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Geoinformatics for Runoff Diversion Planning from the Western Slope of Western Ghat to Godavari Basin in Maharashtra, India

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Abstract

Spatio-temporal variations in water availability are foremost attribute of the majority of river basins, especially in semi-arid environment. Several tasks and schemes have been implemented to overcome the gap between water supply and demand. Unfortunately, most of schemes and tasks are failed due to reduced water retention capacity of the same basins as a result of climate change. Interlinking of river (ILR), inter-basin water diversion (IBWD), gravity base runoff diversion (ROD) etc. are mega concern which are somewhat completed and some are under tribulations. These mega harvesting implementation is challengeable and still uncertain due to absence of realistic data for sustainable planning. In India, immense physical, hydrological, land use and land cover (LULC) and socio-economic diversity prevails where ILR, IBWD and ROD implementation is rather tricky due to environmental, social and technical sound concern. In the Western Ghats, potential water diversion or ROD sites are located in rigid geology, undulating topography, dense vegetation, and allied human ecology which is one of ecological sensitive zone of India. Thus, the real data collection by routing surveying for this region is inflexible, time consuming and costly. In such situation, use of high resolution aerial data, as a part of remote sensing (RS) and advance tools and techniques of Geoinformatics is innovative for ROD planning. It is the technical and scientific discipline which uses spatial and non-spatial dataset to address the problem with real time monitoring, digital mapping, multi-data analysis and huge data management. This attempt is haulage the discussion about capabilities of Geoinformatics for ROD planning from western slope of the Western Ghat to Godavari Basin.

Keywords: River basin, Runoff diversion, Geoinformatics, Sustainable planning.

Introduction

A river basin is a part of terrain drained by rivers and its sub-tributaries in specific hydrological and physical environment. Most of land surface of the world, apart from the most arid and cold areas are isolatable into river basins[1]. It sustains the seam ecological environment contained by river basin and its tributaries. The flow of river is spatio-temporally variable, which is animatedly impact upon river geomorphology, ecology and human civilization[2]. The origin of almost all upstream of the west and east flowing river is in the Western Ghat, which is prime water resource to linked regions in India. However, due to topographical and climatic variations the water yield from runoff and its distribution are spatio-temporally uneven in all connected basins of the Western Ghat. Similarly, seasonal and spatial variation in the west and east flowing runoff is the function of monsoon and non-monsoon seasons, as an annual behavior in this undulating physiographic precinct. Therefore, in this region, nearly all river basins consisted with uneven hydrological characteristic with surplus and deficit performance[3].

Decreasing water quality of river water in most of basins is due to constant discharge of polluted effluents, river bank erosion[4] and municipal solid waste (MSW) governed by urbanization[5] are responsible for growing fresh water demand in most of regions. In India, total demand for water is projected to reach around 784–843 km^3 by 2025 and 973–1180 km^3 by 2050[6]. Current research studies forecast that, if the demand and supply gap continues to augment, nine basins that have over four-fifths of the total water use in India will face physical water scarcity by 2050[7]. The symptoms of supply-demand gap such as protest for water demand, intra-basin dispute, depletion of groundwater level, water scarcity problem etc. are previously seen in the various part of India. To overcome the water demand in drought prone basin while managing the flood in water surplus basin several conservation methods and costly practices have been implemented. Unfortunately, most of tasks and practices are failed without sustaining the water demand problem in majority of regions. Similarly, an annual floods and droughts occurrence in various part of India is a common reality of each year.

