Transboundary impact assessment of Indian dams: a case study of Chenab River Basin in perspective of Indus Water Treaty

Shakeel Ahmad and Javed Iqbal*

Institute of Geographical Information Systems, School of Civil and Environmental Engineering, National University of Sciences and Technology, H-12, Islamabad, Pakistan

*Corresponding author. E-mail: javed@igis.nust.edu.pk

Abstract

Several transboundary rivers are being shared in South Asia by neighbouring states within a certain framework. A comparative analysis of the Indus Water Treaty has been carried out with other South Asian water treaties while suggesting measures to enhance mutual cooperation over shared rivers between India and Pakistan. With a specific focus on Chenab River, transboundary impact assessments of Indian dams have been carried out keeping in view the aspects of quantity, quality and temporal change in river course. A decreasing trend and significant fluctuation in river discharge was observed with an average decrease of 0.5 billion \((10^9)\) cubic metres per year in annual inflow. In terms of water quality, pH (7.90 to 8.06), nitrates and other parameters were found within permissible limits. Total coliform (34 to 280 no/100 ml) and faecal coliform (21 to 193 no/100 ml) values were higher than permissible limits in three streams, whereas \(Escherichia\ coli\) was found +ve in only the Jammu Tawi River. Water was found unsuitable for drinking while suitable for agriculture and aquatic life. Temporal analysis shows significant change in river course over a span of 40 years. As a result of impact assessment evolving threats and their remedial measures have been suggested.

Keywords: Chenab River Watershed; Indus Water Treaty; Transboundary rivers; Water basins; Water conflict; Water management; Water resources; Water sharing treaties

1. Introduction

Rivers do not follow political borders while flowing on their natural courses. It is estimated that about 148 states have international basins which are being shared. There are 276 transboundary river basins in the world out of which 64 are in Africa, 60 are in Asia, 68 are in Europe, 46 are in North America and 38 are in South America. These transboundary rivers are shared between two or more countries, while the Danube River is shared by the maximum number, i.e. 18 countries. There are several examples where water sharing proved to be a source of cooperation rather than conflict (http://www.unwater.org). Generally three mind-sets exist regarding sharing of water between different countries: firstly

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the upper riparian mind-set (Harmon Doctrine), which claims the sovereign right of water into their territory; secondly the downstream riparian mind-set (historic existing mind-set), which claims integrity of river flows; and thirdly the water sharing mind-set (need based), which is based on cultivable land, population, existing uses and future projects. There are several existing examples of all these mindsets in various parts of the world. Instead of comprehensive multilateral treaties, numerous basins are being governed by bilateral treaties (Transboundary Freshwater Dispute Database (TFDD), 2011).

Conflicts emerge on sharing of water resources due to obvious reasons based on needs and benefits linked with availability of fresh water. Various international rules and conventions exist as a guideline for customary law and principles for water sharing. There are established transboundary water resources management principles that are recognized by international conventions, treaties and judicial decisions. The Berlin Rules (2004) ‘United Nations Convention on Non-Navigational Uses of International Watercourses’ (1997) and ‘Helsinki Rules (1966) on the Uses of the Waters of International Rivers’ by the International Law Association are based on these principles and are the guiding documents in this regard. Eleven factors from the Helsinki Rules are deliberated in defining ‘a reasonable and equitable share’ and deciding the share of water (Salman, 2007; Rahaman, 2009a, 2009b; Donzier et al., 2011).

Since the early 1990s, due to the obvious increase in water uses, strain on the Indus Water Treaty (IWT) increased resulting in a water stress situation between India and Pakistan. This tension is generally attributed towards growing demand, declining availability of fresh water resources and reliance on transboundary water resources, which eventually leads to risks and crises (Wescott et al., 2000). According to Falkenmark’s Water Stress Index which is generally used to assess water scarcity, India is a ‘water stressed’ country while Pakistan is a ‘water scarce’ country. Besides quantity, it is imperative to focus on quality, as to ignore the relationship between quality and quantity is to ignore hydrologic reality (Kaufman et al., 1997). Risk perception in relation to water stress and then carrying out risk assessment is of key importance in the decision-making process over common rivers. High population density, low income and unfriendly relations between countries increase the possibility and intensity of disputes due to scarcity of freshwater supply, which may inevitably result in instability thus leading towards political or military conflict (Bernauer & Kalbhenn, 2010).

1.1. Statement of the problem

Although all Western Rivers of the Indus basin are becoming a matter of concern, the Chenab River is more vulnerable because Pakistan has not constructed any large dams on it, as compared to the Jhelum and Indus Rivers which have Mangla and Terbela reservoirs on them. After signing of treaty, India has constructed a number of structures on the River Chenab like Salal Dam, Baglihar Dam and Dul Hasti Dam due to which downstream water flows have been affected. Salal Dam has been constructed almost 72 km upstream of Marala head works with 690 megawatt (MW) installed capacity, whereas Baglihaar Dam is constructed 147 km upstream of Marala headworks with 450 MW installed capacity. These projects have large reservoirs which can effect and control the downstream flows to Pakistan. These effects include transboundary pollution, decrease in quantum of water, manipulation of water flows and downstream temporal change in land cover and river course due to decrease in water flows. Therefore, it is necessary to carry out a transboundary impact assessment in order to anticipate the scale of the threat and to find remedial measures within the established legal framework between both the countries, i.e. IWT (1960). Such assessment can help in improving institutional coordination and collaboration between various governments and their institutions.
2. Scope of the study

A transboundary impact assessment of the Chenab River has been carried out keeping in view the aspects of water quantity and quality, and change in river course. In order to identify remedial measures a review of the IWT with respect to other regional treaties is essential to suggest improvements in the treaty. Therefore the objectives of this study have been set as follows:

- **Management Framework.** To carry out a comparison of the IWT with other regional transboundary treaties while keeping a focus on India being the upper/lower riparian thereby suggesting measures for improvement and sustainability of the IWT.
- **Water Quantity.** To carry out assessment of temporal change in river discharge of the Chenab River before and after construction of Indian dams.
- **Water Quality.** To assess transboundary water quality of the Chenab River by ascertaining the pollutants present in its water.
- **Mapping and Monitoring of Water Bodies.** To assess transboundary temporal change in river course of the Chenab River before and after construction of Indian dams.

