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Optimal River Interlinking using Data Driven Machine Learning Techniques

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Abstract: India's increasing population, rapid urbanization and indiscriminate destruction of water bodies creating a grave threat on its existing water demand and supply balance. Primary fresh water sources such as rivers and wells are gradually getting dry. As a consequence, it is estimated that India would become a water scarce nation by 2050. To address the issue, massive survey work was conducted and various inter basin water transfer schemes were chalked out. However, these schemes became subject of controversy owing to its technical risk and huge cost. To make this effort cost efficient, in this investigation, computational approaches have been undertaken to assist in the decision making process. Current research endeavour suggests that these efforts are quite accurate, less costly and can be carried out in much less time. The inputs to these computational models are landscape elevation, land use data, soil information, precipitation level etc.. The estimated optimal river interlinking routes will be the output of the proposed model. Several efforts have been undertaken earlier in this direction with various limitations. In this paper, we address the same issue using machine learning approach. For experimental purpose Jogigopa-Tista link is considered as the test case. Optimal routing path is been estimated using the developed technique. Thereafter, the results are compared with the National Water Development Agency (NWDA) proposed routes. It is found that the proposed model's outcome exhibits a considerable amount of similarity with the NWDA proposed route.

Keywords : Dijkstra Algorithm, MSO, Multiple Linear Regression, Optimal River Route, River interlinking.

I. INTRODUCTION

As per 2011 census India became a water deficient nation. It is expected that by 2025 India will become water stressed nation and by 2050 it will be a water scarce nation [1]. It shares 16% of the global population whereas only has 4% of the world's total fresh water to meet their need [2]. The country has relied heavily upon Himalayan glaciers and seasonal rainfall as its primary source of fresh water. These sources keep the surface water bodies and underground aquifers rejuvenated. India receives an average annual rainfall of 4000 Billon Cubic Meter (BCM), mainly lasting for 4 to 5 months in a year. Out of which 1869 BCM contributes to the average annual surface runoff and the rest are lost in the form of evapotranspiration and soil infiltration. The variations in rainfall pattern are also too high with respect to time and

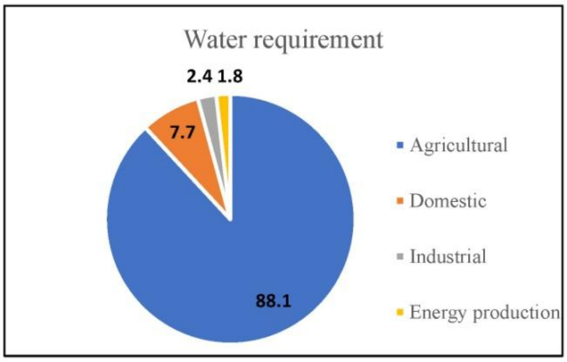

Fig. 1. India's water demand [3]

place. For instance, western part of Rajasthan, one of the most arid states of India, gets mere 100 mm average rainfall whereas Cherrapunji (Meghalaya) receives 11,000 mm of rainfall per year. India sees very heavy rainfall from June to September which is termed as Monsoon period. The water accumulated due to this rainfall contributes about 90% of the total river flow. Sometimes, some places in India receive around 50% of the total per annum rainfall within a span of mere 15 days. This heavy rainfall often results into instances of flash flood. As a consequence, drought and flood are experienced in different regions of India simultaneously. If appropriate water management scheme can be applied by channeling excess flood causing water to water deficient rivers or to a water storage location (such as lakes etc.), it will meet up the demand of fresh water in the other required parts of India to a certain extent. It is reported that, out of the available surface water, the actual amount that is effectively utilizable is further much low. It is estimated that, only 18% of the total rainwater is used effectively. According to the Central Water Commission (CWC), another 36% of total available water can be utilized by adopting appropriate water management strategies [3]. The details about India's available water resource are included in the Table I.

Table- I: India's available water resource

Average precipitation volume per annum	4000
Natural runoff (Surface and ground water)	1869
Surface water usability potential	690
Ground water resources	432

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Water utilization is another important factor. A fair share of water is required for activities other than domestic consumption such as agricultural needs.

It is also required to support the needs of growing population, and better standard of living. In a report published in the year 2017 by The Energy and Resources Institute(TERI), (supported by NitiAayog, Government of India), it was reported that nearly 88% of the total consumed water was used for agricultural purpose and rest 12% was used in other areas. The details of available water resources are shown in Fig. 1.

