Asian Journal of Environment & Ecology

Volume 22, Issue 3, Page 153-175, 2023; Article no.AJEE.107720
ISSN: 2456-690X

Urban Water Management Linked to WASH (SDG-6) of Greater Hyderabad City, India

Siba Prasad Mishra [a*], Kumar Chandra Sethi [a] and Kamal Kumar Barik [a]

[a] *Civil Eng. Department, Centurion Univ. of Technology and Management, Bhubaneswar, Odisha, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2023/v22i3500

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/107720

Original Research Article

Received: 06/08/2023
Accepted: 14/10/2023
Published: 18/10/2023

ABSTRACT

The water planning of the Musi River sub-basin, a tributary of the river Krishna faces challenges of urban floods, drainage disposal, and irrigation deficiencies which must be addressed with the escalation of the demography of Hyderabad city. The river is of length 240km and lies in Telangana state of the basin area of about 11270km^2 and is of urban origin and is the lifeline to Hyderabad City. The 21st-century status of the river is polluted and needs immediate rejuvenation. In the present case, the hydrologic model is structured using the Soil and Water Assessment Tool, ArcSWAT10.3.1, that builds up having an interface with ArcGIS 10.3.1, ERDAS IMAGINE to the DEM Data from Satellite origin (LISS-III RESOURCESAT-1), and SWAT Model to study the soil characteristics Musi Basin, Watershed delineation, HRU Analysis, slope delineation, and reclassification of the basin against Land use (LU). The bearing to the LU changes of the Musi and adjacent basins have been investigated during the years 2005-2006 and 2015-2016. The study has inferred that Sustainable Development Goal 6.1 (SDG) has been well attempted by the basin

**Corresponding author: E-mail: 2sibamishra@gmail.com;*

managers and administration but failed to achieve SDG (6-2) to have bearable portable quality drinking water, effective management of wastewater and ecosystems to protect the people of Hyderabad and its environment. The Water, sanitation and hygiene (WASH) for one million slum dwellers have been neglected. The model results infer that the sediment fluctuation is due to expansion and changes in the city, agricultural practices, and industrial establishments. Recommendations for effectively moderating floods, 100% sewage and septage disposals, and crop planning in the basin are discussed.

Keywords: Hyderabad; heritage; HRU analysis; Musi River; swat model; ArcGIS.

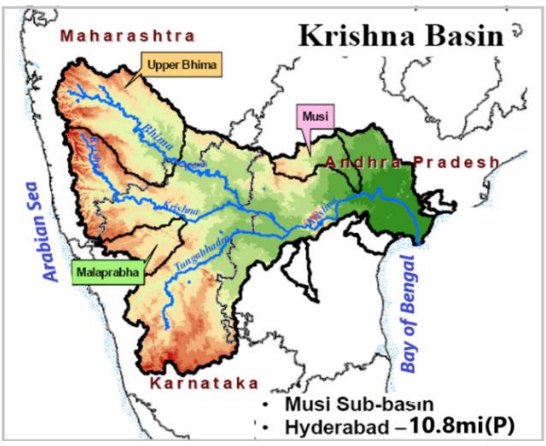
1. INTRODUCTION

The degradation of water resources has turned into major social, climatological, and environmental issues throughout the globe. Water pollution is instigated by either a point or non-point source or from both. The non-point sources are more significant. A decline in the fresh runoff in the tributaries or distributaries of rivers along the east coast of India mainly due to soil, erosion, land use and land cover changes (LU&LC), and anthropogenic activities, affecting drinking water, flood inundation, irrigation, industries, pisciculture sectors.

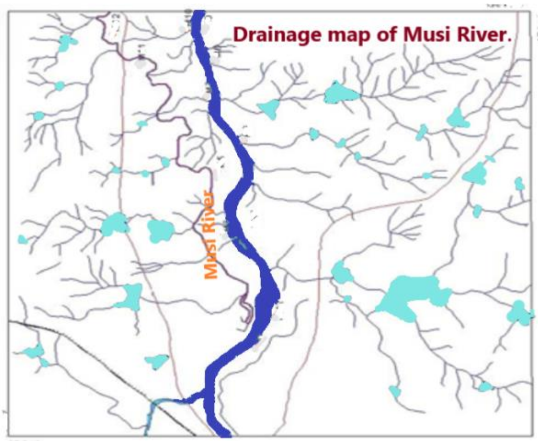
Estimation of the hydrologic limitations as well as surface runoff, evapotranspiration (ET), and yield of sediment using standard techniques for distant and remote regions is time-consuming. a herculean task. Adapting some appropriate alternate methods and techniques for the hydrological assessment of watersheds is desired to estimate the multiple hydrological parameters. The present study uses remote sensing (RS), and (GIS) geographic information systems and big data management through High-speed computers. Mathematical models for hydrologic analysis are substantial instruments that make the problem a comprehensive, fast, and reliable solution. Watershed management with accurate data acquisition by assessing the hazards and getting solutions after getting the land use pattern over geospatial multiple periods is innovative, [1,2]. Models add to decision-making, mainly where data is scarce. Sometimes the field data delimits its reliability or unavailability or scanty for running the model in achieving the decision-making process of watershed management.

The M*usi sub-basins* are the Tributaries of the river Krishna have been investigated, (Fig. 1 (a), (b), (c), and (d). In the present case, the SWAT2010 (Soil and Water Assessment Tool, ArcSWAT10.3.1) is a physically based semi-appropriated hydrologic model with an interface with ArcGIS 10.3.1. The Krishna River covers about 11270sq. km.

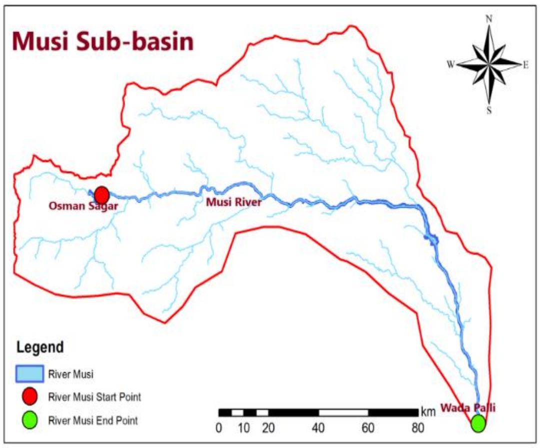
Research Rationale: Musi River (16° 65' N to 18° 48' N latitude and 77° 26'E to 80° 20'E longitude), is a tributary (River Krishna) housed in the Deccan Plateau bifurcating through the Hyderabad city, India, the merging of two drainage channels Moosa and Esi, confluence point is the Tipu Khan bridge near Golconda (Fig. 1(a), (b), (c) and (d)).



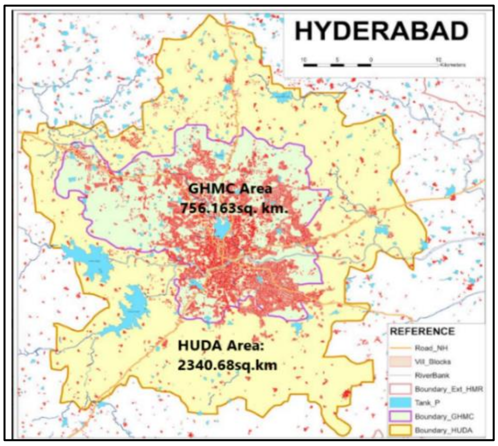
(a)



(b)



(c)



(d)

Fig. 1. (a) The Krishna basin (b) water bodies Musi sub-basin (c) Drainage map of Musi Sub-basin (d) The Hyderabad city under Greater Hyderabad Municipal Corporation

The Musi River starts in Ananta Giri Hills nearby Vikarabad, Ranga Reddy district, which is 90 km, the west direction of Hyderabad, flows towards the east, and falls in the Krishna River at Vadapally in the Nalgonda district flowing for a distance of about 240 km. Hyderabad, the historic old city have a present population of more than one million. Himayat Sagar and Osman Sagar are two reservoirs built over it which act as the source to cater water requirement of Hyderabad city. The Musi watershed covers ≈10858 sq. km and the rest of 11270 is in the Krishna basin. The length of the stretch is 224.058 km of which the stretch from Osman Sagar to Vadapally is about 481.4 km via NH 65 km the Musi project is the main project over Musi R along with other reservoir schemes (Fig. 1(a) &(b), (c) and (d)).

2. REVIEW OF LITERATURE

Musi River as a sub-basin has been studied for its flood, sewage/stormwater disposal, and irrigation for agriculture by many researchers from the early 19^{th} century. At present, the sewage water amounting to ≈ 200 MGD from an area of GHMC agglomerated to 727 Km^2, [3,4].

The Land Use (LU)/ Land cover (LC) changes taken by hydrological modelling of the similar basin are used to compute the surface runoff under urbanization, and altered land use management practices and reported that the surface runoff was varied (increased or decreased) from the prior basin parameters, Mishra et al., [5], Zhou et al., [6], Gogoi et al., [7], Jaiswal et al., [8], Turner et al, [9], Pande et al, [10], Nuissi et al., [11], Talib et al., [12]. The consequences of LU/LC changes on the hydrological system have little effect on modifications in vegetation changes or soil stratification changes on river flow in rainy/dry seasons of the year. However apparent variations were noted in the dry weather flow for both sub-basins. Ranjit et al. [13], Tripathy et al. [14], Stehr et al., [15], Showqi et al., [16], Meshesha et al., [17], Hussain et al., [18], Chauhan et al., [19], Sidi et al., [20], Mishra et al., [21], Mekonen et al, [22].

The GIS/RS in Hydrological Modeling is an effective instrument to decide the morphological physiognomies (stream length, drainage density, aerial aspects, stream frequency, structure ratio, Bifurcation ratio, form factor, elongation ratio, *etc.*) and environmental issues of a basin like soil erosion, land degradation, water logging, surface and groundwater contamination, and ecological changes, Strahler, [23], Tripathi et al., [24], Srivastav et al., [25], Achu et al., [26], Rawat et al., [27], Tiwari et al., [28]. The hydrological constraints can be integrated with GIS/RS that can recognize the advantages of watershed delineation by using the GIS-based techniques over standard procedures, a pre-requisite for suitable watershed planning and growth, [29-36].

The Soil & Water Assessment software (SWAT) is a typical model which delineates a watershed into sub-watersheds/sub-basins finally to solitary minute hydrologic response units (HRUs), the similar areas of collective soil, LU, and slope values are applied in the model even for modelling of ungauged basins Manguerra et al., [37], Fohrer et al. [38], Wang et al, [39], Kaffas et al., [40], Das et al., [41], Bera et al., [42], Beharry et al., [43] Glick et al, [44], Nagireddy et al., [45].

Project reports have been submitted to the Federal bodies about the flood, stormwater, and irrigation water management of Krishna River and its tributaries sub-basin such as Tungabhadra, the Musi River sub-basin. The Musi River Sub-basin has also been studied by various geoscience technocrats but only the land use where the analysis of the study area is poorly presented Srinivas et al., [46], Sudheer et al., [47], Achu et al., [26], Sonu et al., [48].

The study of floods, drinking water supply systems, storms/sewage water disposal, and septage digestion is not satisfactory and blindly overlooked in the shanty settlements. The flood moderation and water supply action plans have been given priority to cater for the population demand, but mixed grey water storm stormwater has made urban lowlands a dungeon.