3. India as upper and lower riparian state

India shares many rivers with neighbouring countries and plays an important role being upper and lower riparian. There are generally four major basins in this region which include Ganges, Meghna, Brahmaputra and Indus basins. These basins consist of huge rivers (Ganges, Brahmaputra and Meghna and Indus) flowing into various countries of South Asia including China, Nepal, Bhutan, India, Pakistan and Bangladesh. Transboundary riparian policies of India especially affect four countries, namely Nepal, Bhutan, Pakistan and Bangladesh, on three river systems, i.e. Indus, Ganges and Brahmaputra-Meghna river systems.

3.1. India-China transboundary rivers

The Tibet autonomous region of China is a source of many rivers and three main river systems; Brahmaputra, Ganges and the Indus are connected to it. India and China do not share any rivers exclusively between them. All transboundary rivers of India and China are also shared with other neighbours. Initially a memorandum of understanding (MoU) in 1954 was signed between India and China for sharing of data of the Brahmaputra River. The Sino-Indian war in 1962, resulted in abandonment of the MoU, however later negotiations continued and in 2002 an MoU was again signed between both the countries for sharing of hydrological data for the purpose of flood control (Uprety & Salman, 2011). Currently construction of dams on the Brahmaputra River by China is a cause of tension between both the countries (Denyer, 2013).

3.2. India-Nepal transboundary rivers

There are three treaties between India-Nepal: Gandak Treaty (1959), Kosi Treaty (1954) and Mahakali Treaty (1997) on Gandak, Kosi and Mahakali rivers, respectively. According to the Gandak and
Kosi treaties, dams have been constructed on these rivers keeping in view aspects of flood control, hydroelectric power generation and irrigation. These dams are built in Nepal territories with Indian funding near the border and power generated is being shared between both the countries (Rahaman, 2009a, 2009b; Uprety & Salman, 2011). The Gandak and Kosi treaties have been revised keeping in view Nepal’s concern, and still resentments exist in Nepal, on share and right of water through these treaties, especially in the months of February to April for trans-valley uses (Rahaman, 2009a, 2009b; Jha, 2013). The Mahakali Treaty encompasses the affairs related to the share of electricity from already built dams ‘Sarada’ and ‘Tanakpur’ and one new dam ‘Pancheshwar Multipurpose Project’ to be constructed under the treaty. The treaty bounds both parties for equitable utilization and sharing of benefits without causing significant harm to either party. Moreover, the treaty recommends joint entities for the new projects to look after the affairs of execution and operation (Salman & Uprety, 1999).

3.3. India-Bangladesh transboundary rivers

India announced its intention to construct Farakka Barrage on the Ganges River in 1951, located 17.6 km upstream of the India Bangladesh border and completed it in 1975. The Barrage was constructed to divert the natural flow of the Ganges River towards the Hugli River flowing towards Kolkata. In 1972, an agreement was made between both the countries however, no substantial advantage could be gained from this commission and in 1976 Bangladesh approached the United Nations (UN). The UN General Assembly reached a consensus that both the countries should mutually find a peaceful solution of the issue. Consequently in 1977, an agreement was made for a period of 5 years between both the countries to reach a consensus on the share of water. This agreement expired and years passed without any agreement and finally in 1996 a treaty was signed for allocation of water from Farakka Barrage (Swain, 1998; Salman & Uprety, 2002). The treaty was signed for a period of 30 years and it was also agreed to make agreements for the other 53 shared rivers between both the countries. Nevertheless the main source of contention has still not been resolved which is to find a solution to augment the flow of the river in the dry season. The treaty lacks a clear and detailed mechanism for resolving the disputes between both the countries (Uprety & Salman, 2011).

3.4. India-Bhutan transboundary rivers

In 1949 a treaty was signed between India and Bhutan for mutual cooperation and non-interference by India. This treaty led to the basis for construction of hydroelectric projects on tributaries of Brahmaputra in Bhutan and exporting of electricity to India. This approach constitutes a good example of transboundary rivers management which encompasses the advantages of regional economic development, benefitting both the countries in improving the quality of life of people through poverty alleviation, income generation and environmental conservation (Biswa, 2011).

3.5. India-Pakistan transboundary rivers

After independence in 1947, conflicts arose between both the countries on sharing of transboundary rivers. With the involvement of the World Bank both countries constituted a working group to carry out talks on the issue. Both parties shared their studies and concerns with each other but a consensus could not be achieved (Beach et al., 2000). The World Bank asked both countries to prepare their plans to
reach a consensus. Negotiations continued and finally in 1960 the IWT was signed between both the states with the World Bank as a third party for certain purposes (Alam, 2002; Salman, 2008; Zawahri, 2009; Wani & Moorthy, 2013). The importance of the treaty can be studied at various interrelated and manifold scales (Haines, 2014). Although China and Afghanistan also make up part of the Indus basin they were not included in this treaty as 86% of the basin is occupied by India and Pakistan. As per the treaty, water of three Eastern Rivers (Ravi, Sutlej and Bias) was given to India whereas three Western Rivers (Jhelum, Chenab and Indus) were allocated to Pakistan with certain exceptions. Pakistan was required to carry out some projects to divert waters of Western Rivers to Eastern Rivers and India was to ensure unrestricted flow of Western Rivers to Pakistan with certain exceptions. These exceptions included use of water by India for ‘domestic uses’, ‘agricultural uses’, ‘non-consumptive uses’ and for ‘power generation’ without storing the water. Both sides were bound to share data related to rivers with each other with the help of a permanently established ‘Indus Water Commission’ which would watch over the treaty affairs. A deliberate dispute mechanism was also provided in the treaty. In case of dispute, it would first be attempted to resolve the dispute at commissioner level, failing to do so would result in this ‘difference’ being taken to a ‘Neutral Expert’ and if the dispute was beyond the mandate of the Neutral Expert it would be taken to the ‘Court of Arbitration’ (Uprety & Salman, 2011). The IWT can be concluded as a successful story from an implementation point of view (Wheeler, 2009).