Agricultural water demand in India is solely met through rivers bodies and underground water reserve. However, because of variant rainfall and massive deforestation rivers are ceasing to exist. Same is the case with underground aquifers. With technology to dig deeper and indiscriminate usage, water beds are getting depleted rapidly. This is adding further pressure on the deteriorating demand-availability balance of water situation in India. To deal with this problem government of India has set up for Inter basin water transfer plans which are expected to ease up the existing pressure on the surface and subsurface water resources. Countries like America, China, and Canada already have sizable number of inter basin water transfer projects. India started the same endeavour about three decades ago but this is yet to make any significant progress.

With regards to the framework of proposed links and taking cognizance of different contributing factors, we wanted to find a reliable and practical solution which can be used to model this interlinking process. The developed model is expected to bring various decision-making parameters into consideration while preparing the solution.

The present work aims at developing models that will help in making decisions as how to interlink different rivers basins in the most effective way considering the pertinent practical constraints. The solutions of the proposed methodology will help in interlinking related decision making processes. Here, different machine learning techniques have been adopted to find the optimal river liking routes. The emphasis of the optimizing strategy would be to obtain optimal interlinking routes in the face of multiple constraints and finding the best possible solution which will maximize the water management profit.

The organizational structure of this paper is as follows. Section II and III provides a brief discussion about the NWDA's river interlinking project and challenges it is facing. Section IV introduces different methodologies adopted in this experiment. The challenges and experimental setup and results obtained are discussed in Section V. Finally, Section VI presents the conclusion and future scope of work.

II. BACKGROUND INFORMATION

Water resources are distributed among various river basins around the country. There are twelve prominent river basins available with a total catchment area of 25.3 Lakh sq.km. In addition to these twelve basins another eight composite river basins combinedly cover around 81% of the total geographical area of the country. The details published in the web domain of Water Resources Information System of India about different river basins are included in Fig. 2.

Ganga-Brahamputra-Meghna basin being the largest with catchment area of about 11 lakh sq.km, almost half of the total

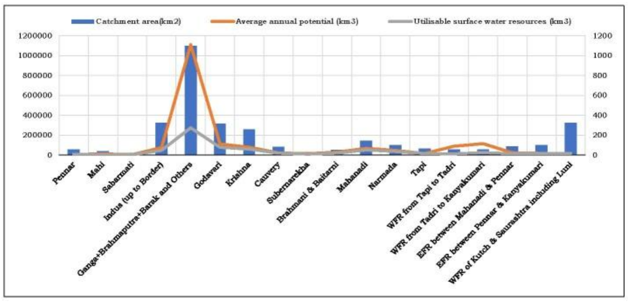

Fig. 2. Water resource potential of India's prominent river basins [4]

catchment area of all major rivers. However, the ratio of utilizable surface water resource and the average water resource potential is the lowest because of various reason such natural terrain, inter boundary etc.. Hence, the water management strategies become much more complex due to these constraints. Here the proposed machine learning based computational solutions will be much helpful. If implemented, it will provide significant benefits in the form of irrigation, transport, energy production etc. for the country.

The Government of India formed a committee in the name of National Water Development Agency (NWDA) in the year 1982, to look into the matter of inter basin water transfer and prepare a plan in this regard. The idea was to build reservoirs and develop strategies to link water surplus rivers with water deficient ones to maximize the optimum utilization of water. The committee after inducting a detailed survey, identified probable sixteen peninsular and fourteen Himalayan river inks for this purpose [5]. Details about these links are included in Fig. 3. The proposed Himalayan river links are:

1) Brahmaputra–Ganga link (Manas–Sankosh Tista–Ganga)
2) Kosi–Ghaghra link
3) Gandak–Ganga link
4) Ghaghra–Yamuna link
5) Sarda–Yamuna link
6) Yamuna–Rajasthan link
7) Rajasthan–Sabarmati link
8) Chunar–Sone Barrage link
9) Sone Dam–Southern Tributaries of Ganga link
10) Ganga–Damodar–Subernarekha link
11) Subernarekha–Mahanadi link
12) Kosi–Mechi link
13) Farakka–Sunderbans link
14) Brahmaputra–Ganga link (Jogighopa–Tista–Farakka)