2.1 Objective

Key issues for the city are pollution encroachment, inaccessibility, incompatible land use, growth of slums, lack of heritage, and natural vistas (Rock Precincts) of Hyderabad, and underutilization of open spaces. The issues concerned are steep river gradient, construction of dams only at selected historical flood levels, and intense activity between Tipu Khan to Chaderghat Bridge.

The objectives are to (a) Analysis of urban agglomerations (b) find current and future water flood and WASH activities including slum dwellers (c) Plan for STP and sludge digestion effluents for irrigation and plant nutrients, through SWAT analysis and (d) Futuristic approach by Promenades, Natural Vistas and Heritage

2.2 Climate of Musi-sub-basin

The area belongs to the semi-arid region with a rainfed climate and heavy spells of rain cause floods in the sub-basin. The month-wise climate data is given in Fig. 2.

The causes of urban floods by the Musi River are the outflow of huge numbers of tanks and illegal structures on the flood plains of the river. The Köppen (BSH), cold -semi-arid steppe type is the climate of Hyderabad City When it rains heavily, the city gets inundated, and citizens are put to urban flooding. The average (av.) daily optimal temp. in the study area ≈32.0°C (maximum) and 21.8°C (av. min.) with av. annual rainfall of the area is 925 mm (from 2000-2016) during the Southwest (SW) and Northeast (NE) monsoon periods, (https://en.climate-data.org/asia/india/Hyderabad/Hyderabad-2801/).

2.3 Past Floods in River Musi

The river is of urban origin, the lifeline to Hyderabad City, functioning as a sewerage drain. It is considered dead, defunct, and polluted at present, and urges immediate rejuvenation, CSIR report 2019. There are 788 water bodies (tanks and lakes) in the Musi River basin. The river has a rocky and steep drop and passes urban areas that had cloudbursts which have caused flash and urban floods in past. In 1908, Hyderabad confronted a devastating urban flood of the river Musi, which inundated the city on 2nd Sept 1908 and had fatalities ≈15000, (https://www.thehindu. com/profile/author/Serish-Nanisetti-669/).

	January	February	March	April	May	June	July	August	September	October	November	Decembe
Avg. Temperature °C (°F)	22.2 °C (72) °F	24.9 °C (76.9) °F	28.2 °C (82.7) °F	30.7 °C (87.3) °F	32 °C (89.7) °F	27.9 °C (82.3) °F	25.6 °C (78) °F	24.9 °C (76.8) °F	25 °C (77) °F	24.7 °C (76.4) °F	23.2 °C (73.7) °F	21.8 °C (71.3) °F
Min. Temperature °C (°F)	16 °C (60.8) °F	18.4 °C (65.1) °F	21.4 °C (70.5) °F	24.4 °C (76) °F	26.6 °C (79.8) °F	24.3 °C (75.8) °F	22.9 °C (73.2) °F	22.4 °C (72.3) °F	22.1 °C (71.7) °F	20.6 °C (69) °F	18 °C (64.3) °F	15.9 °C (60.7) °F
Max. Temperature °C (°F)	28.6 °C (83.4) °F	31.4 °C (88.5) °F	34.6 °C (94.3) °F	36.9 °C (98.4) °F	37.8 °C (100) °F	32.3 °C (90.1) °F	28.9 °C (84) °F	28.1 °C (82.5) °F	28.7 °C (83.7) °F	29.3 °C (84.7) °F	28.6 °C (83.4) °F	27.9 °C (82.3) °F
Precipitation / Rainfall mm (in)	7 (0)	3 (0)	10 (0)	19 (0)	27 (1)	101 (3)	159 (6)	162 (6)	129 (5)	98 (3)	26 (1)	4 (0)
Humidity(%)	50%	43%	37%	38%	37%	62%	74%	77%	78%	69%	59%	53%
Rainy days (d)	1	1	1	3	4	10	13	13	11	9	3	1
avg. Sun hours (hours)	9.3	9.9	10.6	11.1	11.4	9.6	8.1	7.7	7.9	8.6	8.7	9.0

Data: 1991 - 2021 Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days. Data: 1999 - 2019: avg. Sun hours

Fig. 2. Mainly weather averages (1991 – 2021) of Hyderabad city
(source: https://en.climate-data.org/asia/india/hyderabad/hyderabad-2801/)

Table 1. The heavy spells in the Musi River basin from 1903 to date

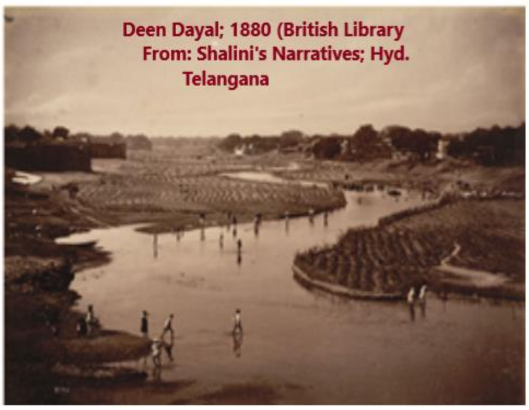
Year	1903	1908	1954	1970	1989	2000	2001	2002
Peak R/F (mm)	117	153.2	190.5	140.0	187.7	240	230.4	179.4
Fatalities	NA	15000	NA	NA	10	26	0	0
Year	2006	2008	2016	2019	2020	2021	2022	2023
Peak R/F (mm)	218.7	220.7	215	132	192	192.3	244.4	192.5
Fatalities		14	08	0	81	0	0	NA

Source: Telangana today, 15th Oct 2023, Decan Chronicle, 16th July, and Aug 1, 2022, Sultana et al, 2021, Swathi v., Oct 16, 2020 (The Hindu), Harini 2023: NA: Not available

The flood that devastated Hyderabad city on 28th September 1908 with a rainfall of 153.2mm killed about 15000 people causing devastation to Mohd. Quli Qutb Shah's "Hyderabad" of 1591. History of Hyderabad recorded 14 high floods till 1908. The historical flood years in the Musi River were during 1631, 1678, 16871803, 1903, and 1908. The floods in the Musi River after independence were in 1968, 1984, 2000, 2007, 2016 and 2020, 2023. (Shalini Hyd, & 28th September 2022, Siasat.com/News/Hyderabad) [49,50].

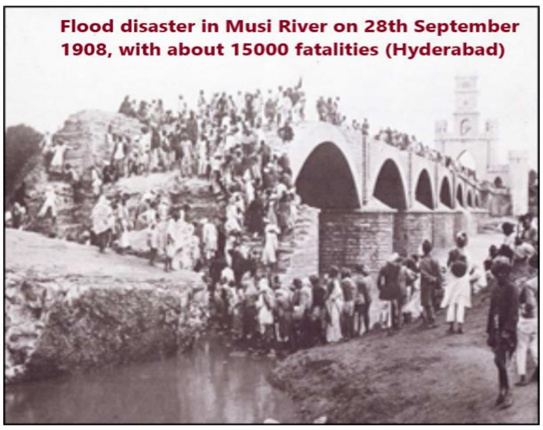
2.4 Past and Future Landscape

The Past landscapes of 1880 (Fig. 2(a)), The post-flood scenario of 1918 (Fig. 2(b)), The future promenades (Fig. 2(c) and the current year flood 2023 (Fig. 2(d)) are shown below.



(a)

(c)



(b)

(d)

Fig. 3(a). Musi River view (1880), Dayal retrieved 2023, Fig. 3(b). Future promenades along Musi Fig. 3(c). The historic flood Sept 28th flood (JS Iftekhar, 27th September 2022 Siasat Daily) Fig. 3(d). The Musi River on 28th July 2023 flood

(Source: Shalini 2023, British Library)

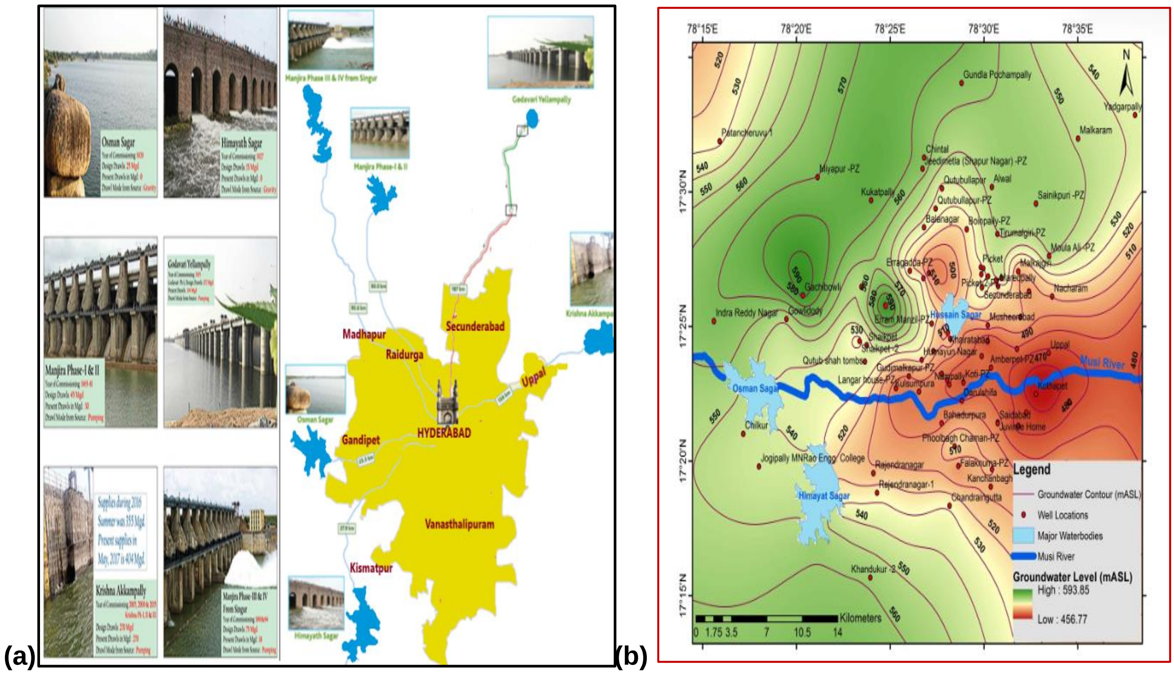


Fig. 4. The various reservoirs for flood control, and drinking water supply schemes in & around Hyderabad (www.hyderabadwater.gov.in). (b) The groundwater sources of Hyderabad

2.5 Water Resources Management

Directed by the then Nizam Mir Osman Ali Khan, to create Hyderabad as a flood-proof city, Syed Azam Hussaini prepared a project report on October 1st, 1909. A dam started in 1920 across the river, 16 km upstream across Osman Sagar. The other reservoir was created on the Esi drain (a tributary of Musi) named Himayat in 1927 Fig. 3(a), (b), (c) & (d) and Fig. 4.

To moderate flood havoc in GHMC and mitigation of the drinking water problem for the rising population of one million people, the present hydraulic structure, and dams are given in (Fig. 4). The Hyderabad urban flood havoc is mounting with a small amount of storm rainfall as Hussain Sagar is shrinking substantially, some lakes are depleted and their foreshore area encroached.

2.6 Present Drinking Water Supply

The major drinking water source created for Hyderabad city by 2005 is 1265MLD to cater for their water demand. After the bifurcation of AP and Telangana, project proposals are under process for waste resources, water supply and irrigation growth [51].