4. Chenab River and its basin

The most conflictive and closely related aspects in transboundary water management appear to be ‘infrastructure and water quality’, which indicates a rise in weight of negative events in recent times (De Stefano et al., 2010). According to the IWT, India’s share from Western Rivers has been fixed at 4440 million cubic metres (MCM) or 3.6 million acre feet (MAF) and India is allowed to construct run-of-the-river hydroelectric dams without storage. A number of dams have been planned by India on the Chenab River, however five major dams with large storage capacity are mentioned with present status in Table 1. India can use live storage of already completed dams, i.e. Dul Hasti Dam, Baglihaar Dam and Salal Dam, to stop water for a certain time as and when desired. Average mean discharge data were obtained on all these sites to assess the number of days, for which India can stop water in various months of the lean period. The details and number of days worked out are shown in Table 2.

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Status</th>
<th>Installed capacity (MW)</th>
<th>Pondage (MCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dul Hasti</td>
<td>Near Kishtwar on Chenab River</td>
<td>Completed</td>
<td>780</td>
<td>10.68</td>
</tr>
<tr>
<td>Baglihaar (I&amp;II)</td>
<td>On Chenab River about 147 km upstream of Marala Headworks</td>
<td>Completed</td>
<td>450 +450</td>
<td>202.58</td>
</tr>
<tr>
<td>Salal (I&amp;II)</td>
<td>72 km upstream of Marala on Chenab River</td>
<td>Completed</td>
<td>690</td>
<td>98.93</td>
</tr>
<tr>
<td>Ratle</td>
<td>55 km upstream of Baglihaar Dam on Chenab River</td>
<td>Under construction</td>
<td>850</td>
<td>23.86</td>
</tr>
<tr>
<td>Pakal Dul</td>
<td>On Marusadar River, right bank tributary of Chenab River</td>
<td>Under construction</td>
<td>1000 (Ultimate 1500 MW)</td>
<td>108.55</td>
</tr>
</tbody>
</table>

*Source: Pakistan Indus Water Commission.*
In order to ascertain the pattern and trend of water inflow at Marala Headworks, data of 35 years was obtained from the Indus River System Authority (IRSA). The data were analysed for annual, Kharif (April to September) and Rabi (October to March) seasons inflow. A downward trend was observed in inflows at Marala Headworks as shown in Figures 1–3. Significant fluctuations are also observed in the lean period during which water inflow becomes critical for Pakistan.

To recoup water shortage at Marala Headworks in case of stoppage by India, an unexplored potential site ‘Rohtas Dam’ downstream of Mangla Dam was identified with the help of remote sensing and geographical information system (RS and GIS) techniques, on the Kahan River using a digital elevation model (DEM) with 90 m resolution. By generating contours and using ArcGIS 10.1 tools the approximate volume of water was calculated using contours. The volume which can be stored is approximately 2467 MCM while keeping the height of the dam up to 30 m. The watershed and lake area of the dam is shown in Figure 4. This dam can be used to store water during the flood season, exceeding the storage

<table>
<thead>
<tr>
<th>Months</th>
<th>Dul Hasti Dam</th>
<th>Baglihaar Dam</th>
<th>Salal Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manipulatable storage capacity (10,683,230 cubic metres)</td>
<td>Manipulatable storage capacity (202,585,952 cubic metres)</td>
<td>Manipulatable storage capacity (98,929,790.57 cubic metres)</td>
</tr>
<tr>
<td>Oct</td>
<td>Monthly avg from daily flow (m$^3$ s$^{-1}$)</td>
<td>No. of days</td>
<td>Monthly avg from daily flow (m$^3$ s$^{-1}$)</td>
</tr>
<tr>
<td>230</td>
<td>0.5</td>
<td>339.25</td>
<td>7</td>
</tr>
<tr>
<td>122</td>
<td>1</td>
<td>204.13</td>
<td>11.5</td>
</tr>
<tr>
<td>98</td>
<td>1.25</td>
<td>161.49</td>
<td>14.5</td>
</tr>
<tr>
<td>80.5</td>
<td>1.5</td>
<td>153</td>
<td>15.3</td>
</tr>
<tr>
<td>72.5</td>
<td>1.7</td>
<td>182.3</td>
<td>12.86</td>
</tr>
<tr>
<td>89.5</td>
<td>1.4</td>
<td>311.6</td>
<td>7.5</td>
</tr>
<tr>
<td>70.25</td>
<td>2</td>
<td>152.12</td>
<td>16</td>
</tr>
<tr>
<td>Average leanest year</td>
<td>70.25</td>
<td>2</td>
<td>152.12</td>
</tr>
</tbody>
</table>