The proposed probable links of Peninsular rivers are:

15) Mahanadi (Manibhadra)–Godavari (Dowlaiswaram) link
16) Godavari (Inchamaplli)–Krishna (Pulichintala) link
17) Godavari (Inchamaplli)–Krishna (Nagarjunasagar) link
18) Godavari (Polavarm)–Krishna (Vijayawada) link
19) Krishna (Almatti)–Pennar link
20) Krishna (Srisailam)–Pennar link
21) Krishna (Nagarjunasagar)–Pennar (Somasila) link
22) Pennar (Somasila)–Cauvery (Grand Anicut) link

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23) Cauvery (Kattalai)–Vaigai (Gundar) link
24) Ken–Betwa link
25) Parbati–Kalishindh–Chambal link

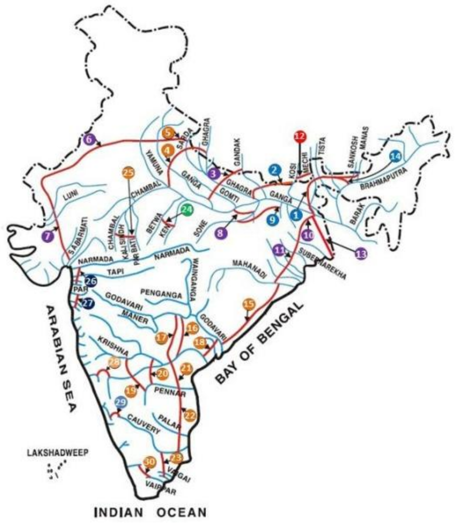

Fig. 3: Proposed route map of various links [5]

26) Par–Tapi–Narmada link
27) Damanganga–Pinjal link
28) Bedti–Varda link
29) Netreavati–Hemavati link
30) Pamba–Achankovil–Vaippar link

The project though is under lot of criticism. There is huge concern about the ecological imbalance due to the artificial diversion of water. Political issues like diplomatic relationship with neighbouring countries is another concern. For example, Bangladesh is already protesting against some of the links [6]. Moreover, construction of upstream blockade to control and redirect water, involves ominous risk of displacing human settlement. Political compulsion also can play a big role. Therefore, it will be beneficial to use computational models to incorporate these constraints for developing solution to help interlinking related decision making process.

III. RESEARCH BACKGROUND

In India, due to financial constraints and technical hurdles, the idea of river interlinking is confined to mere lines drawn on a map without significant practical implementation. Substantial scientific and technical information regarding the proposed scheme is not available in the public domain. As a consequence, limited number of research endeavours is available in this domain. Only, works of Saravanan et. al. could be traced in this regard which addresses the issue of inter basin water transfer from the implementation point of view [7]. In their investigation, the authors implemented a machine learning based hybrid technique to calculate an optimal interlinking route. It used linear regression methodology to model the spatiotemporal behavior of different points in the vicinity of the basins under consideration. It then used machine learning based approaches to find the best possible route by connecting those calculated points. However, the said approaches did not consider very important factors such as elevation of the candidate places in the proposed model equation. This fact limits the acceptability of the computational approach to find the river interlinking routes. For example, route may choose a path through high-altitude places which is if executed will incur huge financial or other penalties. Moreover, the proposed approach is devoid of any explanation about how to connect the candidate points. In this investigation we have modified the model by incorporating the elevation factor in the model equation. The route computation process is further been improved by incorporating graph based path selection approach. The achieved result shows better correlation with the proposed route laid down by NWDA.

IV. MODELS USED

A. Multiple Linear Regression

Multiple linear regression helps to examine how multiple independent variables are related to a dependent variable by fitting a linear equation through the observed data. Once the coefficients of the equation are learnt by suitable technique, the equation can be used to make powerful and accurate predictions. Formally, the model for multiple linear regression with n observations can be defined by:

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_n x_{in} + \epsilon_i \qquad i = 1, 2, .., n \qquad (1)$$

Here, y_i is the target or dependent variable. Set of independent variables are represented by x_i. ε represents the error in prediction, that is variance that cannot be accurately predicted by the model. It is also known as residuals. β_0 denotes the y-intercept at time zero. $\beta_1 \ldots \beta_n$ are known as the regression coefficients.