The Manjira Reservoir (Phase-I, & II), The Singur Dam (Manjira Ph-III & IV), The Krishna Dam (Phase-I, II, III) and Yellampally Barrage across Godavari (Phase-I). Presently the Hyderabad water supply schemes have created the potential of total installed capacity by HMWSSB (delimits GHMC up to ORR) of 602 Mgd out of which the present supply is 430 Mgd. The total demand projected of 932.02Mgd by 2024.(https://jalamjeevam.telangana .gov.in /about-hyderabad/about-water-supply/). The water demand of the 175,019 slum dwellers is not considered (Table 2).

2.7 Stormwater and Liquid Waste Disposal

More than 27 drains under HMWSSB are joining the Musi and other drainage channels from the Osman Sagar area to Vadapally. Many sewage treatment plants (STPs) have been installed in the last five decades, matching population growth in the Musi watershed area. The total sewage generation projected is ≈1625 MLD by the year 2029 against the present capacity is 725.8 MLD, creating a deficit of approximately 900 MLD by the year 2029. Saha Consultant projected 2814 MLD and 3,715 MLD of sewage in Hyd. city by 2036 and 2050, recommended 62 STPs (31 in GHMC and 31 in ORR areas) to cater to sewage treatment necessities until 2051(Singh BJ. 05th Sept. 2022, The New Indian Express).

Table 2. The water supply through completed or in the pipeline projects from dams and reservoirs

Source, Scheme	River	Start year.	Potential Mgd	Design (Mgd)	Present drawls	Reservoir	Dist. Hyd.
Osman Sagar	Musi	1922	86	25	15(gravity)	Osman Sagar	15 Km
Himayat Sagar	Musi	1927	63	15	05 (gravity)	Himayat Sagar	8.6 Km
Manjira barrage	Manjira	1965	167	45	0 (Lift)	Manjira	58 Km
Phase I		1981					59 Km
Phase II		1991				Singur	80 Km
Phase III							
Manjira/Singur (Phase IV)	Manjira	1994	279	75	0(Lift)	Singur	80 Km
Krishna-Water Sch.	Krishna	Pumping		270	270(lift)	Nagarjuna Sagar	130 Km
Phase I Stage I		(pipeline)					
Phase I Stage 2		2005-	45				
Phase II		2006-	45				
Phase III Stage 1		2011-	90				
Phase III Stage 2		2016-	45				
		2021-	45				
Godavari Ph- I, II, III (Ghanpur MBR completed)	Godavari	2015 Pipeline	172Mgd	172	162(Lift)	Yellampally Barrage	188 Km
Total			1337Mgd				

Source: www.hyderabadwater.gov.in; & https://www.hyderabadwater.gov.in/en/index.php/more / projects/Krishna-water-supply-project/,(45Mgd =205M LD), PL: Pipeline, Rao, GR.2019 [52]

The present stormwater drain (SWD) system can handle runoff from just 20 mm/hr rainfall (Deccan Chronicle, September 7, 2017). The river Musi ranked as a polluted river Priority-I for its stretches of garbage accumulating in drainage channels of length ≈390km. The accumulations arise due to many diversions and approximately 900 bends because of city agglomeration, land use changes, illegal encroachments, dumping of construction wastes, etc.

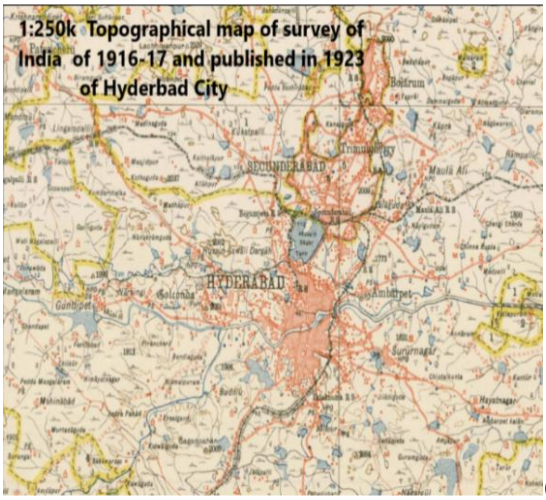
Hyderabad City in Past and Present: The Satavahanas, to the Nizams (300 years BC to 18th century AD) the feudatories (Jaghirdars) and rulers have made Hyderabad the largest princely state of the country.

After the freedom (1947), Nizam's city was expanded to the left flange centred at Secunderabad. The developments in the expansions in Hyderabad city are shown in (Fig. 5 and Fig. 6)

2.8 The Rationale of the Study

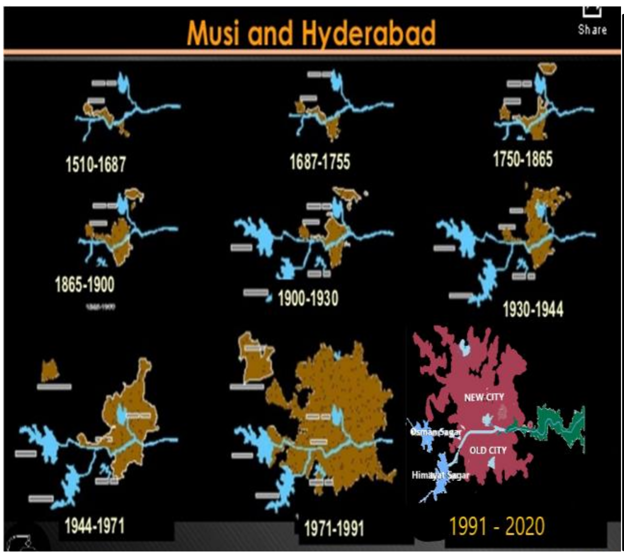
The soil is under high erosional process due to intense paddy cultivation. The Basin is highly erosional and urges judicious integrated watershed management by planning through hydrological simulation using GIS and RS techniques. The present LU changes and their insinuations in the field adaptations as per the model results are the scope of the present study.

(a)



(b)

Fig. 5. (a): The SOI map, survey year 1916-17; Fig 5(b) Shrunken Musi River 2020 (Source: GHMC and SOI)



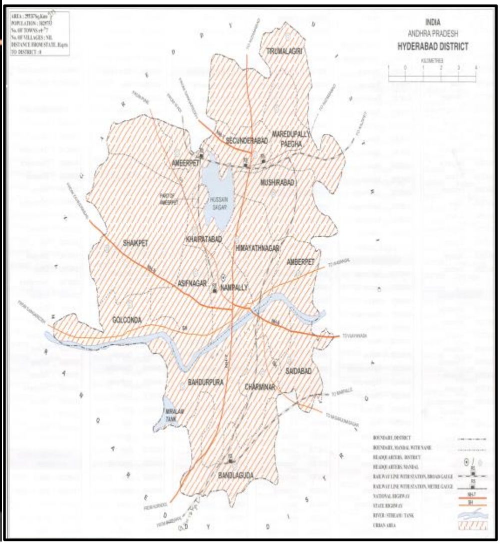


Fig. 6(a). The river Musi and the Hyderabad city with time 6(b) Hyderabad city 1960

Due to unselective urban sprawl and lack of planning the river valley has turned into a receptacle of untreated solid and liquid waste dumping yards in and out of Hyderabad city. It is estimated that ≈1000 MLD (Million Liters a Day) of industrially and domestically polluted grey water is added through both banks of the river. The downstream flow of the city remains highly polluted, which is deteriorating the ecology and needs immediate attention.

2.9 Model Use

The use of the SWAT 2012 decides the usefulness of the hydrological parameters like surface runoff, evapotranspiration and sediment yield of the river basin, Musi, a sub-basin of the matured Krishna River Basin. The comparative study has been done through LULC maps of the area for the years 2005-06 and 2015-16, by generating the Digital Elevation Model (DEM) and soil maps, evaluation of the HRU, and the impact on water resources (WR).

3. MATERIALS AND METHODS

Out of many simulation models in vogue, the land use management of water, sediment, nutrient loss, etc. on the watershed. The models are CREAMS (Chemicals, Runoff Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), GLEAMS (Groundwater Loading Effects of Agricultural Management System), AGNPS (Agricultural Non-Point Source Pollution), SWRRB (Simulator for Water Resources in Rural Basins).

SWAT (Soil and Water Assessment Tool) is one of the innovative models created conjointly by the United States Department of Agriculture (USDA), the Agricultural Service and the Agricultural Experiment Station in Texas. The geospatial techniques are used to find the hydrologic study of the Musi River basin by using the GIS technique. The RS and other data used are SRTM DEM (30-meter resolution), LISS III (23.5 resolution) data for (2005-06 and 2015-16) period, FAO soil layer, and the Weather (SWAT Global Weather Data).

The software used in the present investigation is for Land use/Land cover Mapping, (ERDAS Imagine 10.4, ArcGIS 10.3, Google Earth Pro), Geospatial Analysis (ArcGIS 10.3.1), SWAT Model Implementation and SWAT 2012 (Arc SWAT 10.3.1). For analysis and report writing of the article, the software used is Microsoft Excel and Word to compute hydrology, climate, sedimentation, soil temperature, plant development, nutrients, pesticides and agricultural management. The organization for analysis for the Musi Sub-basin is given in Fig. 7.

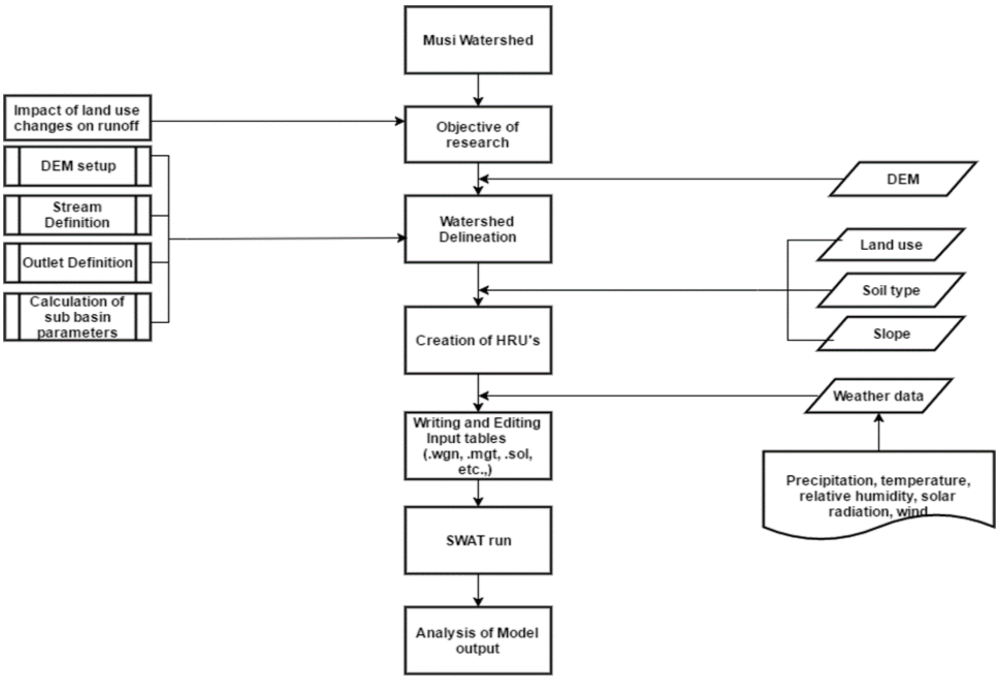


Fig. 7. Methodology for the analysis of inherited data hydrologic models

3.1 Data Assortment and Dispensation

The *SWAT model* is data-driven to give data on geography, land use, Land cover, topography, soil, atmosphere, etc. The data needed were for *the digital elevation model* Fig. 1:(DEM) where the bare-earth raster grid referenced to a vertical elevation is in (Fig. 8(a), 8(b) & 8(c)).