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capacity of Mangla Lake. This will eventually ensure a reliable storage to supply extra water at Marala Headworks through a link canal from Rohtas reservoir or the already proposed canal ‘Mangla Marala Link Canal’ (MMLC). Mangla Dam original storage capacity has been reduced from 7253 MCM to 5660 MCM (5.88 MAF to 4.59 MAF) due to silting in its reservoir. Although its reservoir capacity has been enhanced by raising the level of dam, still the necessity exists to store water in the flood season for use in the lean period. Water will be diverted to Rohtas Lake through a tunnel 7 km in length. A dyke on the north-east of the lake will be required to protect Dina City (layout is shown in Figure 4).
5. Water quality of Chenab River

Analysis of world over treaties reveals that environment and water quality issues have risen to dominance and obvious consideration of water quantity is becoming less prominent in transboundary water law. In developing countries, up to 90% of sewage and untreated wastewater is released in lakes, rivers and coastal zones. Pollution is not restricted by borders; it flows downstream and affects food security, health and other basic uses of water, as 80% of water being used the world over is not treated before use (Corcoran, 2010). According to the IWT any undue pollution of water, which might occur due to disposal of sewage or industrial waste into river water, will be prevented. Owing to lower and more controlled flow in Eastern Rivers and linked drains, a high level concentration of pollution has been observed due to disposal of sewage and industrial waste by India, especially in the River Ravi (Mehmood et al., 2014). Similarly, water of the Jhelum River is also observed to be polluted and a high level of pollution has been noticed during analysis of Jhelum River and other drains’ water (Khan et al., 2012). The contamination by hazardous substances can pose harmful effects to human health, especially through the food chain.
Just after crossing the Line of Control, two tributaries, Jammu Tawi and Munawar Tawi, join the Chenab River upstream of Marala Headworks. To check the water for its suitability for drinking, agriculture and aquatic life, samples were taken from the Chenab River and its tributaries and then downstream of Marala Headworks after confluence of all streams, making a total of four sampling sites. Laboratory analysis of collected samples was carried out to ascertain their suitability for drinking, agriculture and aquatic life with respect to water quality standards of ‘World Wide Fund for Nature – Pakistan’ (WWF-Pakistan, 2007). The results are shown in Table 3.

6. Change in land cover and river course

A decrease in quantity of water also raises questions regarding the probability of any surface or tunnel diversion of water of the Chenab River or its tributaries. To address this concern RS and GIS were used to ascertain the probability of diversion. Using a 90 m resolution DEM, the watershed area of Jammu and Kashmir was delineated using ‘hydrology’ tools in ArcGIS 10.1. The elevation profile of the watershed area shows that the river is bounded by steep hills and there is no possibility of open channel diversion. However, water can be diverted with the help of a tunnel positioned at a suitable location.

Table 3. Water quality parameters of Chenab River and its tributaries.

<table>
<thead>
<tr>
<th>Water quality parameters</th>
<th>Jammu Tawi</th>
<th>Chenab Main</th>
<th>Munawar Tawi</th>
<th>Marala HW</th>
<th>Guidance value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Drinking</td>
</tr>
<tr>
<td>Electric conductivity (EC)</td>
<td>550</td>
<td>298</td>
<td>378</td>
<td>343</td>
<td>1250</td>
</tr>
<tr>
<td>pH</td>
<td>7.88</td>
<td>7.88</td>
<td>8.06</td>
<td>8.01</td>
<td>6.5–8.5</td>
</tr>
<tr>
<td>Alkalinity (ppm)</td>
<td>232</td>
<td>102</td>
<td>182</td>
<td>142</td>
<td>–</td>
</tr>
<tr>
<td>Bicarbonates (ppm)</td>
<td>232</td>
<td>102</td>
<td>182</td>
<td>142</td>
<td>–</td>
</tr>
<tr>
<td>Calcium (ppm)</td>
<td>81</td>
<td>41</td>
<td>41</td>
<td>37</td>
<td>–</td>
</tr>
<tr>
<td>Chloride (ppm)</td>
<td>24</td>
<td>10</td>
<td>12</td>
<td>20</td>
<td>250</td>
</tr>
<tr>
<td>Hardness (ppm)</td>
<td>262</td>
<td>152</td>
<td>192</td>
<td>172</td>
<td>300</td>
</tr>
<tr>
<td>Magnesium (ppm)</td>
<td>34</td>
<td>12</td>
<td>34</td>
<td>19</td>
<td>–</td>
</tr>
<tr>
<td>Potassium (ppm)</td>
<td>5.3</td>
<td>2.1</td>
<td>1.4</td>
<td>2.5</td>
<td>–</td>
</tr>
<tr>
<td>Sodium (ppm)</td>
<td>16</td>
<td>4</td>
<td>11</td>
<td>6</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate (ppm)</td>
<td>27</td>
<td>38</td>
<td>13</td>
<td>19</td>
<td>–</td>
</tr>
<tr>
<td>Nitrate (ppm)</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Total dissolved solids (ppm)</td>
<td>303</td>
<td>164</td>
<td>208</td>
<td>189</td>
<td>1000</td>
</tr>
<tr>
<td>Biochemical oxygen demand (mg/l)</td>
<td>11</td>
<td>8</td>
<td>10</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>Chemical oxygen demand (mg/l)</td>
<td>19</td>
<td>15</td>
<td>18</td>
<td>–</td>
<td>25</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/l)</td>
<td>6.37</td>
<td>5.87</td>
<td>5.92</td>
<td>6.29</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Total coliforms (No/100 ml)</td>
<td>280</td>
<td>66</td>
<td>34</td>
<td>72</td>
<td>50</td>
</tr>
<tr>
<td>Faecal coliforms (No/100 ml)</td>
<td>193</td>
<td>23</td>
<td>21</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>+ve</td>
<td>-ve</td>
<td>-ve</td>
<td>-ve</td>
<td>-ve</td>
</tr>
<tr>
<td>Sodium absorption ratio</td>
<td>0.38</td>
<td>0.14</td>
<td>0.31</td>
<td>0.2</td>
<td>–</td>
</tr>
</tbody>
</table>

* indicates no guidance value set.