According to some engineer, planner and environmentalist, in India IBWD and ROD is a long-term alternative to mitigate the spatial and temporal mismatch of water availability and demand8. Several researchers[9-14] were studied the ILR, IBWD and ROD issues along with diverse angles. In the Western Ghat, water diversion issue is in discussing phase from last few decades. Yadupathi Putty et al., were studied the water diversion issues in the (Western Ghat) Karnataka[15]. Likewise, due to growing water demand in upper Godavari basin (UGB) of Maharashtra, water diversion or ROD issue from western slope of the Western Ghat to Godavari basin is also lift up. Implementation of tools and techniques of Geoinformatics for ROD planning will be supportive through enough scale spatial and non-spatial data processing within minimum time, resources and budget. Krishnaveni et al., discussed the GIS and visualization capabilities for interlinking planning of Indian rivers[3]. Similarly, Gupta et al., used the Geoinformatics for identification of potential dam and reservoir sites with delineation of the optimal route for canals to transfer water from the Brahmaputra basin to the Ganga basin[16].

ROD, ILR and IBWD issues are typically associated with hydrological, geological, environmental, LULC, socio-economic and other cultural aspects. Most of the components of the 'National Water Grid' considered by the national water development agency (NWDA) remain unrealistic due to various reasons like environmental, social and political supports and seem to be forgotten already. Those links associated in the peninsular component, which are proposed to divert from western slope of west flowing streams to the eastern slope of east flowing rivers basins, particularly in the Western Ghats (Sahyadri Range), continue to be talked and investigated. Almost all west flowing streams / rivers are hydrologically surplus in nature are intended to divert or connect to the east flowing deficit rivers on the water divider stretch of the Western Ghat. The NWDA is preparing the pre-feasibility reports of the Intra-State links which as proposed by the various State Governments. Maharashtra is one of the states which are also promoting the water diversion scheme from the western slope of Western Ghat to the eastern deficit region. Taking into consideration of this regions background, associated water problem, regional topography, increasing protest between upstream and downstream populations use of Geoinformatics in ROD planning will be advantageous for precise and sustainable water resource management in this area. Geoinformatics is the scientific discipline which uses spatial information to address the problems of geosciences[17] and related branches with monitoring, digital mapping[18], precise surveying and huge scale data analysis. Therefore, in this attempt discussed the capabilities of tools and techniques of Geoinformatics for ROD planning in UGB of Maharashtra, India. The reported information in this attempt will be supportive for decision support system (DSS) and water diversion planning in UGB of Maharashtra.

ILR, IBWD and ROD

The idea of IBWD or ILR is essentially based on availability of surplus water in the donor river especially at the point of diversion to the deficit river basin. Rao et al.,[14] stated that, if the surplus water is available after meeting the needs of irrigation at least 60 % of area in the basin is cultivable. Only this water from such a basin can be diverted to deficit basins. According to protagonists, it is an economically viable, technically feasible, environmentally sound and viewed as the future main stay for the sustainable progress[18]. In India, observed, nearby 40 M ha flood prone areas while 51 M ha drought prone areas, because of diverse rainfall pattern. Some rivers are perennially dry and some rivers discharge huge quantum of water to the sea every year. Thus, need to relocate water from surplus to deficits basins[3] in India by massive task of ILR, IBWD and ROD.

In India, two grand schemes that were proposed in the 1970s (i) Ganga-Cavery canal proposal of K. L. Rao[19] and (ii) Garland canal system proposed by D. J. Dastur[20]. In 1980s NWDA was made proposal of ILR via two components, (i) Himalayan Rivers Development Component and (ii) Peninsular Rivers Development Component. There are 14 link canals in Himalayan component and 16 link canals in peninsular component were suggested for ILR. The effective planning of ROD is based on multidisciplinary data which should be stored at one place in digital form for easy manipulation and analysis. The concept of collecting surface runoff in canals cut across the western slopes of the Western Ghat, in order to divert a part of surplus flow of west flowing rivers to the east flowing river on the basis of gravity, is being promoted and somewhat implemented via diversion weir in western slope of the Western Ghat connected to the Godavari basin in Maharashtra.