The built-ups and natural vegetation aren't included in a DEM, which is beneficial in the effective planning and management of hydrologic and land use of an area. (Barik et al., 2021)The present study utilizes SRTM DEM of 30-meter resolution data of the newly formed Telangana state downloaded from the online database of USGS (Earth Explorer) and clipped the elevation data of the Musi sub-basin. Fig. 8(a) exhibits the DEM of the sub-basin clipped from the DEM of Telangana. The DEM map indicates the dark portion is at a low elevation and vice versa.

3.2 Land Use/Land Cover Database

LULC maps for the years 2005-06 and 2015-16 are prepared using LISS III data acquired from the Indian website "Bhuvan". LULC maps are prepared by visual interpretation techniques. The LISS-III RESOURCESAT-1 (IRS-P6) are RS satellites of the ISRO organization (Indian Space Research Organization), India. The Musi sub-basin data is clipped from LISS III data by using ERDAS IMAGINE and ArcGIS. Fig. 8((a), (b) and (c)) shows the Musi Sub-basin data clipped which gives the drainage channels, waterbodies, and agriculture area.

3.3 Visual Interpretation Technique

Analysis of remote sensing images includes the identification of objects in the image, like shape, pattern, texture and shadow. The study has used those targets that might be natural or artificial features which comprise points, lines and polygons. Visual interpretation technique was used to make the LU/LC maps of 2005-06 and 2015-16 by using ERDAS IMAGINE and ArcGIS and were compared (Panda et al., 2021).

3.4 Swat Model Description

SWAT (Soil and Water Assessment Tool), is used to analyze a watershed, or river basin scale model formed by Dr Jeff Arnold of USDA and ARS which can tell about the impact of sediment, water and land management practices, and chemical yields of a watershed. The disparities in LU, soils, and managing strategies are also obtained over time. The Swat model requires hydrological parameters like weather data, hydrologic cycle, runoff, Evapotranspiration (ET), Potential Evapotranspiration (PET), and sediment yield according to various formulae described in any Hydrology textbook [53]. A long series of climate parameters from 18 points located in the Musi basin comprising temperature, relative humidity (RH), rainfall, solar radiation and wind speed was obtained from the Global Weather Database of SWAT [54]. The SWAT incorporates the XGEN climate generator model, Sharpley et al., [55] to produce climatic information or fill in, Pandey et al., [56] missing records.

3.5 Watershed Delineation

The steps involved in watershed delineation are defining the data to prepare DEM. The DEM data should be in an appropriate projected coordinate system. In watershed delineation, the catchment area is divided into sub-basins based on the flow accumulation algorithm as in the drainage map (Fig. 9), [57,58].

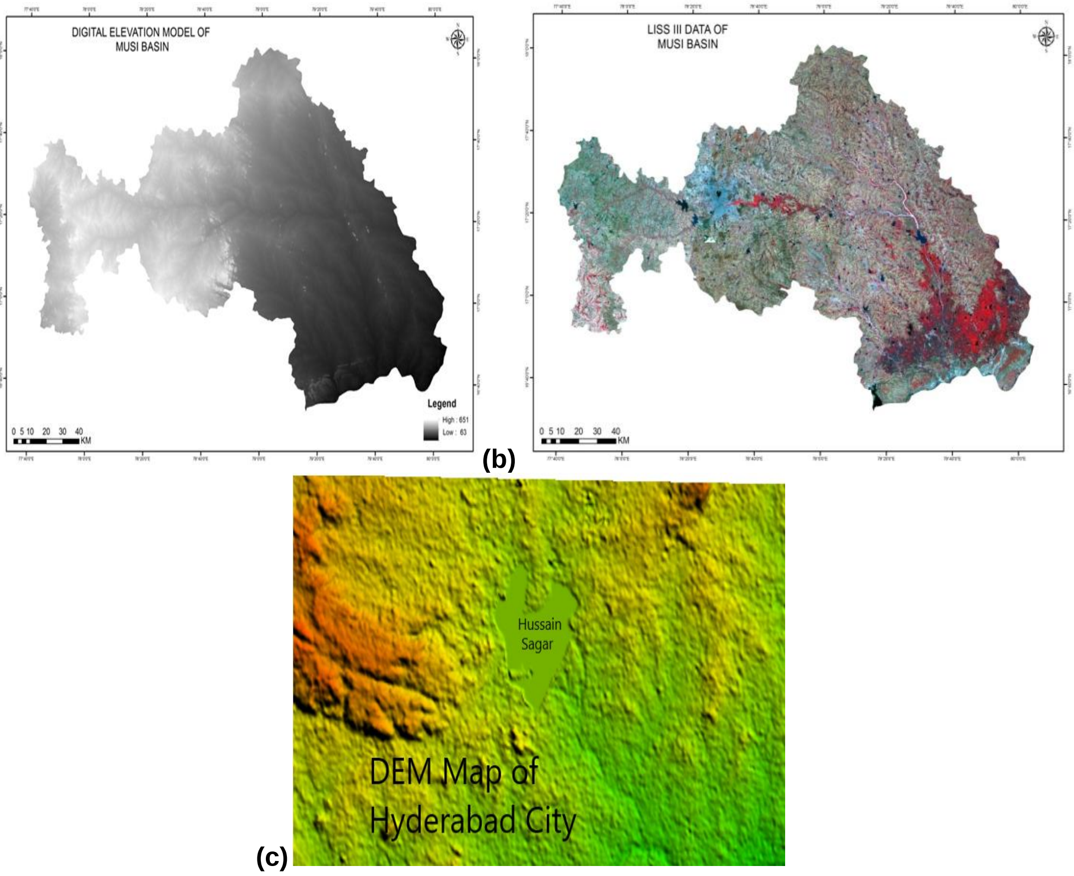
Fig. 10 (a) & (b) indicate the interface of watershed delineation with inputs Stream definition, stream network, watershed outlets, and delineated watershed. After the selection of the delineated watershed, the map should add a polygon feature class with sub-basins, Jaiswal et al., [59].

3.6 HRU Analysis

HRU, the hydrologic response unit, shows the Land use/soils/slope definition. The interfaces lump the congregation of land use, soil and slope of a small sub-basin. The LULC prepared is converted into raster data and given as input to the model. The LULC classes are reclassified into SWAT Land Use/Land Cover classes by using Lookup (Table 3), Singh et al, [60].

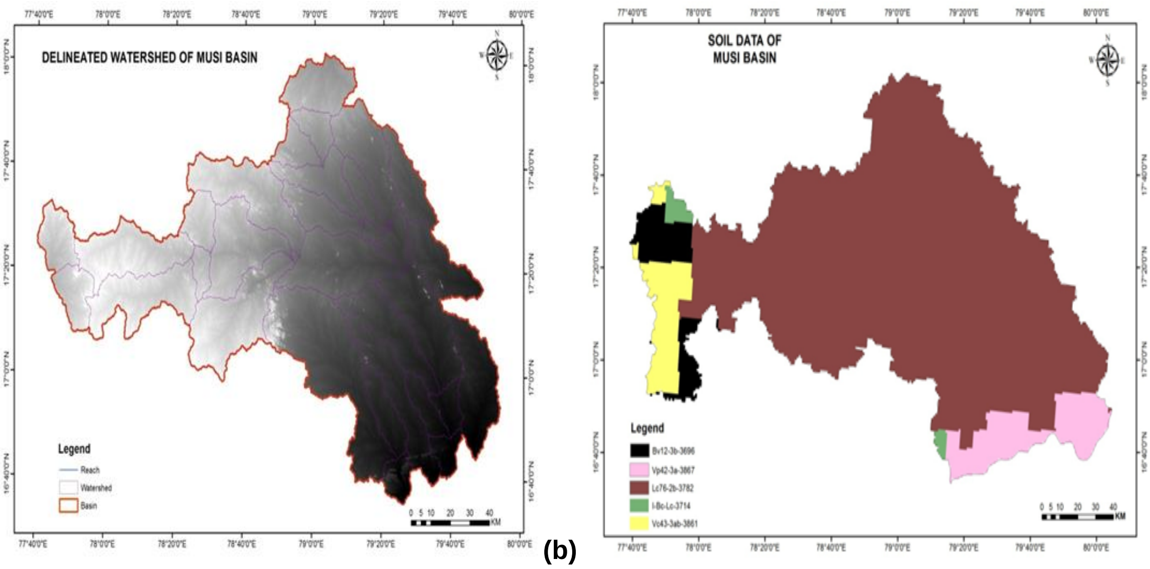
3.7 Soil Data

For the present Musi sub-basin, the soil data is clipped from the World soil layer on a 1:5000000 scale set by the FAO (Food and Agricultural Organization). The soil layer of the Musi River basin is clipped from the world soil layer by using ARG GIS (Fig. 10 (b)). The soil texture observed is generally loamy, clayey, loamy skeletal, clayey skeletal and rocky. As per FAO categorization soils, Musi sub-basin soils are Bv12-3b-3696 (Loamy), I-Bc-Lc-3714, Lp13-3ab-3861, Vc43-3ab-3861, Vp42-3a-3867. As per lookup Table 3, the soil database was linked to the soil layer, and later the window used the reclassification made by USAID and Honeywell Inc.



(a) (b) (c)

Fig. 8(a). The digital elevation map, 8(b). LISS data of the Musi sub-basin, Fig. 8(c). DEM map of Hyderabad city (Using Global mapper)



(a) (b)

Fig. 9(a). Delineation of the watershed Fig. 9(b). The soil map of Musi River Sub-basin

3.8 Slope Delineation

This window is used to assign slope attributes to generated HRUs with Multiple slope options. Three slope classes were used for reclassification purposes. Finally, the information on land use, soil layer and slope are combined to generate HRU analysis and slope delineation.

3.9 Weather Database Definition

The step is to select the weather geodatabase from SWAT. For this study, WGEN_US_COOP_1980_2010 is chosen to simulate the information for the 2005-06 and 2015-16 periods. Weather data (rainfall, temperature, wind velocity and solar insulations) collected from the IMD data that is housed in the Musi sub-basin are given as input to the model.

3.10 Swat Database Table and Model Simulation

Soil, Groundwater, Stream, pond, watershed, soil chemical and water use data were generated in this window was used in the SWAT model Simulation. The Har Greves (HG) based on air temperature, Priestley-Taylor (P-T) based on solar radiation and the Penman-Monteith (P-T) based on the combination of air temperature and solar radiation, humidity and wind speed were used to estimate the Potential evapotranspiration (PET). Two model simulations are done in this study for a period of 7 years starting from 1st Jan 1999-2006 and 1st Jan 2009-2016 for better performance 2 years of warm period NYSKIP=2 is considered. Rainfall distribution is based on the skewed normal distribution method. SWAT.exe Version 32bit debug is used for this simulation.

4. RESULTS AND DISCUSSION

The present study includes the LULC changes and various set-ups created utilizing SWAT. The model discusses the effect of LULC changes on the hydrological parameters like surface runoff, ET, sediment yield and percolation.

The built-up compact, built-up sparse, rural, industrial, mining, cropland, fallow land, plantation, forest, grassland, wasteland, barren rocky and water bodies are the classes circulated in the regions of Nalgonda, Hyderabad, Ranga Reddy, Vikarabad, Medak and Mahbubnagar districts (Fig. 11).