* as per standards of WWF-Pakistan.
This location demands the need for water pondage and a nearby stream network where water can be diverted with the help of the shortest tunnel length. The watershed area of the River Ravi was delineated and its stream network was also generated using the same DEM. Landsat 8 imagery was downloaded and its classification was carried out to delineate water bodies of the Chenab River and Ravi River basin. The shortest possible diversion tunnel can be constructed with a length of approximately 10 km at latitude 32°47′40.88″N and longitude 76°25′9.61″E. This tunnel can divert water to Madhopur Headworks which has been constructed on the River Ravi in India. However, by analysing the water bodies delineated during classification, there is no indication of the water pondage required to raise the water level for diversion, which rules out any probability of the existence of a diversion tunnel. Having ruled out the possibility of any surface or tunnel diversion, the only existing option available with India is the stoppage of water of the Chenab River using dams for a certain number of days, as discussed above.

Alteration in sediment dynamics, stability of river bed and bank, movement of nutrients and aquatic organisms are affected by in-channel structures like check dams (Wohl, 2006). A change in hydraulic behaviour of the flow takes place due to in-channel structures which cause important morphological effects in the river bed (Boix-Fayos et al., 2007). To observe the change of river course in Pakistan Punjab Province due to Indian dams, the watershed of the Chenab River in Pakistan was delineated using a DEM with 90 m resolution. After delineation of the watershed, suitable Landsat tiles were downloaded from the archive for a 30-year time period with an interval of 10 years from 1980 to 2010, images were mosaicked and clipped according to area in order to monitor the change in land cover. There were changes in vegetation and built-up area, however, noticeable change was observed in the river course. The extracted water bodies after classification of imagery for all selected years are shown in Figure 5.

7. Discussion and suggested measures

7.1. IWT and other regional treaties

In comparison to other regional treaties the IWT can be described as a success story which even survived after three wars between both the countries. In case of the China-India war in 1962 the abandoned MoU on Brahmaputra River was signed again after a lapse of 40 years in 2002. Due to lack of any agreement, a situation of tension exists between both the countries over construction of new dams on the Yarlung-Tsangpo River. China claims to adopt a responsible approach towards projects on transboundary rivers, while India takes the stance that construction of dams indicates no regard for downstream neighbours.

In the case of India and Nepal, three treaties exist for sharing of water and equitable distribution of benefits over shared rivers. Unlike the IWT, these treaties have been revised on a need basis to address the concerns of both countries, especially Nepal. Although some concerns still exist, these treaties can be quoted as an example of reasonable utilization, equitable distribution of benefits, and an obligation not to cause significant harm. The most significant thing is the joint investment in the new hydroelectric project on the Mahakali River and the later sharing of electricity by both the countries, like the electricity shared from the Gandak and Kosi Rivers. This principle can be adopted in the IWT as Pakistan is facing a shortage of electricity and is in the process of planning to import electricity from neighbouring
countries. Based on the principle of ‘equitable distribution of benefits’ provisions can be introduced in the treaty such that both countries could invest in new hydroelectric projects on Western Rivers and then electricity can be imported to Pakistan. This will not only promote and enhance mutual cooperation but also projects can be undertaken in less time due to the interest of both countries. As stated by Wani & Moorthy (2013), India and Pakistan have not been involved in any matter requiring joint planning due to which disputes on various projects are mounting every now and then, widening the chasm between the two neighbours. In case of Chenab Basin, transmission lines infrastructure will be reasonably low due to its proximity to the highly populated Punjab Province with obvious high demand for energy. Moreover, it will enable both the countries to take part in a joint investment resulting in regional development and cooperation over the disputed territory of Kashmir. This model if successful can be adopted in various other fields as well.

The same cooperation can be observed in India and Bhutan on sharing of water and equitable distribution of benefits. The treaty enabled both the countries to undertake combined power generation projects over Brahmaputra tributaries in Bhutan, and then trading of electricity to India, making it an example of mutual cooperation in shared basins. The positive synergies between India and Bhutan at
present should also be considered in an India-Pakistan perspective and such provisions can be discussed for inclusion in the IWT.

Bangladesh and India share 54 transboundary rivers but no treaty existed for quite a long time for sharing of water. After a long history of differences, Bangladesh’s lower riparian rights were recognised and the treaty was signed on the Ganges River only for a period of 30 years. Besides that the issue regarding flow of the river in the dry season has not been resolved, and the treaty also lacks any comprehensive dispute resolution mechanism. In the case of Pakistan-India, a treaty was signed in a much earlier time frame and persisted over a long span of time despite disputes arising sporadically. In case of disputes a comprehensive mechanism exists in the treaty which provided a suitable verdict in resolving differences arising during the Baglihaar hydroelectric project on the Chenab River.

Making a comparison with regional treaties shows that the IWT spanning over more than half a century, proved to be a success story although both countries claim that it favours the other side. This provides a peaceful platform from which to reach mutual consensus regarding conflicts as in the case of Bangladesh where, despite going to the UN, both countries were directed to find a solution mutually. The situation could have been worsened in the absence of the IWT as both countries relations have remained tense since signing the treaty. Nevertheless, due to emerging challenges, it is high time that both countries should be involved in talks over new provisions in the treaty by making use of Article XII of the IWT, to address environmental and technical issues on hydroelectric projects on Western Rivers to avoid frequent conflicts. From the analysis of the strengths and weaknesses of the IWT in relation to the UN Watercourses Convention, it appears that the treaty would need to be amended to account for emerging needs and to promote cooperative water management between the two countries (Sarfraz, 2013). In the case of the Baglihaar Dam controversy, a Neutral Expert verdict gave a clear indication that the treaty needs to be reviewed to make it compatible with current trends and advancement in technology. The Neutral Expert verdict stated that ‘IWT gives a clear indication of the rights and obligations of the parties, and that rights and obligations should be read in the light of new technical norms and new standards as provided by the Treaty’ and taking into account ‘the best and latest practices in the field of construction and operation of hydraulic plants’. Verdict interpretation gives evident necessity to review the treaty in order to incorporate new norms and trends in management of water resources.