Background of study area

Present study area is located in NW Maharashtra and consists with the Nashik, Thane and Ahmednagar districts. The extent of study area is 19° 08' 26" to 20° 32' 11" north latitude and 73° 03' 37" to 74° 11' 28" east longitude. The national water divider (NWD) line passing through this study area and divide the runoff flow of west and east flowing rivers (Figure-1). Western part of the UGB is characterized with high rainfall, geological breaking, lateritic rocks and non-soils Ghat sections covered by dense vegetation. Topography is undulating hilly, comprises 1100-1300 m. average height from mean sea level (MSL), however few of the pinnacles have greater heights; the tallest are the Kalsubai (1,646 m) near Igatpuri, Harichandragarh (1,422 m), Ghanchakar Donger (1,497 m) and Salher (1,567 m) in the Nashik district.

The average rainfall is around 3000 to 4000 mm in monsoon seasons. Thus, this region is a source place of east and west flowing rivers. Due to abundant rainfall observed the dense vegetation cover with evergreen and semi evergreen vegetation belt and small patches of agricultural.

It forms an almost unbroken rampart on the fringe of western peninsula parallel to the west coast and often hardly 40 - 60 km from the Arabian Sea. Geologically, most of escarpment, especially at western slope breakings, structure and steep slopes are observed along with arid and semi-arid environment (Figure-2).

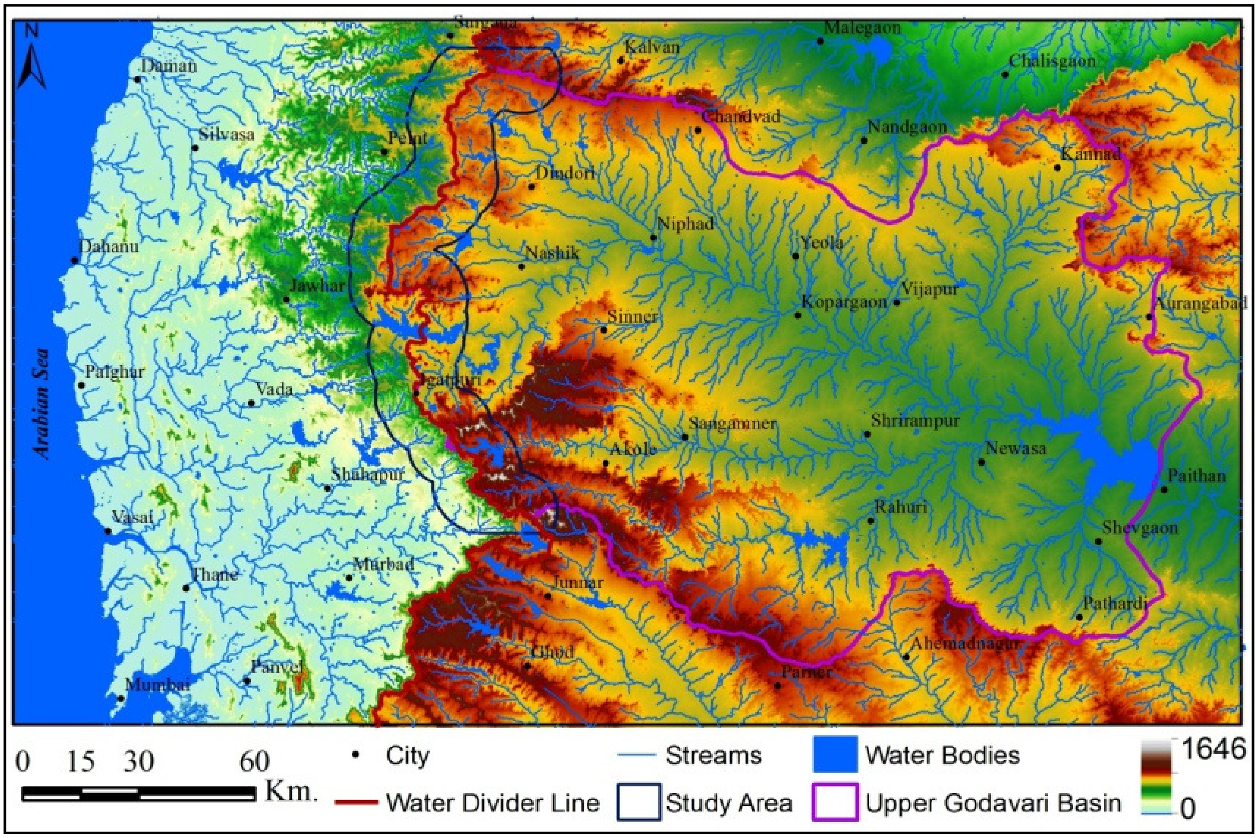

Figure-1
Location map of the study area showing the physical and hydrological situation