Musi river basin mainly has paddy cultivation with higher LU in the countryside. Over 75% of the paddy is cultivated in the Nalgonda region followed by cotton in Nalgonda, (40%), Rangareddy and Mahabobnagr regions. Maize and jowar are sparse crops but uniform. The Built-up areas including industries cover ≈80% of Hyderabad and Rangareddy city. Vikarabad and Medak cover the forest areas (Table 3).

4.1 Changes of LULC

On physical examination, a huge change in LU/LC has been observed in the decade, (2005-15). LULC maps (Fig. 11A& B) and tables (Table 4) demonstrate the changes in LU/LC.

The cropland replaced the fallow lands along the Musi River flood-prone areas. Built-up-compact, sparse, vegetated and rural areas have increased in 10 years due to a surge in population. Table 4: From the comparative study for the decade, it is observed that the changes

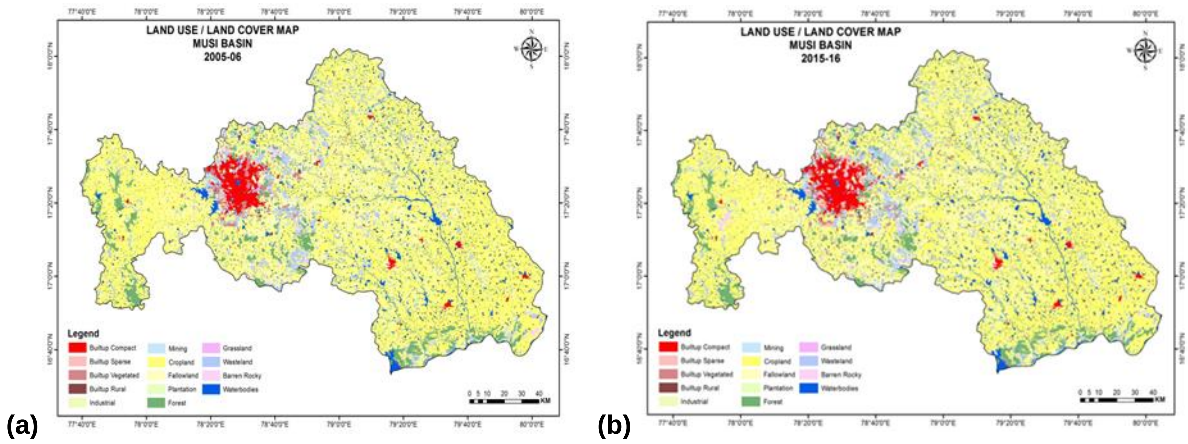


Fig. 11. A comparative study of the Land use/ Land cover Musi River basin 2005-06 & 2015-16

Table 3. Land use / Land cover changes between 2005-06 & 2015-16

LULC	2005-06		2015-16	
	Area (km)	% Area	Area (km)	%Area
Built up-Compact	422.11km	2.58%	475.06km	2.9%
Built up-Sparse	48.96 km	0.29%	64.29km	0.39%
Built &Vegetated	236.36 km	1.44%	287.05km	1.75%
Rural	353.02 km	2.16%	387.38km	2.3%
Industrial	100.9 km	0.61%	112.36km	0.68%
Mining	123.07 km	0.75%	146.35km	0.89%
Cropland	9297.82 km	56%	9032.52km	53.92%
Fallow land	2695.78 km	16.5%	2858.42km	19.51%
Plantation	203.8 km	1.2%	178.82km	1.09%
Forest	592.29km	3.62%	552.18km	3.3%
Grassland	9.22km	0.05%	4.79km	0.02%
Waste Land	1144.48km	6.96%	1138.87km	7.26%
Barren rocky	215.1km	1.31%	199.95km	1.22%
Waterbody	904.86km	5.53%	854.368km	5.22%

Table 4. Land use / Land cover changes between classes for 2005-06& 2015-16

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Tot
1	422.11														422.11
2	18.62	30.34													48.96
3	11.28	26.77	198.31												236.36
4	5.8	1.24		345.98											353.02
5					100.9										100.9
6			4.96		1.4	116.6						0.14			123.07
7	0.97	2.1	16.17	29.18	0.43		9001.	136.5	26.12			85.3			9297.82
8	1.96	1.39	25.64	0.74	2.16	8.08		2640.7	3.5			11.6			2695.78
9			0.32				20.76	22.38	149.2			11.1			203.8
10	0.5		2.36				1.8			542.2		6.3	39.14		592.288
11	0.63	0.91	0.32		0.6		2.31				4.5				9.22
12	10.23	1.54	37.32	11.46	6.87	11.48	1.81	55.32			0.3	1000.5	1.96		1138.87
13			0.32	0.02		10.22				9.98		72.5	122.0		215.1
14	2.96		1.33				4.78	3.57				1.02	36.83	854.4	904.86
Tot	475.1	64.3	287.1	387.4	112.4	146.4	9032.5	22858.	178.8	552.2	4.8	1186.6	199.9	854.4	16342.2s

between 2005-06 and 2015-16 classes. 2005-06 classes (in rows) and 2015-16 classes are in columns based on the value given to the classes in the above Table 4.

A wasteland of 10.23 sq. km from 2005-06 is converted into a built-up and -compact. 26.77 sq. km. of built up-vegetated is converted into built up-sparse. 37.22 sq. km. of wasteland is altered into built-up-vegetated. 29.18 sq. km of cropland is converted into rural area.6.87 sq. km of wasteland is converted into an industrial area.8.08 sq. km of fallow land 11.48 sq. km of waste land and 10.42 sq. km of barren rocky is converted into mining. 20.76 sq. km of plantation is converted into cropland. 136.46 sq. km of cropland is converted into fallow land 26.12 sq. km of cropland is converted into a plantation. A Forest of 39.138 sq. km is converted into barren rock. The water body of 2.96 sq. km is converted into a built-up and compact.

4.2 Reclassification of LULC for SWAT

LULC classes prepared by GIS methodology are reclassified under SWAT configuration as some LULC classes are unavailable in the SWAT model. For example, cropland classes were re-classified as rice, Jowar, maize, groundnut, soya bean, sugarcane and mixed crops (Table 5).

The paddy cultivated area surged between 2005-06 from 12.63% of the total area to 18.84% in 2015-16 due to an increase in demand for paddy. The area under cotton harvest with (COTP) has lessened from 3845.52 sq. km in 2005-06 (17.7% of the total basin area) to 13.89% (i.e.2832.88 sq. km) in 2015-16. The area under Agricultural Land-Row Crops (AGRR) has extended from 2104.69 sq. km in 2005-06 (32.34% of the total basin area) to 1665.9sq.km in 2015-16 (23.62% of the total basin area).

The residential-med/Low-density (URML) area has expanded from 589.38 sq. km in 2005-06

(3.76%) to 674.43 sq. km (4.12% of the total area of the basin). The area under Soybean (SOYB) has increased from 1042.28sq.km in 2005-06 (8.67% of the total area of the basin) to 668.7sq.km (5.57%) in 2015-16 (Fig. 12).

4.3 Outputs of SWAT Model

4.3.1 Impact of LU/LC over surface runoff

Model simulation is done for 2001-06 and 2011-16 years based on monthly data. The results are represented in the form of graphs between precipitation and surface runoff. The graphs indicate that surface runoff generated has reduced between the 2001-06 model simulation compared to the 2011-16 model simulation. The area under agriculture has decreased from 2005-06 to 2015-16 as discussed previously. Urban and Rural settlements have increased from 2005-06 to 2015-16 which has made the land impermeable (concrete jungles) that enhances surface runoff, [61-63].

4.3.2 Impact of LU/LC over Evapotranspiration (ET)

The model result points towards the increase of ET between 2005-06 and 2015-16, (Fig. 13 and Fig. 14).

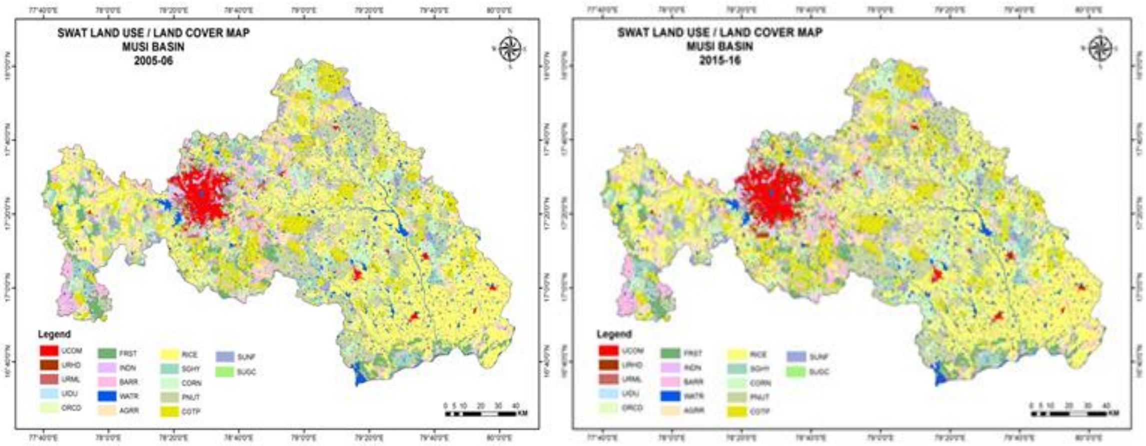


Fig. 12. The LULC map based on model Arc SWAT re-constructed for the Musi sub-Basin

Table 5. SWAT LULC changes between 2005-06&2015-16

	2005-06		**2015-166**	
	Area (km)	**% Area**	**Area (km)**	**% Area**
Commercial	422.11	2.83	475.06	2.9
Residential-High Density	48.96	0.76	67.29	0.41
Residential-Med/Low-density	589.38	3.76	674.43	4.12
Industrial	223.97	1.48	258.71	1.58
Orchard	203.8	1.47	178.82	1.09
Forest Mixed	592.28	3.29	552.18	3.37
Indiangrass	9.22	0.03	4.79	0.03
Barren	1353.97	8.28	1386.57	8.48
Water	904.86	5.37	854.36	5.22
CROP LAND SWAT LULC	**2005-06**		**2005-06**	
Agri-Land-Row Crops	2104.69	32.34	1665.9	23.62
Rice (RICE)	1501.82	12.63	2259.29	18.84
Upland Cotton-harvested with	3845.52	17.7	2832.88	13.89
Peanut	1358.87	11.33	1001.21	8.42
Sorghum Hay	712.4	5.94	1015.48	8.54
Corn	814.529	6.85	802.63	6.75
Sunflower	987.07	8.23	907.27	7.63
Soybean	1042.28	8.76	668.7	5.57