7.2. Water quantity

The water inflow trend line shows that it is decreasing with the passage of time. A lot of fluctuations can be observed while discharge below Salal Dam is decreasing with the passage of time. Analysis of 35 years of inflow data shows that annual discharge decreased from 40 BCM to 22 BCM indicating an average decrease of 0.5 BCM per year. Since construction of the dams, India has got the capability for manipulation and stoppage of flow of the Chenab River for a certain number of days during lean months as shown in Table 2. Moreover, India can restrict the flows of the Chenab River for the historic 10-daily mean discharge 210 cubic metres per second (m$^3$ s$^{-1}$) and minimum discharge of 113.28 m$^3$ s$^{-1}$ for 20 and 38 days, respectively, corresponding to storage of 185 MCM. Under-construction dams shown in Table 1 can add up to 14–25 days due to their large reservoir capacity. Similarly a number of dams which are under consideration will enhance capability for manipulation and stoppage of river flow, on completion.

7.2.1. Impact assessment of water stoppage of Chenab River. Relations between India and Pakistan have never remained cordial and four wars have been fought between both the countries since their
independence. In the event of India materializing her capability of water regulation on the Chenab River, Pakistan may have to face critical consequences. Alignment of the Chenab River is from NE to SW covering a considerable length and depth of Punjab Province, a vital province of Pakistan. Flooding of this river will seriously affect the low lying areas of Punjab and Sindh. All lines of communications will be seriously damaged consequently disrupting mobility means within the affected areas. Civil population will be the first hit which will demand conduct of major relief operations. Major cities of Punjab Province will also be affected, which will incapacitate the capability for industrial production. Security concerns will also rise due to prevalent state of response paralysis. India can stop the water in critical days during war to reduce the efficacy of obstacle systems on the borders.

In case of stoppage of water, crops will be affected especially sowing of wheat and ripening of paddy crop. To discuss the probable effects on agriculture the real time problem which occurred during initial filling of Baglihaar Dam will be described: newly constructed reservoirs are required to be filled according to explicit provisions in the treaty rendering that filling will be carried out by mutual discussion. After completion of any project over the Chenab River, new dams are required to be filled during the peak of monsoon season, between 21 June and 31 August; and it must be ensured that at any time the flow above Marala Headworks in the Chenab Main should not drop below 1557.5 m$^3$ s$^{-1}$. Pakistan claimed that stoppage of water was carried out from 19 August to 5 September, whereas India maintains that it was up to 28 August. Consequently, flow of the Chenab River dropped down drastically, which affected the agriculture downstream of Marala Headworks. India seized 5664 m$^3$ s$^{-1}$ of water in the months of September and October during paddy crops ripening time and also created acute water shortage for Kharif crops, especially sowing of the wheat crop. Arable land with an area of more than 40,470 km$^2$ was affected in many districts like Gujranwala, Sialkot, Jhang, Sheikhupura and Faisalabad, besides causing early depletion of Mangla Dam. According to one estimate by the Punjab Irrigation Department, a loss of almost 37 billion (10$^9$) Pakistani Rupees was experienced by the economy of Pakistan due to blockade of water of the Chenab River (Mustafa, 2008). Similarly, by examining the water flow pattern and fluctuation an unprecedented drop in flow at Marala Headworks can be observed in the lean season of 2001–02. This was the time when armed forces of both countries were escalated to borders and war was imminent. These incidents highlight the issues linked with water stoppages and importance of remedial measures to avoid any untoward situation.

To predict the inflow at Marala Headworks keeping in view the last 35 years’ data, regression analysis using SPSS software was carried out.

\[ Y = a + bx \quad (a = \text{slope}, \, b = \text{intercept}) \quad (1) \]

\[ \text{Flow} = 549.564 + (-)0.260 \times (\text{Year}) \quad (2) \]

Using constants mentioned in Equations (1) and (2) indicates that flow can reduce by up to 23.064 billion (10$^9$) cubic metres in the next 10 years. Inflow forecasting can be carried out using different methods such as ordinary linear regression, autoregressive moving average (ARMA) and autoregressive integrated moving average (ARIMA) models and artificial neural networks. However, the ARIMA model has a better performance than the ARMA model because it makes time series stationary, in both calibration and forecasting phases (Valipour et al., 2012a, 2012b, 2013).
7.2.2. Remedial measures to mitigate effects. In order to counter the shortage of water in case of stoppage, Pakistan needs a storage dam near Marala Headworks site. Unfortunately, the topography of the area does not allow storage of water in that area. However, Marala Headworks can be linked with the help of a canal to mitigate the effects due to shortage of water in critical days. Pakistan has established a very well-organised link canal system in order to ensure the distribution of water from Western Rivers towards the Eastern Rivers command area. There is a requirement of an extra $255 \text{ m}^3 \text{s}^{-1}$ of water at Marala Headworks to address the issue of shortage. A canal from Rohtas lake or MMLC (shown in Figure 6), with approximate length of 100 km and $283 \text{ m}^3 \text{s}^{-1}$ capacity from Mangla Dam to Marala Headworks can help to recoup the water shortage in case of stoppage from India. While recouping the shortage of water in critical days, the construction of MMLC or a link canal from Rohtas reservoir will bring other benefits like approximately 365 km$^2$ of new command area along the link canal route can be developed for irrigated agriculture. Furthermore it will feed the defence line canal system downstream of Marala Headworks. However, there are some interprovincial reservations in regard to diversion of water towards Marala Headworks, as it is feared that lower areas may not get their due

