station.name_station order by ceil (avg (discharge)) DESC ";
```

```
$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;

while ( $i_stn < $rows_stn )

    {   echo "<tr>" ;


        $result_stn1 =pg_fetch_array($result_stn);

        //$stn[$i_stn] = $result_stn1[0];

        //$stn[$i_stn] = $result_stn1[1];

        //$stn[$i_stn] = $result_stn1[2];

        //$stn[$i_stn] = $result_stn1[3];


            //print ("$stn[$i_stn] Cusecs <br><br>");

        echo "<td><div align='center'>$result_stn1[0]</td>" ;

        echo "<td><div align='center'>$result_stn1[1]</td>" ;
```

```
echo "<td><div align='center'>$result_stn1[2]</td>" ;

echo "<td><div align='center'>$result_stn1[3]</td>" ;

echo "<td><div align='center'>$result_stn1[4]</td>" ;

echo "<td><div align='center'>$result_stn1[5]</td>" ;

$i_stn++;
}

pg_close($dbconn_stn);
}

$dbconn_stn = pg_connect("host=localhost dbname=RIVERINDUS user=postgres password=bangkok") or die("Couldn't Connect");

if ($vv == 'daily' )
```

```
{
echo "<table width='663' border='2' class='style5'> " ;
echo "<tr> ";
echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
echo "<td width='30000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
echo "<td width='10000' rowspan='1'><big><b><div align='center'>Date</div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Gauge (ft) </div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Discharge (Cusecs)</div></td>" ;

echo "</tr>" ;
echo "<tr>" ;
print "<br><br>";
echo " HISTORICAL INFLOWS--------------DAILY ";

$query_stn = "SELECT gd_indus.sid, id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge FROM gd_indus,id_station WHERE (date = '$dd') and (gd_indus.sid = '$id') AND gd_indus.sid = id_station.sid group by gd_indus.sid,id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge order by gd_indus.date ASC ";


$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);
```

```
$i_stn =0;

while ( $i_stn < $rows_stn )

{

$result_stn1 =pg_fetch_array($result_stn);

$stn[$i_stn] = $result_stn1[0];

echo "<td><div align='center'>$result_stn1[0]</td>" ;

echo "<td><div align='center'>$result_stn1[1]</td>" ;

echo "<td><div align='center'>$result_stn1[2]</td>" ;

echo "<td><div align='center'>$result_stn1[3]</td>" ;

echo "<td><div align='center'>$result_stn1[4]</td>" ;

echo "<tr>" ;
```

```
$i_stn++;

}

pg_close($dbconn_stn);

}

else if ($vv == 'monthly')
{
echo "<table width='663' border='2' class='style5'> " ;
echo "<tr> ";
echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
echo "<td width='30000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
echo "<td width='10000' rowspan='1'><big><b><div align='center'>Date</div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Gauge (ft) </div></td>" ;
echo "<td width='6000' rowspan='1'><big><b><div align='center'>Discharge (Cusecs)</div></td>" ;

echo "</tr>" ;
```

```
echo "<tr>" ;
print "<br><br>";
echo " HISTORICAL INFLOWS--------------MONTHLY ";

$query_stn = "SELECT gd_indus.sid, id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge FROM gd_indus,id_station WHERE Date BETWEEN '$dd' AND '$ddd' and (gd_indus.sid = '$id')AND gd_indus.sid = id_station.sid group by gd_indus.sid,id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge order by gd_indus.date ASC   ";

$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;

while ( $i_stn < $rows_stn )

    {

        $result_stn1 =pg_fetch_array($result_stn);

        $stn[$i_stn] = $result_stn1[0];
```

```
echo "<td><div align='center'>$result_stn1[0]</td>" ;

echo "<td><div align='center'>$result_stn1[1]</td>" ;

echo "<td><div align='center'>$result_stn1[2]</td>" ;

echo "<td><div align='center'>$result_stn1[3]</td>" ;

echo "<td><div align='center'>$result_stn1[4]</td>" ;

echo "<tr>" ;

$i_stn++;

}
```

```
pg_close($dbconn_stn);