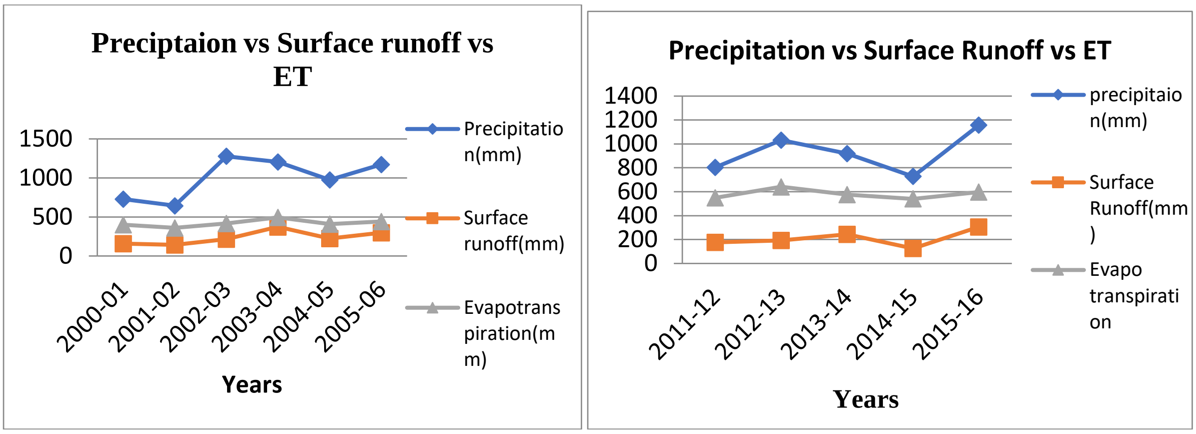


Fig. 13. Model study comparison of rain, runoff, & and ET of the Mushi sub-basin from 2001-06 to 2011-16)

4.3.3 Impact of land use/land cover over Sediment Yield

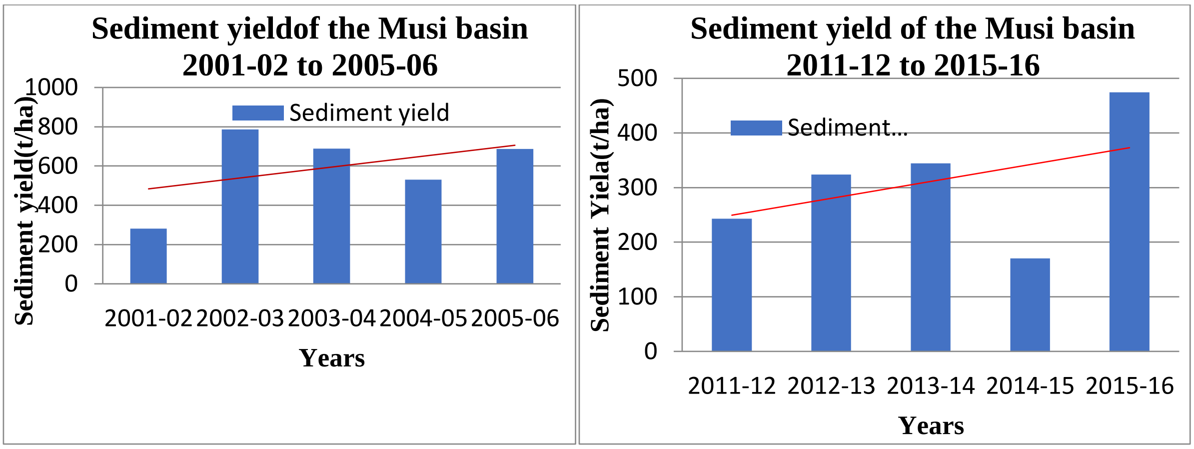


Fig. 14. Comparison of the Sediment yield Musi sub-Basin (2001-02 to 2005--06) to (2011-12 to 2015-16)

The sediment yield indicates fluxes in the Musi sub-basin. The reasons can be the annual stress of urbanization, intensive agriculture and industrial growth within the area (Table 6).

The water resources development essential for Hyderabad city and its peripherals in the Musi River stretch (mostly from Osman Sagar to Wadapalli a 19km stretch, and the adjoining Krishna River basin in the Telangana state are flood control, water supply, stormwater disposal and septage management. A heuristic framework is imperative to comprehend the water demand. The influence on LU change and flood/drought management in GHMC. Adhering to the stipulatory provisions in sustainable goals 6, 11.5 and 13 it is high time to make strategic formulations to save Greater Hyderabad from floods, irrigation shortfalls, safe drinking water and proper liquid waste management, [64].

4.4 The Water Resources Problem Discussed

Flood Control: Flood control management has been attempted through the construction of Osman Sagar, Himayat Sagar, Singur at Manjira, Krishna Yadav all, and Akkampally Balancing Reservoir over the Krishna and the Godavari Rivers. The frequency of floods in the Musi River has surged due to sediment filling, erratic rainfall (climate change), and concretization of the city. Less GW infiltration, encroachment of floodplain, the proliferation of water hyacinth, Ipomeas, water-born health hazards, grey and stormwater added to the influxes, [65] Hyderabad

Table 6. Hydrological parameters simulated by SWAT model of Musi Basin (2001 to 2006)

Years	Rainfall (mm)	Surface Runoff (mm)	ET (mm)	PET (mm)	Sediment yield((T/ha)
2001-02	644.6	142.42	360.51	1113.64	281.42
2002-03	1277.05	419.56	417.11	1056.39	786.21
2003-04	1203.58	373.52	494.71	1065.69	688.39
2004-05	976.8	223.55	407.12	1065.92	530.05
2005-06	1172.82	399.11	441.91	1073.65	686.93
Hydrological parameters simulated by SWAT model (20011-2016).					
2011-12	802.82	176.03	548.06	1915.42	243.26
2012-13	1030.44	193.27	641.45	1824.41	323.62
2013-14	918.62	244.82	575.54	1799.2	344.32
2014-15	727.54	125.49	539.77	1845.18	170.62
2015-16	1156.37	305.53	598.35	1709.09	474.23
2011-12	802.82	176.03	548.06	1915.42	243.26
2012-13	1030.44	193.27	641.45	1824.41	323.62

Metropolitan Water Supply & Sewerage Board (HWWS&SB) is the custodian of the water resources management.

4.5 Floods in Hyderabad

It is studied from the contour map of the Hyderabad area and the Musi sub-basin that the low-lying and flood-plain are Husain Sagar, Saroor Nagar tank, Errakunta, Balakapur, Kawadiguda, Damalguda, Ashokanagar, Bhawani Nagar, Bhavani Nagar, Begumpet, Lunger House, Afzal Sagar, and Mallepally, etc, and encroachment in those adjoining areas. Major flood-causing drainage channels in GHMC are Hussain Sagar surplus Nallah-1, Balakapur N., Durgam Cherruvu Nallah, Afzal Sagar Nallah, Durgam Sagar Nallah, Kissan Bagh Nallah, Old City Nallah, Murki N. Saroor Sagar surplus nallah etc.

At Full tank level (FTL) level, storage Capacity, inflow and outflow of Himayat Sagar are 537.51m, 3TMC (where 1TMC = 28.3168 billion litres), 50.97cumecs and 58.33cumec respectively while that of Osman Sagar the same are 545.59m, 3.9TMC, 13.48cumec and 12.74cumec respectively. The travel time of outflow is almost the same as they are parallelly housed. Hyderabad City's water supply, drainage management and floods are managed by the HMWS&SB. A coordinated interaction, planning, and unanimous decision for the opening of gates by the line departments has been lagging over the past few years. They aimed at discharge from the local drains and local water bodies need renovation to absorb a part of the floods along with removing illegal construction from the ≈30km stretch of the river. The depleted and disappearing water bodies must be rejuvenated.

Floods clean the rivers from their marshy islands, floating trash, ipomoeas and water hyacinth, and pollutants, that sustain the river sections and its flood plains. The Guttala area near Begumpet has disappeared as a real estate hotspot, which needs administration intervention to rejuvenate the drainages (Yunus Lasaniaus, Journalist, HYD).

Major Storm water drainage congestion and clogging occurring in GHMC are Zone XII, (Kukatpally), Zone XIII (Alwal) and Begumpet areas which need immediate de-silting and de-clogging. Renovation of all SWD channels needs to be renovated to augment the sustenance of the waterbodies, groundwater (GW) recharging, separate conduits for grey water, and polluted lakes. However, several STPs function in treating the sewages and septage of the area, avoiding health hazards in the city.

4.6 Drinking Water Supply

The City of Hyderabad has chalked out plans (by USAID, and Honeywell Inc.), to supply safe drinking water through Kiosks or ATMs. After full implementation of these schemes, deliverance of innocuous water to its citizens within GHMC shall be possible as conventional water supply system has less response. The scattered shanty towns accommodate >1.95 million slum dwellers living in 4060k houses and 1476 slum patches are in Hyderabad. The Manjira, the Singoor, the Krishna, and the Godavari River along with Osman Sagar, and Himayat Sagar have the potential to cater for the water demand needs of

GHMC of ≈ 2068 MLD. By harnessing the potential, the city shall be 100% drinking water efficient in meeting its future demand. Concurrent GHMC has a water supply of 1337Mgd which satisfies the present demand. The slum dwellers are deprived of their full quota.

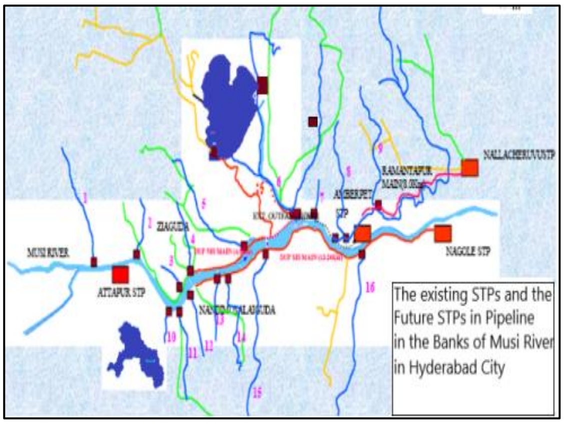
4.7 Sewage and Septage Disposal

The present city generates 1950 MLD of sewage per day. Hyderabad city produced 1650 MLD and the rest by GHMC and the outer ring road (ORR). The GHMC sewage disposal system constitutes 51 stormwater drains with the potential for 772 MLD (46.78%) of the total wastewater. There are proposals for 31 STPs and 25 well-functioning, MA&UD and GHMC authorities report on 23.09.2021. To date, the storm and sewage drainage system is only utilized in some parts of the city and it is connected to sewage Treatment Plants (STPs). HMWSSB needs to construct an extra 137 MLD capacity service reservoirs and dispose of liquid sewage through 2,100 Km, pipelines on a priority basis as an immediate solution to the 100% sewage disposal problem of the GHMC [4].

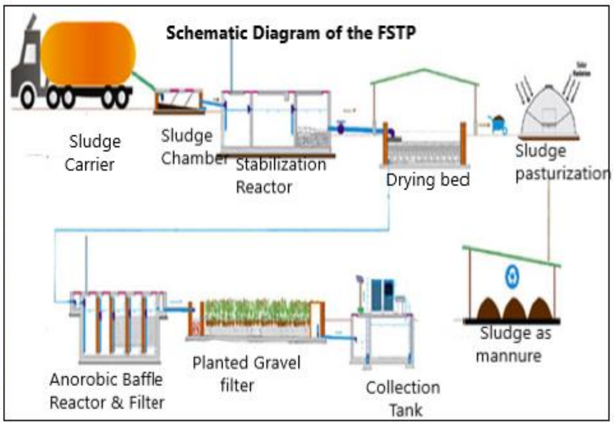
The management of faecal sludge or septage (FSSM) for GHMC is through the faecal sludge Treatment Plants (FSTPs). The plants can be planned near Nalla Cheruvu and Uppal. The FSTP Plant at Uppal could treat a sludge capacity of 40 KLD (≈14 truckloads/day) collected from the vicinity covering approximately 80,000 people. Effective Sludge treatment is essential because one gram of Fecal sludge may contain: 100 parasites eggs 1000 Protozoa 1,000,000 Bacteria 10,000,000 Viruses as per (National Institute of Urban Affairs, Delhi MoUHA) causing cholera, Typhoid, and other waterborne diseases.