share of water due to diversion of water towards Marala Headworks. A new storage site, i.e. Rohtas Dam, can address this problem as extra water will be available in the case of provision of water to Marala Headworks. This dam will act as an extension of Mangla Dam, where extra water after filling of Mangla reservoir can be directed with the help of a 7 km long tunnel to Rohtas reservoir. Extra electricity can be generated at the inlet and outlet of the guiding tunnel of Rohtas Lake and subsequently when releasing the water through Rohtas Dam. Besides storing extra water during the flood season, this dam will also help in mitigating frequent disasters occurring due to floods. In the flood season a lot of fresh water is wasted by allowing it to flow into the sea. There are concerns of Sindh Province regarding essential flows required downstream of Kotri Barrage to stop sea water intrusion. To cater for the concerns of Sindh Province a study has already been carried out by an Independent Panel of Experts (IPOE) in order to ascertain the minimum essential requirement of water (shown in Table 4) to address environmental hazards. The panel’s recommendations indicate the need to construct new water storage dams in order to conserve fresh water in the flood season. These dams will also ensure the maintenance of the minimum discharge required downstream of Kotri Barrage in case of reduced flow due to seasonal variations. Moreover, the MMLC can provide essential water to surroundings areas of the Ravi River, where environmental hazards are on the increase due to lack of fresh water supply.

7.3. Water quality aspect

Results of water quality parameters of the Chenab River and its tributaries, Munawar Tawi and Jammu Tawi, show that the effect of sewage disposed of in the river gets diluted and its hazardous effect reduces to an acceptable limit when reaching to Pakistan territories, especially when all streams join upstream of Marala Headworks. Water is not found to be suitable for drinking as sewage is present in the water, however due to the dilution effect it is suitable for agriculture and aquatic life as all the parameters are within the prescribed limit of water quality parameters of WWF-Pakistan. Monitoring of water quality throughout the year is essential as contaminant concentrations vary with the amount of seasonal flow. Water quality of the Jammu Tawi River is comparatively worse as the river passes from the highly populated areas and contains sewage and industrial waste of Jammu City in India. If historical records of water quality of the Chenab River had been available, the results could have been analysed more significantly by monitoring the concentration of pollutants with the passage of time. There is no such department which is monitoring water quality parameters regularly. There is a need to establish such a setup and enhance the capacity of the Indus Water Commissioner office so that such issues can be monitored on a regular basis. This highlights the fact that effects of pollution

| Table 4. Water escapages recommended downstream of Kotri Barrage by IPOE. |
|----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                      | Kharif (Apr–Sept) |        |        |        |        | Rabi (Oct–Mar) |        |        |        |        |        |        |
|                      | Apr     | May    | Jun    | Jul    | Aug    | Sept   | Oct    | Nov    | Dec    | Jan    | Feb    | Mar    |
| In m$^3$ s$^{-1}$    | 141.6   | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  | 141.6  |
| In MCM               | ≥370    | ≥370   | ≥370   | ≥370   | ≥370   | ≥370   | 370    | 370    | 370    | 370    | 370    | 370    |
| Total Kharif = 2220+ MCM |         |        |        |        |        |        |        |        |        |        |        |        |
| Total Year = 4440+ MCM |         |        |        |        |        |        |        |        |        |        |        |        |
| Source: IRSA.        |         |        |        |        |        |        |        |        |        |        |        |        |
are more pronounced in Eastern Rivers and their tributaries like the Hudiara drain which brings untreated domestic and industrial waste from India to Pakistan and then pollutes the water of the River Ravi and Kasur drains, thus necessitating a need for regular monitoring of water quality of all the transboundary rivers.

### 7.4. Indian dams, a matter of concern

With rapid population growth and expanding industrialization, both countries need water for irrigation and energy generation, hence both countries have extensive plans for different uses (Sarfraz, 2013). Dams being constructed on Western Rivers are characterized as ‘run-of-the-river projects’ which are assumed to cause negligible or no downstream impacts as these projects have small pondage. However, the facts discussed highlight that this assumption is ‘false’. Serious impacts can be instigated by such run-of-the-river projects while disturbing river flows to downstream areas. Each run-of-river project enhances India’s capability to influence the timing of flows. In this regard, live storage is of key importance as this storage matters for altering the timing of flows. Confining live storage to a minimum on these projects is the only measure to stop upstream manipulation of flows by India. Furthermore, a large number of planned projects in series over the Chenab River will create large cumulative live storage capacity by using the option of sequential filling thereby enabling India to manipulate the downstream flow to Pakistan territories. Other than the existing projects, India is planning a number of mega projects on the Chenab River like Bursar, Kiru, Gyspa, PakDul, Kwar and Sawalkot hydro projects at various locations. Sawalkot hydroelectric project is planned downstream of the Baglihaar project and upstream of the already completed Salal Dam. Bursar Dam is the biggest ever dam in the Doda district with 1020 MW generation capacity and also has huge storage which is intended to regulate flow to downstream areas during lean-flow months. This dam will not only be capable of flow regulation but will also enhance the capability of all downstream dams like Dul Hasti, Pakal Dul, Sawalkot, Ratle, Baglihaar and Salal hydroelectric projects (Akhtar, 2010). Gyspa Dam is another dam with huge storage capacity of around 1480 MCM at a height 10,000 ft above sea level in Himachal Pradesh which is against International Commission on Large Dams policies. All these dams when completed will give an unquestionable capacity for controlling the flow of the Chenab River.