Upper part of Godavari River is located in the study area. It is second largest river in India with a catchment area of 312,812 km^2 and a long-term average annual surface flow of 110 km^3, of which 76 km^3 is estimated as non-utilizable[21]. There are two major diversion structures has been already proposed in the lower basin. The Sri Ram Sagar Project (upstream of Polavaram) and the Arthur Cotton Barrage (downstream of Polavaram) provide irrigation water to 390,000 ha and 170,000 ha, respectively, in the lower Godavari basin[22]. However, in upper section of basin observed the high intensity of water scarcity from last few decades. The source tributary of Godavari River, receives 3500 to 4000 mm annual rainfall during the month of June to September. However, most of water from upper reach of Western Ghat is flowing toward west direction and congregate in Arabian Sea. In the Konkan region seasonally surplus water which needs to divert from the western slope of Western Ghat to the Godavari basin for reduce the water scarcity problem in UGB of Maharashtra.

Capabilities of Geoinformatics

Data integration and management: Optimal design and management of ROD require large quantity of spatial and non-spatial data such as topographical, geological, soils, vegetation, LULC, hydrological, socio-economic, government reports and field survey data8. For decision and execution planning related data information should be stored at one place in digital form for easy retrieval, updating and analysis for effective planning[3]. GIS and GPS are powerful spatial technology which provides the functionalities to store infinite amount of data and its transformation, analysis in GIS software. Considering the huge physical, hydrological and LULC nature of the present area, the RS dataset like, satellite imageries, SRTM, ASTER and LIDAR DEM can be pre-processed in GIS software along with topographical and allied maps for regional database integration and its management.

Remote sensing data: As compare to convectional data RS data is most useful for aerial mapping, monitoring and tracing the spatial entities information at precise level. Similarly, it gives general LULC impression with and without image processing. RS data provide the aerial information at 2D and 3D form which is more appropriate for surface reality understanding, monitoring and could be used for DSS[23]. It consists with spatial, spectral, radiometric and temporal characteristic with fine resolution. Satellite image, aerial photograph, ASTER DEM, World clime data, synthetic aperture radar (SAR) data[24] etc. are some common example of RS data. Such types of RS data are useful for detection of potential water diversion sites, optimal water diversion options, LULC idea, environmental and topographical study and precise canal-tunnel sites detection.

Figure-2
(A) Eastern slope of Western Ghat, Locality: upper Mula river basin, near Kumshet village, Akole Tahsil, (B) Western slope of Western Ghat, Locality: upper Shai river basin, near Chinchwadi village, Sahapur Tahsil

Digital mapping: Digital data created from digital mapping which gives accurate representations of a particular area, detailing of major rivers and stream entities and other related information. It is useful for calculation of distances from once place to another, monitoring of places which can be performed with Google Earth or GPS satellite network, used in standard automotive navigation systems. Due to advancement of digital technology many convectional maps are converted in digital format which transformation; updating is easier then convectional data mapping3. In present area various physical, hydrological, LULC aspects digital mapping like as water bodies' identification, streams/rivers measurement, settlement location identification etc. can be possible to map from available digital data.

Digital Elevation Model (DEM): A digital elevation model (DEM) is a representation of earth terrains in 3D view. DEM is a quantitative model of part of surface in the digital form which is useful in river path detection, slope analysis, topographic, hydrologic modeling and delineation of streams, basin and sub-basin area. DEM can be generated in GIS software from topographical map, meanwhile various space born mission with imaging instrument such as SRTM (Shuttle Radar Topography Mission), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) also provides the orthorectified DEM for spatial analysis. Slope, aspect, topography and contour maps can be generated from the ASTER DEM (30 M. resolution) in GIS software. Similarly, cross section, line of sight (LOS), cut and fill volume can be also derived from ASTER DEM.