B. Multi Swarm Optimization (MSO)

Multi Swarm Optimization (MSO) is a technique for estimating optimal solutions to a complex problem under several constraints. It is a variant of Particle swarm optimization (PSO) technique which was developed by Dr. Eberhart and Dr. Kennedy in 1995. It is a population based stochastic optimization technique, inspired by social behaviour of birds flocking or fish schooling. The pertinant difference between MSO and PSO is that MSO augments the idea of PSO by creating multiple swarms of particles instead of just one (used in PSO).

In PSO, each single solution is called a particle in the search space. All particles have fitness values which are obtained by evaluating the fitness function to be optimized, and in terms it calculates velocities of the particles by which it moves in the search space. The particles fly through the problem space by following the current optimum particle. In every iteration, each particle is updated by following three "best" values as shown in (2).

$$\begin{aligned} V_i(t+1) = {} & w * V_i(t) + (r1 * c1) \\ & * \left(P_i Best - P_i(t)\right) \\ & + (r2 * c2) * \left(S_i Best - P_i(t)\right) + \\ & (r3 * c3) * \left(GBest - P_i(t)\right) \end{aligned} \qquad (2)$$

Here, $V_i(t)$ is the current velocity with which a particle is moving and $P_i(t)$ is its current position. Term w is known as the inertia factor.

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It encourages a particle to move in its current direction. P_iBest is the best position known to each particle (personal best).

This helps in motivating particles to keep moving towards its historical best known position. S_iBest represents intra-swarm best known position (swarms best). It encourages particles to move towards the best position learned within the swarm. Similarly, *GBest* is the inter-swarm best known position (global best). It finally helps all the swarms to converge to a global best. Values *r1, r2* and *r3* (lies between 0 and 1) are random values used to achieve randomization effect for each velocity update. *c1, c2* and *c3* are all constants, known as learning factor. All these constant parameters are user supplied coefficients.

Once the new velocity is calculated, particles update their current position by calculating:

$$P_i(t+1) = P_i(t) + V_i(t+1) \quad (3)$$

This process continues in the same way until no further convergence is possible or the numbers of iterations are completed.

V. EXPERIMENTATION & RESULTS

The prime objective of river interlinking is to transfer water from a water surplus river body to a water deficit river and planning the route in such a way that maximizes benefits for the interconnecting regions by satisfying various constraints. River flow and its behaviour is a very complex phenomenon. Various parameters are responsible for its existing form and play an important role in plans of river interconnection. Some of the attributes are discussed below:

1. **Elevation (y1)**: Elevation plays a very important role in defining river flow direction. Water always flows from high to low altitude along the earth's surface. Planning an optimal river rerouting can greatly be affected by elevation factor. This has been incorporated into the proposed model equation.
2. **Precipitation (y2)**: It is perhaps the most important feature which determines the state of a river. Most of the Indian River's water is attributed by seasonal rainfall. Besides this majority of landmass depends completely on the annual rainfall for agriculture and cultivation purpose.
3. **Cultivable land (y3)**: Cultivable land is the area of land which is suitable for growing crops. Effort needs to be invested to maximize water availability to this area and minimum damage incurred due to the rerouting activity.
4. **Net Sown Area (y4)**: Net sown land includes total area under umbrella of cultivation and crop production. Availability of sufficient water around the region can make a lot of difference.
5. **Irrigated land (y5)**: Areas facing severe drought can be benefited by drawing links through this area. Not only the ground water reserve but also the agricultural production will increase eventually.
6. **Forest land (y6)**: Forest areas are shrinking day by day. Large scale destruction to it is irrecoverable. In order to preserve ecological balance and environmental sustainability minimum damage to the forest cover should be the main goal.
7. **Population Density (y7)**: Displacement of human settlement is a big issue if it falls on the path of interconnection route. Moreover, resistance against such planning is eminent and should be avoided at all cost. Thus, making it a very important factor of consideration in planning.

For this experiment, Jogighopa-Tista link is chosen. Adjoining districts which falls in this basin are selected and essential information as stated above are collected from various sources [8]–[13]. A brief insight into the data is provided in Table II.