It is also required to highlight issues regarding the hydroelectric generation capability of these dams in the lean season. Baglihaar Dam is almost 900 MW which necessitates a minimum flow of 860 m$^3$ s$^{-1}$ but the Chenab flow can fall down to 70 m$^3$ s$^{-1}$ in winter, similarly Salal Dam with 690 MW water requirements raises the question of viability of these projects. Small hydroelectric dams are required to be pursued keeping in view low flows which can be achieved almost throughout the year.

### 7.5. Need to build new off-channel dams

Keeping in view India’s mad rush for hydro projects on the Western Rivers, Pakistan should not be in any ambiguity about India’s intentions for pursuing these projects on the Chenab River on fast track for their early completion. To minimize the anticipated threats, Pakistan needs to focus on an emergency basis in planning and construction of large/small dams. Owing to topographic layout, Pakistan has limited sites available for storage of water on large river courses. Distant from main river channels, off-channel reservoirs and guiding canal networks to suitable selected storage sites, like Rohtas Dam,
are required to be explored with the help of the latest trends in technology, being otherwise a difficult task owing to financial constraints. With advancement in RS and GIS techniques all probable sites can be reconnoitred with open-source datasets and later site-specific high-resolution imagery, DEM and other requisite datasets can be purchased to help in feasibility studies. This will assist in ascertaining layout and estimation of civil works, extents of reservoir lakes, displaced population and areas for settlement with quite reasonable accuracy while saving time and effort. Furthermore there is a dire need to reach a consensus at national level for exploration of new sites for building storage dams to counter India’s claim of less storage reservoirs, mismanagement of water resources and a massive unutilised amount of 46,870 MCM of waters flowing to the Arabian Sea every year.

7.6. Siltation and change in river course

Owing to constant changes in environment, variations in the river geomorphologies can be observed at both the spatial and temporal scale. While observing the Chenab River pattern over 40 years of span, prominent changes at various locations can be observed in width and course of the river. Watershed disturbance due to environmental change and human activities can cause an increase in transportation of sediments which contribute towards change in river morphology. River discharge and the sediments are independent variables for stable meandering channels like the Chenab River which have less erosive energy due to which they do not migrate considerably within a small span of time. Therefore a major contribution in morphology and behaviour of a river reach can be caused due to water and sediment discharges from upstream (Yeasmin & Islam, 2011; Sinha & Ghosh, 2012). In-channel structures like check dams increase the potential of downstream erosion (Boix-Fayos et al., 2008). Changes in sediment yield and discharge, as a result of Indian dams regulating activities will trigger variations in rates and modes of channel migration as well as changes in width, pattern and shape of the river which will disturb the agriculture activities and shelters constructed astride the river. Besides affecting water flow, these dams also remove nutrient-rich silt which is a source of nourishing agriculture downstream. Over the past two decades, the width of the Chenab River has been reducing significantly whereas river course pattern change is increasing with time.

An abrupt change in river discharge and sediment transportation is expected due to the advantage given to India by the Neutral Expert decision on the Baglihaar Dam. The Neutral Expert determined that ‘in conformity with the state of the art, the conditions at the site of the Baglihaar plant, including hydrology, sediment yield, topography, geology and seismicity, require a gated spillway’. The Neutral Expert pointed out that the treaty is ‘not well developed with respect to its provisions on sediment transport’ and ‘reflects the status of technology on reservoir sedimentation in the 1950s’. This allows India to use the gated spillway giving capability for flow regulation and construction of under-sluice gates that will yield a huge amount of sediments downstream when intended, which can affect functioning of Marala Headworks as well as causing considerable diversion of river course.

7.7. Joint management of Indus Basin

Experience over a long time frame indicates that there is no alternative available for South Asian countries other than cooperation with each other in management of their transboundary rivers (Biswas, 2011). Integrated water management will become critical in times to come due to the effects of climate change. Brahmaputra, Indus, Sutlej and Kosi Rivers are more likely to be affected as all these
are snow-fed rivers. Owing to the expected reduction in water flows a joint regional management framework may be established for all river basins in order to address concerns of all affected countries. Demand for water is likely to increase due to growing water needs and the amount of snowfall will decrease resulting in reduced supply from the upper courses of these rivers. Increase in consumption by the upper riparian will affect the flow towards lower sections of these major rivers in India. Due to global warming, the water balance is getting disturbed causing abrupt increases and subsequently decreases in the quantum of water (Briscoe & Qamar, 2006). In order to counter this situation an integrated basin water management will help in reducing the negative impacts of climate change. These climate scenarios result in changing water availability (both increasing and decreasing) due to higher temperatures and uncertain precipitation. Analysis shows basin-wide economic benefits to water policies that use an economic basis for allocation of the Indus River Basin water as an adaptive response to climate change (Yang et al., 2014). To commit to a new management plan or joint authority, upgradation of skills and capacities is required to be carried out for switching to integrated water resources management with regard to a new management paradigm.

8. Conclusion

Being an agricultural economy, water is undoubtedly the most precious commodity for Pakistan and is completely dependent on transboundary rivers. Assessment of various transboundary effects highlights the growing threats to the treaty as well as the quantity and quality aspects in relation to the Chenab River and other Western Rivers. Growing mistrust between the countries may lead to abrogation of the treaty proving a disaster for the region. Being neighbouring countries there is no other option but to carry out risk assessment and its management within the already established framework of the IWT for sustainable peace.

Studies with similar objectives can be carried out on other Western Rivers as well as Eastern Rivers to assess the nature of various threats in order to take remedial measures. More accurate assessment and suitability of dam sites can be carried out with acquisition of high resolution and other auxiliary data, necessary for ascertaining site suitability for dams. In case of availability of transboundary data, simulation can be carried out to ascertain runoff generated at desired locations with respect to amount of snowfall and rainfall. There is a dire need to review this framework keeping in view emerging challenges and concerns of riparian states.

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