Overlay analysis: In ILR, ROD and IBWD various physical, hydrological, LULC and cultural aspects analysis are major concern. GIS software allow such aspects data handling at multiple layers such as hydrology, topography, soils, vegetation, settlement, city region etc. The drainage networks, reservoirs and other non-spatial aspects can be superimposed over ASTER DEM for general modeling of the area. GIS software allows for demarcation of watershed/basin from DEM and could be overlay over DEM for general impression about selected area. Layer consisting of proposed canal of any particular stretch can be overlaid over the vegetation cover map and from resulting layer; one can get the information of affected vegetation cover3. In view of this, in UGB total land acquisition, affected settlement and delineated canal or tunnel impact on environment can be accessed from this overlay analysis.

Extraction of hydrological features: The detection and measurement of water bodies' area and streams especially at inaccessible region is not always possible due to time and cost involved in surveying. RS satellites at different spatial, spectral and temporal resolutions provide an enormous amount of data being primarily used for detecting and extracting water bodies and streams with the help of GIS[25]. Lidong and Hao were used the normalized difference vegetation index (NDVI)[26] and Coa and Li used normalized difference water index (NDWI)[27] methods for water bodies detection. In the present study, area under water bodies/reservoirs, small streams, as a first order streams can extracted from satellite images, DEM data.

Visualization capabilities: Visualization The visualization tool is providing a variety of benefits to the planner with real world visual impact. Visualization provides supplementary insights to results which would otherwise be displayed in as surface reality. The virtual GIS are making a revolution in 3D analysis which enhancing the use of GIS as decision making tool. It is possible to visualize the landscape of water diversion project site in a virtual manner. The streams of regions can be digitized along with topography for spatial visualization. Literature reviews by Zube et al., Sheppard and Krishnaveni et al., described an extensive range of simulation techniques which are readily available to environmental designers to identify water diversion cannel design ideas, and to present the potential effects of the water diversion project on its surrounding region[3,28]. In the decision making process with optimal diversions options visualization become effective and could be supportive for funding sources.

Spatial interpolation: The surveying or measurement of any aspect in large area is not always possible due to time and cost involved in data collection. Therefore, interpolation at unknown locations based upon selectively measured values could be one of the alternatives[29]. In this techniques rainfall, spatial height, water table and related aspects sample level data can be interpolated for estimation of unknown areas values. Spatial variation detection from surveyed points or available stations data within the study area can be interpolated for further decision. From the interpolated data we can access the values/data where the data collection could not possible.

Network analysis: Water scarcity problem cannot mitigate until the proper supply of water to the demand places. Therefore diverted water management is based on canal delineation and its network analysis. Equal distribution of diverted water through canal is a massive task in front of planner. GIS software provides the canal network analysis with shortest route and least cost path analysis function. From this network analysis canal alignment can be implemented with maximum precise level in the study area. Similarly, optimum and shortest possible options can be resolute before execution of water diversion canal[3] in UGB.

Environmental issues: ROD, ILR and IBWD are the massive tasks where large scale of land modifying with topography, water flow, environmental and socio-economic alterations. UGB is connected with the Western Ghat. Thus, most of potential water diversion sites in this region can face the similar issue. For the rapid assessment of such environmental issues Geoinformatics will be one of the best solutions. By using Geoinformatics approach, extent of land submergence as well as forest destruction due to construction of reservoirs and canal hydraulic structures can be assessed before the initiation of IBWD project in UGB. EIA of related region can be assessed rapidly with minimum budget. So that alternatives to allied project can be planned accordingly in area. In UGB, ecological aspects are very sensitive due to hot spot diversity in the Western Ghats. The project canals, reservoirs and other irrigation structures may be planned accordingly, so that the species will not affected to the maximum extent possible. Present region is consisting with the tribal population also. Thus, socio-economic assessment such as tribal community, gender, social status of the people, traditional practices with respect to occupation, land acquisition, rehabilitation etc. can be study at micro level using GIS. The multi layer analysis capabilities of GIS will speed up the completion of entire process of land acquisition and related aspects analysis in this area.