Presently the sewage generation is 650 MLD in the GHMC area. There are 25 STPs in operation to treat 772 MLD of sewage. The construction of 31 new sewage treatment plants The New STPs

(a)



(b)



(c)

Fig. 15. (a) The Uppal sewage treatment plant (STP Phase I) in Hyderabad (Trial Run); https://www.hyderabadwater. gov. in/en/index.php/newsview?newsid=7047) (b) Positioning of STPs in Musi River Sub-basin. (c) Old practice and effective new sludge disposal schematic diagram of FSTP

treat 878MLD in three packages. Package I aim for 8 STPs in Alwal, Malkajgiri, Kapra, and Uppal Circle where 402.50 MLDs of sewage will be treated. In Package II, 6 STPs are to be constructed for Rajendranagar and LB Nagar to treat 480.50 MLD of sewage. Similarly, Package III includes 17 STPs to serve the Kukatpally, Quthbullapur, and Serilingampally areas to discharge 376.5 MLDs of sewage. If these 31 STPs get operational, the sewage problem in the city will be solved in 100%. The new STPs are being constructed with advanced sequencing batch reactor technology. The HMWS&SB panelled 87 Septic Tankers of private and municipality ownership. They are used for cleaning, transport and operators associated with the ASCI for conveyance and safe disposal septage by the STP, and FSTP (Fig. 15).

Project prerequisites are the construction of interceptor sewers, erection of STPs, Policy on encroachment and enforcement, Slum rehabilitation, and construction of promenades. As per SWOT analysis, the upper and lower reach farms should be supplied with quality but nutrient water for better yield.

4.8 Natural Vistas and Heritage

Promenades and growth corridors need to be constructed and sustainably maintained so that there should be water retention at adequate places without water logging, and developments along and adjacent to the banks. The various precincts can be developed in various corridors are Tipu Khan Bridge to Puranapul (7.28 km) as the *ecological precincts*, the Heritage Precinct from Puranapul to Chaderghat, (3.98 km) and finally the metropolitan precinct from Chaderghat Bridge to Nagole bridge (8.64 km).

After the development of the proposed town planning action plans and construction of the present Hyd. The city shall be taken up so that its Natural Vistas and Heritage shall be enhanced (Fig. 16). The program needs to be chalked out to conserve and supply uninterrupted drinking water, reuse the wastewater for irrigation to augment yield downstream fields and encourage tourism for the economic development of the people. The slum dwellers must be well provided with portable water, efficient sewage and septage disposal. Proper water treatment, construction of rapids and stepped fall across the Musi River can make the water clear and useable. Construction of promenades, water retaining structures intermittently, smart city appraisals, and heritage precincts with proper illumination can add to its magnanimity and make it world-class.

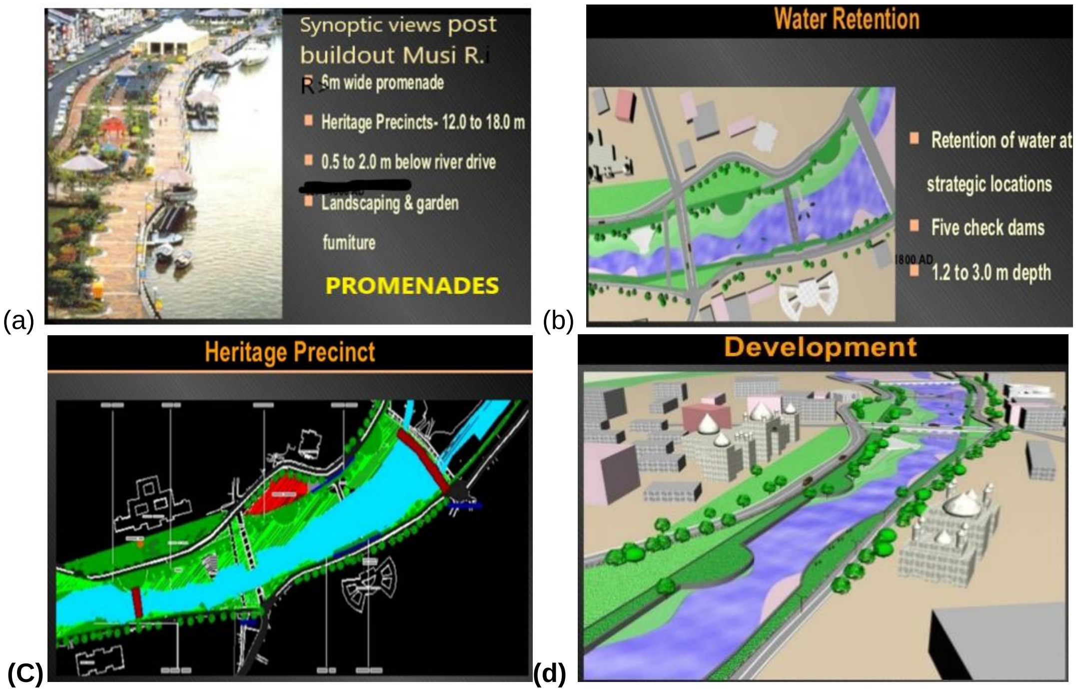


Fig. 16. The Schematic development strategies like Promenades, Water retention, Heritage precinct and the future developments imagined

4.9 Sustainable Development Goals (SDGs)

SDG 6.1 narrates for availability of safe drinking water, and SDG 6.2 demands adequate and equitable WASH (Water, Sanitation and Hygiene) by 2030 with special attention to the necessities of women and girls and those in vulnerable situations. Other SDGs that need to be stressed are 11.5 and SDG-13. In the case of greater Hyderabad city, it should be our target to fulfil the goal.

5. CONCLUSIONS

Deterioration of quality of drinking water, disposal of stormwater, septage of millions and irrigation of the basin is a billion-dollar question for the millennium-old Hyderabad city and geriatric Musi sub-basin, which is the topic discussed at present. The growth of the city and penalties levied by the floods of the Musi River left its imprint in 1908. Dams and barrages were constructed from time to time to moderate floods and to create drinking water sources and sewage disposal till 2036 which has been planned and partly satiated.

The problem lies in the disposal of stormwater, sewage and septage have posed problems for which no or little action plan has been prepared. No preventive measures for the WASH (Water, sanitary and hygiene) programs for more than one lakh slum dwellers in the GHMC. The upper and lower reach of the Musi Sub-basin is full of on-farm activities without proper agricultural planning. The SWAT software (SWAT-2012) and its HRU analysis have indicated the Agriculture, Irrigation, and crop planning of the rural settlement to satisfy the sustainable development goal.

To bridge the gap between the Sendai framework (SDG 6, SDG 11.5, and SDG 13), it is essential to have multi-institutional coordination between, national, and state-level disaster management, which can be overcome by authorizing key sectors and line departments both at the community and country levels.

ACKNOWLEDGEMENT

We all the authors are obliged to Maj. Tahir Mustaffa, DSS, for his guidance and inspiration to complete the article.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Spruill C, Workman S, Taraba J. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. Trans ASAE. 2000;43: 1431–1439.
2. Das B, Jain S, Singh S. Thakur P. Evaluation of multisite performance of SWAT model in the Gomti River Basin, India. Appl Water Sci. 2019;9:134. Available:https://doi.org/ 10.1007/s13201-019-1013-x
3. Dimri P. Down-to-earth; 20 October; 2020. Available:https://www.downtoearth. org. in/blog /water/so-just-why-did-Hyderabad-flood--73875
4. Harini V. The impact of Musi floods along the catchment areas of Hyderabad- A study. IOP Conf. Ser.: Earth Environ. Sci. 2023;1210 01203. DOI: 10.1088/1755-1315/ 1210/1/012031
5. Mishra SP, Das K. Management of Soil Losses in South Mahanadi Delta, India, International Journal of Earth Sciences and Engineering. 2017;10(02):222-232. DOI: 10.21276/ijee.2017.10.0213
6. Zhou X, Chen H. Impact of urbanization-related land use land cover changes and urban morphology changes on the urban heat island phenomenon. Sci Total Environ. 2018;635:1467-1476. DOI: 10.1016/j.scitotenv.2018.04.091
7. Gogoi PP, Vinoj V, Swain D, et al. Land use and land cover change effect on surface temperature over Eastern India. Sci Rep. 2019;9:8859. Available:https://doi.org/10.1038/s41598-019-45213-z
8. Jaiswal T, Jhariya DC. Impacts of Land Use Land Cover Change on Surface Temperature and Groundwater Fluctuation in Raipur District. J Geol Soc India. 2020;95:393–402. Available:https://doi.org/10.1007/s12594-020-1448-6
9. Turner BL, Lambin EF, Verburg PH. From land-use/land-cover to land system science. Ambio. 2021;50:1291–1294. Available:https://doi.org/10.1007/s13280-021-01510-4

10. Pande CB, Moharir KN, Khadri SFR. Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques. Appl Water Sci. 2021; 11:96 . Available:https://doi.org/10.1007/s13201-021-01425-1
11. Nuissl H, Siedentop S. Urbanisation and Land Use Change. In: Weith T., Barkmann T., Gaasch N., Rogga S., Strauß C., Zscheischler J. (eds) Sustainable Land Management in a European Context. Human-Environment Interactions. 2021;8. Springer, Cham. Available:https://doi.org/10.1007/978-3-030-50841-8_5
12. Talib A, Tio R. Long-term effects of land-use change on water resources in urbanizing watersheds. PLOS Water. 2023;2(4). DOI: org/10.1371/journal.pwat.0000083
13. Ranjit Premalal De Silva, Madusha Chandrasekhar. Impacts of land use changes on Hydrological Regime- A case study of Randenigala & Kotmale catchments in Sri Lanka. Map Asia; 2000.
14. Tripathi MP, Panda RK, Raghuwanshi NS. Identification and Prioritisation of Critical Sub-watersheds for Soil Conservation Management using the SWAT Model. Biosystems Engineering. 2003;365-379.
15. Stehr A, Aguayo M, Link O, Parra O, Romero F, Alcayaga H. Modelling the hydrologic response of a mesoscale Andean watershed to changes in land use patterns for environmental planning. Hydrol. Earth Syst. Sci. 2010;14:1963-1977.
16. Showqi I, Rashid I, Romshoo SA. Land use land cover dynamics as a function of changing demography and hydrology. Geo Jr. 2014;79:297–307. Available:https://doi.org/ 10.1007/s10708-013-9494-x
17. Meshesha TW, Tripathi SK, Khare D. Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. Model. Earth Syst. Environ. 2016;2:1–12. Available:https://doi.org/10.1007/s40808-016-0233-4
18. Hussain S, Mubeen M, Ahmad A, et al. Using GIS tools to detect the land use/land cover changes during forty years in Lodhran District of Pakistan. Environ Sci Pollut Res. 2020;27:39676–39692. Available:https://doi.org/10.1007/s11356-019-06072-3
19. Chauhan N, Kumar V, Paliwal R. Quantifying the impacts of decadal land use change on the water balance components using soil and water assessment tool in Ghaggar river basin. SN Appl. Sci. 2020;2:1777. Available:https://doi.org/10.1007/s42452-020-03606-0
20. Sidi Almouctar MA, Wu Y, Kumar A, et al. Spatiotemporal analysis of vegetation cover changes around surface water based on NDVI: A case study in Korama basin, Southern Zinder, Niger. Appl Water Sci. 2021;11:4. Available:https://doi.org/10.1007/s13201-020-01332-x
21. Mishra SP, Mohapatra SK, Sethi KC. The Values and Blue Carbon Ecosystem of the Chilika Lagoon through Ages, India. Environ Sci Arch. 2023;2(2):164-184.
22. Mekonnen YA, Manderso TM. Land use/land cover change impact on streamflow using Arc-SWAT model, in case of Fetam watershed, Abbay Basin, Ethiopia. Appl Water Sci. 2023; 13:111. Available:https://doi.org/10.1007/s13201-023-01914-5
23. Strahler AN. Quantitative geomorphology of the drainage basin and channels networks. In: Ven Te Chow (Ed.). Handbook of Applied Hydrology. McGraw Hill Book Company, New York. 1964;4:9–76.
24. Tripathi MP, Panda RK, Raghuwanshi NS. Runoff estimation from a small watershed using SWAT model. Hydrological Modelling; 1999.
25. Shrivastava PK, Tripathi MP, Das SN. Hydrological modelling of a small watershed using satellite data and GIS technique. J Indian Soc Remote Sens. 2004;32:145–157. Available:https://doi.org/10.1007/BF03030871
26. Achu AL, Raghunath R, et al. Mapping of groundwater recharge potential zones and identification of suitable site-specific recharge mechanisms in a tropical river basin. Earth Syst Environ. 2020;4:131–145. Available:https://doi.org/10.1007/s41748-019-00138-5