The process of finding the optimal routing path is been decomposed into three steps. First step involves modeling the relationship between the selected parameters and the corresponding locations. For this purpose Multiple Linear Regression (MLR) is used. MLR is useful to explain the relationship between one continuous dependent variable and two or more independent variables. Here, a particular place on the map identified by its latitude-longitude value represents the independent variables whereas different contributing parameters as discussed above are the dependent variables. MLR defined by eqn (1) is suitable to model such a phenomena. MLR (in concept) is a combination of more than one linear regression unit. Therefore, the dependent Y value of a place can be thought of as $\sum_{i=1}^{n} Y_i$ Yi where, Y_i 's are the regression value of contributing factors with respect to that place. The output of first step is formalized in Table III.

Table- II: District wise statistics of Tista-Jogighopa basin

District	Lat	Long	Elevation	Precipitation	Cultivable Land	Net Sown Area	Irrigated Land	Total Land Area	Forest Land	Population Density
Kamrup	26.15692	91.65916	50	1813.4	171684	105212	2090	4345	1429	579
Bongaigaon	26.27470	90.67986	52	3218.7	93603	59429	448	2510	521	361
Dhubri	26.02049	89.97371	43	2702.6	166127	86280	843	2798	412	584
Goalpara	26.16758	90.63173	43	2575.3	128096	72447	1940	1824	337	451
Kokrajhar	26.40147	90.26847	74	3772.2	173865	116843	7398	3169	1120	294

Second step aims to find a fitness value for each of the candidate places. Various y values calculated in the first step are then it is used as input to the Multi Swarm Optimization (MSO) algorithm. In this case MSO computes the best fitness value by using eqn (4).

$$f(y_i) = \sum_{k=1}^{n} w_{ik} {y_{ik}}^2 \quad (4)$$

Where, y_{ik} represents the k regression parameter values of i^{th} place and w_{ik} are the corresponding weights. MSO being a meta-heuristic model tries to calculate the optimal value of w_i's from a population of candidate solutions to find y_i, which represents the membership value of that place.

The third and final step, concentrates on finding the best possible interlinking route. After completion of step two, every places get a membership value. If there exists a possible route then it has to pass through these potential candidate places. Apparently, this part can be visualized as a graph connectivity problem. We have used Dijkstra algorithm for this purpose. It tries to find the shortest path from a given source to a destination by connecting vertices (points on the map) having lowest sum of weights. The path weights are determined by the membership value calculated for each candidate palace in the previous step using MSO. The pseudocode for proposed approach is discussed below.

The overall result of the experiment can be seen in Fig. 4. NWDA proposed route, assuming to be originating from Jogoghopa, passes through Kokrajhar district and then meets with Sankosh Barrage on Indo-Tibetan border.

Table- III: Y-intercept and coefficient parameter

Features (y_i)	Regression Equation (X_1 = Lat, X_2 = Long)
Elevation	Y_1= -58.8442 + 331.3151 * X_1 - 31.1303 * X_2
Precipitation	Y_2= 20.7821 + 271.8322 * X_1 - 276.2078 * X_2
Cultivable Land	Y_3= 13.8839 + -147.1726 * X_1 - 102.4613 * X_2
Net Sown Area	Y_4= 59.5753 + -393.6699 * X_1 - 531.2924 * X_2
Irrigated Land	Y_5= 47.0925 + -591.1821 * X_1 + 139.9502 * X_2
Forest Land	Y_6= 44.0073 + 114.2728 * X_1 - 371.8993 * X_2
Population Density	Y_7= 74.1646 + -127.6948 * X_1 - 39.4482 * X_2

Algorithm 1 Proposed algorithm

```
procedure DIJKSTRA(G : graph; s : vertex)
for each vertex v in G do
  dist[v] ← ∞
  parent[v] ← NIL
dist[s] ← 0
E ← Set of all vertices in G
While E is not empty do
  u ← node with smallest dist[]
    remove u from E
    for each neighbour v of u do
      tmp ←dist[u] + weight(u; v)
      if tmp < dist[v] then
        dist[v] ← tmp
        parent[v] ← u
  return parent[];
procedure MLR(state; data)
  for each i in data do
    Y_i ← Reg(state_i and data)
  return Y;
procedure MSO(Y)
  while maxLoop ≠ 0 do
    for each swarm s_j do
      for each particle p_i do
        Calculate fitness value f(y_i) = Σ_{k=1}^{n} w_ik y_ik^2
        if f_y < PBest_i then
          Update PBest_i
        SBest_j = min (PBest_i)
        GBest = min (SBest_j)
        Calculate velocity using eqn(2)
        Update position using eqn(3)
return GBest
procedure MAIN()
  state, data ← Read coordinates and params of states
  for each state do
    Y[] ← MLR(state, data)
    membershipvalue[] ← MSO(Y)
  Use DIJKSTRA(membershipvalue[]) to compute optimal route.
End of MAIN
```