Other supplementary issues: After the water diversion, water supply management to the demand places, towns, villages, industry, and irrigational route will be one of the challenges. Water supply network can be planned in GIS environment to carry out route tracing and resources allocation. Similarly, the monitoring is essential of water diverted canal in case of sediment logging and breaking of canal. Cropping pattern development should need to suggest according to soils nature and water availability. In this case, GIS can evaluate the water diversion project, cropping pattern related development from available data sources. Spatial analysis of multi component is the capabilities of GIS which will offer excellent facilities towards the planning of the command area along with the link canals and tunnel in proposed ROD or IBWD scheme in the present area.

Sustainable ROD and IBWD in UGB: The implementation of Geoinformatics techniques and tools in ROD planning in UGB will support for micro level sustainable water diversion planning. It will support for precise study of physical, hydrological, LULC, geographical, geological, environmental, socio-economic aspects data with scientific and technical manner. The present study area is diverse in case of natural and cultural aspects; therefore EIA with Geoinformatics will be most accurate for environmental assessment. Similarly, water diversion flexibility evolution, potential water diversion sites detection, canal sites planning without disturb to local tribal ecology, demographic, industrial, agricultural background and total water demand, equal allocation of water and regional development can be assessed and monitored using Geoinformatics. From the huge database of UGB in its processing in GIS software DSS can be developed using Geoinformatics approach to solve various issues in the study area.

Conclusion

The drought crisis and water demand in the UGB is not just over the period of few months, but for years together, and one could date it back to the many decades. From last few decades, there is development of agricultural, industrial, and urbanization in the Godavari River basin. The upstream-downstream water conflicts are becoming more and more severe in the UGB. Water scarcity will intensify in the coming years, and unless basin authorities take timely and proactive steps, it will not take much time for a protest to become a movement[30]. It is necessary to review and identify the water scarcity problem in UGB and to make sustainable solutions to mitigate the water supply problem. Likewise, decreasing water quality of rivers due to constant discharge of polluted effluents and wastewater inflow governed by population and allied industries are responsible for growing fresh water demand. The decreasing nature and large spatial variation in the rainfall is also one of the major controlling factors of water supply and demand gap. For example, around the Mumbai (Maharashtra), Silvasa (Gujarat) city observed the 2000 mm and above rainfall while around the Nashik 1000-2000 mm and around the Aurangabad 200-500 mm rainfall just only.

In such situation, to perform the massive task of water diversion or runoff diversion, the views and guidelines suggested by NWDA (2008) should be primitively needed to consider. They deeply suggested for collection and review of topography, hydro-geological, geotechnical, land use and land cover, irrigation and command area, domestic and industrial water, sociological and socio-economic, environmental, infrastructure, legal, and cadastral details from the suggested areas of water diversion. After that there was a requirement of planning and development of data base. Such types of information can be gathered from topographic maps, satellite images and aerial photographs or images to generate multi-layered georeferenced digital maps in GIS platform. The required spatial and non-spatial information for water diversion planning can be gathered from physical, hydrological and LULC parameters. The collection of these suggested parameters information is quite difficult which require large time span, human resources and economic budget. In view of this tools and techniques of Geoinformatics will be supportive to prepare precise maps with desired information like relief, slope, contour, LULC, forest cover, human settlement, existed reservoir and potential zones of runoff diversion. Similarly, the satellite data with the integration of GIS environment will be helpful for significant digital mapping and regional physical and regional aspects monitoring. Therefore, the allied tools and techniques of Geoinformatics, such as GIS, RS, GPS etc. should be used, as a input, manipulation, processing and analysis of multidisciplinary data.

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