27. Rawat A, Bisht MPS, Sundriyal YP, et al. Assessment of soil erosion, flood risk and groundwater potential of Dhanari watershed using remote sensing and geographic information system, dist. Uttarkashi, Uttarakhand, India. Appl Water Sci. 2021;11(119).
Available:https://doi.org/10.1007/s13201-021-01450-0
28. Tiwari RN, Kushwaha VK. Watershed Prioritization Based on Morphometric Parameters and PCA Technique: A Case Study of Deonar River Sub Basin, Sidhi Area, Madhya Pradesh, India. J Geol Soc India. 2021;97:396–404.
Available:https://doi.org/10.1007/s12594-021-1697-z
29. Tsihrintzis VA, Hamid R, Fuentes HR. Use of Geographic Information Systems (GIS) in water resources: A review. Water Resour Manage. 1996;10:251–277.
Available:https://doi.org/10.1007/BF00508896
30. Dang ATN, Lalit Ku. Application of remote sensing and GIS-based hydrological modelling for flood risk analysis: A case study of District 8, Ho Chi Minh City, Vietnam, Geomatics, Natural Hazards and Risk. 2017;8(2):1792-1811.
DOI: 10.1080/ 19475705. 2017.1388853
31. Thakur PK, Nikam BR, Garg V, et al. Hydrological Parameters Estimation Using Remote Sensing and GIS for Indian Region: A Review. Proc. Natl. Acad. Sci., India, Sect. A Phys. Sci. 2017;87:641–659.
Available:https://doi.org/10.1007/s40010-017-0440-z
32. Arulbalaji P, Padmalal D, Sreelash K. GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: A case study from Southern Western Ghats, India. Sci Rep. 2019;9:2082.
Available:https://doi.org/10.1038/s41598-019-38567-x
33. Sethi BK, Mishra SP, Sethi KK, Barik KK. Deltaic Expansions of the Mahanadi Tri-delta and the Chilika Lagoon: Geospatial Approach; Current Journal of Applied Science and Technology 2020;39(34):46-65.
DOI: 10.9734/CJAST/2020/v39i3431036
34. Natarajan S, Radhakrishnan N, Flood hazard delineation in an ungauged catchment by coupling hydrologic and hydraulic models with geospatial techniques—a case study of Koraiyar basin, Tiruchirappalli City, Tamil Nadu, India. Environmental Monitoring and Assessment. 2020;192:11.
35. Barik KK, Panda SR, Nanda S, et al. GIS-based saltwater vulnerability mapping of the northern coast of Odisha, East coast of India. Arab J Geosci. 2021.14:1365.
Available:https://doi.org/10.1007/s12517-021-07800-1
36. Janjić J, Tadić L. Fields of Application of SWAT Hydrological Model—A Review. Earth. 2023;4(2):331-344.
Available:https://doi.org/10.3390/earth4020018
37. Manguerra HB, Engel BA. Hydrologic Parameterization of Watersheds for Runoff Prediction Using SWAT. JAWRA Journal of the American Water Resources Association. 1998;34(5):1149–1162.
DOI: 10.1111/j.1752-1688.1998.tb04161.x
38. Fohrer ND. An interdisciplinary modelling approach to evaluate the effects of land use change. Physics and Chemistry of the Earth. 2002;655-662.
39. Wang J, Shrestha Ku N, Delavar AM, Meshesha WT, Bhanja SN. Modelling Watershed and River Basin Processes in Cold Climate Regions: A Review. Water. 2021;13:518.
Available:https://doi.org/10.3390/w13040518
40. Kaffas K, Hrissanthou V, Sevastas S. Modeling hydromorphological processes in a mountainous basin using a composite mathematical model and Arc SWAT. CATENA. 2018;162:108–129.
Available:https://doi.org/10.1016/j.catena.2017.11.017
41. Das B, Jain S, Singh S, et al. Evaluation of the multisite performance of the SWAT model in the Gomti River Basin, India. Appl Water Sci. 2019;9:134.
Available:https://doi.org/10. 1007/s 13201-019-1013-x
42. Bera S, Maiti R. Assessment of Water Availability with SWAT Model: A Study on Ganga River. J Geol Soc India. 2021;97:781–788.
Available:https://doi.org/10.1007/s12594-021-1760-9
43. Beharry SL, Gabriels D, Lobo D, et al. Use of the SWAT model for estimating reservoir volume in the Upper Navet watershed in Trinidad. SN Appl. Sci. 2021;3:163.
Available:https://doi.org/10.1007/s42452-021-04201-7
44. Glick R, Jeong J, Srinivasan R, Arnold JG, Her Y. Adaptation of SWAT Watershed

Model for Stormwater Management in Urban Catchments: Case Study in Austin, Texas. Water. 2023;15(9):1770. Available:https://doi.org/10.3390/w15091770

45. Nagireddy NR, Keesara VR, Venkata Rao G, Sridhar V, Srinivasan R. Assessment of the Impact of Climate Change on Streamflow and Sediment in the Nagavali and Vamsadhara Watersheds in India. Applied Sciences. 2023;13(13):7554. Available:https://doi.org/10.3390/app13137554
46. Srinivas G, Naik GM. Hydrological Modeling of Musi River Basin and Impact Assessment of Land Use Change on Urban Runoff, Int. J. of Eng. Res. & Tech. (IJERT). 2017;6(07):1-8.
47. Sudheer KP, Srinivasan K, Narasimhan B, Morphological study of Krishna and Tungabhadra basins using remote sensing technique, Env. and Water Resources Eng. Div., Dep.. of Civil Eng., IIT, Madras, to CWC, MOWR, India; 2019,
48. Sonu Sandeep Ku. Assessment of Land Cover Changes in Musi River Basin: Part of Rangareddy and Hyderabad districts, Telangana, Int. J. of Res. in Social Sc. 2020;10(03).
49. (Shalini) Salvi Suman, Narratives of change of River Mushi in Hyderabad. Telangana; 2023. Available:https://www.livingwatersmuseum.org/narratives-of-change-of-river-musi-in-hyderabad
50. Dayal D. Musi River view, Hyderabad, Courtesy: British Library; 2023. Available:https://www.livingwatersmuseum.org/narratives-of-change-of-river-musi-in-hyderabad
51. Ramachandraiah C, Vedakumar, Manikonda V. International Water Conference, Berlin during. Hyderabad's Water Issues and the Musi River Need for Integrated Solutions; 12-14 September 2007
52. Rao GR, Naresh A, Naik Mg. Management of water supply and sewerage system in Hyderabad. Journal of Indian Water Works Association. 2019;120-125.
53. Chow VT, Maidment DR, Mays LW. Applied hydrology. New York: McGraw-Hill; 1988.
54. Fuka DR, Todd MW, Alister C, Mac Steenhuis TS, Easton ZM. Swat Model: A multi-operating system, multi-platform SWAT model package in R1, J. of the American WR Association. 2014;50(5):1-5.
55. Sharpley AN, Williams JR (eds) (1768) EPIC-Erosion productivity impact calculator, 1. model documentation. U.S. Department of Agriculture, Agricultural Research Service, Tech. Bull; 1990.
56. Pandey A, Bishal KC, Kalura P, Chowdary VM, Jha CS, Cerdà A. A Soil Water Assessment Tool (SWAT) Modeling Approach to Prioritize Soil Conservation Management in River Basin Critical Areas Coupled With Future Climate Scenario Analysis. Air, Soil and Water Research. 2021;14. DOI: 10.1177/11786221211021395
57. Teshome F, Bayabil H, Thakural L, Welidehanna F. Modeling stream flow using SWAT Model in the Bina River Basin, India. Journal of Water Resource and Protection. 2020;12:203-222. DOI: 10.4236/jwarp.2020.123013
58. Sabale R, Jose MK. Conjunctive Use Modeling Using SWAT and GMS for Sustainable Irrigation in Khatav, India. Lectures Notes in Civil Engineering, Springer. 2023;373–386.
59. Jaiswal RK, Yadav RN, Lohani AK, Tiwari HL, Yadav S. Water balance modelling of Tandula (India) reservoir catchment using SWAT. Arab. J. Geosci. 2020;13:148., Available:https://doi.org/10.1007/s12517-020-5092-7
60. Singh S, Sharma P, Sharma SD. Modelling streamflow in the Sot River catchment of Uttar Pradesh, India. Arab J Geosci. 2023;16:562. Available:https://doi.org/10.1007/s12517-023-11659-9
61. Barik KK, Panda SR, Nanda, Mishra SP, et al. GIS-based saltwater vulnerability mapping of the northern coast of Odisha, East coast of India. Arab J Geosci. 2021;14:1365. Available:https://doi.org/10.1007/s12517-021-07800-1
62. Panda S. R., Mishra Siba Prasad, Tripathy, J. Ku. The Failed Resilience, Grim Water Future, and Salinity Intrusion through GIS of Kendrapara Coast, Odisha. International Journal of Lakes and Rivers. Research India Publications. Sept 2021;14(2):161-181. ISSN 0973-4570.
63. Waseem M, Ahmad S, Ahmad I, et al. Urban flood risk assessment using AHP

and geospatial techniques in swat Pakistan. SN Appl. Sci. 2023;5:215. Available:https://doi.org/10.1007/s42452-023-05445-1

64. Sehra V, Punia M. Overcoming Barriers to Urban Flood Resilience: A Case of Hyderabad, India. Intech Open; 2020. DOI: 10.5772/intechopen.93195

65. CSIR-National Environmental Engineering Research Institute (NEERI). Action Plan for Rejuvenation of River Stretches (Priority I and II) in Telangana State. Project Report. Mar, 2019;1-45. Available:https://tspcb.cgg.gov.in/CourtOrders/P-I-VStretches.pdf

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/107720