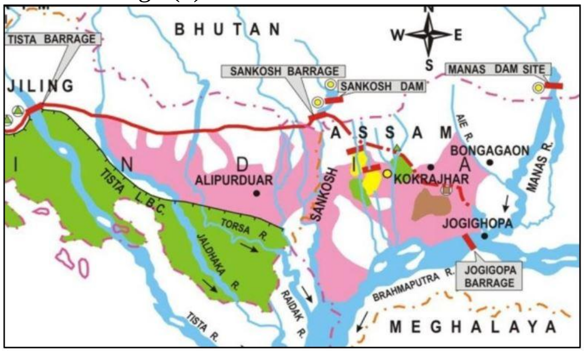
After that it follows approximately a horizontal line crossing through the district of Jalpaiguri and finally meets the Tista river as shown in Fig. 4(a). The output of this experiment is provided in Fig. 4(b). Interlinking route marked using green colour line represents the simulated route calculated using the approach described by Saravanan et. al. [7] whereas the red colour path represents the output of this current experiment. If we compare both the computed routes then it can be observed that the route computed using modified approach exhibits better similarity with the NWDA proposed route except the prominent exclusion of Sankosh Barrage in its path. We believe, it is because of the absence of water reservoir information in our computational model. Augmenting the present work with this new information will probably resolve the issue which will serve as future scope of this work.

VI. CONCLUSION

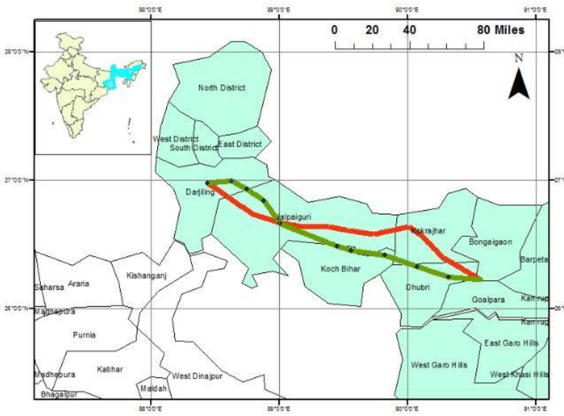
Today abundance of water greatly influences socio economic development of a country in many ways. With increasing population and limited water resources developing countries like India are already reeling under the pressure. Beside promoting judicial water usage, large scale initiative such as river interlinking has become a matter of utmost urgency. Government agencies have chalked out twenty such plans to ease up the pressure a bit. Proponents are claiming this project will bring many benefits and developmental initiatives for the nation. However, there are views concerning its feasibility and side effects. One possible way could be invest for small scale river linking initiatives connecting smaller river basins maintaining balance between the both sides.

This paper presents a solution for inter basin water transfer. The machine learning based approaches are utilized here to identify optimal routes for river interlinking. A multiple linear regression model has been proposed consisting of various contributing factors such as rainfall, population density etc., specially incorporating elevation factor as inputs.

Then MSO is applied to find fitness value of different connecting places which is calculated out using MLR output. Finally, Dijkstra algorithm is used to calculate the optimal route for the river interlinking. Experimental result as shown in Fig. 4 explains the performance of the adopted technique. The optimal path computed as an output of the model showing a close accordance with the route proposed by NWDA. There are minor deviations at some places. Those can be explained as current approach utilizes only seven parameters in the decision making process whereas several other parameters are remaining for their lesser contribution and those represent unknown factors. Information about the number and type of actual parameters NWDA considered, is not available in the public domain. Overall, the performance of the model seems satisfactory can be used as a preliminary model of route optimization process. The obtained results display better performance than the route obtained using approach of Saravanan et. al. [7] which is marked with green colour line in Fig 4(b).



(a) Route proposed by NWDA [14]



(b) Computed route

Fig. 4: India's water demand [3]

The work presented in this paper can further be extended by incorporating attributes other than which are already considered. Moreover, different multi-criterion optimization algorithm can be tested to compare their performance. It will also be interesting to see how the model behaves in case of insufficient data.

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