}

else if ($vv == 'yearly')
{
echo "<table width='663' border='2' class='style5'> " ;
        echo "<tr> ";
            echo "<td width='2000' rowspan='1'><big><b><div align='center'>ID</div></td>" ;
            echo "<td width='30000' rowspan='1'><big><b><div align='center'>Name of River</div></td>" ;
            echo "<td width='10000' rowspan='1'><big><b><div align='center'>Date</div></td>" ;
            echo "<td width='6000' rowspan='1'><big><b><div align='center'>Gauge (ft) </div></td>" ;
            echo "<td width='6000' rowspan='1'><big><b><div align='center'>Discharge (Cusecs)</div></td>" ;

                echo "</tr>" ;
        echo "<tr>" ;
        print "<br><br>";
            echo " HISTORICAL INFLOWS--------------YEARLY ";

        $query_stn = "SELECT gd_indus.sid, id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge FROM gd_indus,id_station WHERE Date BETWEEN '$dd' AND '$ddd' and (gd_indus.sid = '$id')AND gd_indus.sid = id_station.sid group by gd_indus.sid,id_station.name_station,gd_indus.date, gd_indus.gauge, gd_indus.discharge order by gd_indus.date ASC  ";
```

```
$result_stn = pg_query($query_stn)or die('Query failed: ' . pg_last_error());

$rows_stn = pg_num_rows($result_stn);

$i_stn =0;

while ( $i_stn < $rows_stn )

{

$result_stn1 =pg_fetch_array($result_stn);

$stn[$i_stn] = $result_stn1[0];

echo "<td><div align='center'>$result_stn1[0]</td>" ;

echo "<td><div align='center'>$result_stn1[1]</td>" ;

echo "<td><div align='center'>$result_stn1[2]</td>" ;
```

```
echo "<td><div
align='center'>$result_stn1[3]</td>" ;

echo "<td><div
align='center'>$result_stn1[4]</td>" ;

echo "<tr>" ;

}

pg_close($dbconn_stn);

}

else
{
}
?>
</table>
</body>
</html>
```

Appendix C

ANALYTICAL HIERARCHY PROCESS

Appendix Table C1 Pair-wise Comparison Matrix for Physical Factors

Site Selection Criteria	Symbol	A1	A2	A3	A4	A5	A6
Hydrology	A1	1	5	3	7	3	5
Topography of River Valley	A2	0.20	1	3	5	5	3
Geology and Foundation Conditions	A3	0.3	0.33	1	5	3	3
Availability of Material	A4	0.2	0.20	0.20	1	3	3
Spillways Size & Location	A5	0.33	0.20	0.33	0.33	1	5
Earthquakes	A6	0.20	0.33	0.33	0.33	0.20	1
Summation		2.267	7.067	7.86	16.66	15.20	20.0

Appendix Table C2 Synthesized Matrix for Physical Factors

Site Selection Criteria	Symbol	A1	A2	A3	A4	A5	A6	Summation	Weight
Hydrology	A1	0.453	0.708	0.381	0.375	0.197	0.250	2.364	0.394
Topography of River Valley	A2	0.091	0.142	0.381	0.268	0.329	0.150	1.360	0.227
Geology &Foundation Conditions	A3	0.151	0.047	0.127	0.268	0.197	0.150	0.940	0.157
Availability of Material	A4	0.065	0.028	0.025	0.054	0.197	0.150	0.519	0.087
Spillways Size & Location	A5	0.151	0.028	0.042	0.018	0.066	0.250	0.555	0.093
Earthquakes	A6	0.091	0.047	0.042	0.018	0.013	0.050	0.261	0.044
Summation		1	1	1	1	1	1	6	1

CURRICULUM VITAE

NAME : Mr. Faris Qazi

BIRTH DATE : December 31, 1971

BIRTH PLACE : Shikarpur, Pakistan.

EDUCATION :

YEAR	INSTITUTE	DEGREE/DIPLOMA
1998	Univ. of Engg. Pakistan.	B.Sc.Eng. (Civil Engineering)
2009	Kasetsart Univ.	M.Eng. (Civil Engineering)

POSITION/TITLE : Deputy Commissioner

WORK PLACE : Office of Pakistan Commissioner for Indus Waters, Lahore, Pakistan