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Ganges water quality at Kanpur- A Review

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Abstract

The Ganges provides ecosystem services which are of vital importance for the inhabitants of the Ganges river basin. However, the water quality of the Ganges river deteriorates downstream. Indian cities, e.g., Kanpur and Varanasi, are local hotspots of pollution and poor water quality. Downstream of these cities the river's water quality improves, but never restores to its original state. Haentjens (2017) analyzed the physico-chemical water quality of the entire Ganges and identified the city of Kanpur as the major pollution source. This MSc dissertation is a follow up of Haentjens' (2017) study in order to stimulate future discussions and actions on improving the water quality and ecology of the Ganges river. The first objective of this MSc study is to assess the impact of Kanpur's urban activity on Ganges water quality and to identify and quantify Kanpur's major pollution sources into the Ganges. The second objective included the search for an existing biotic index which can analyze Ganges ecological status. The results of this study revealed alarmingly high levels of nutrient- and organic pollution in the Ganges along Kanpur. Along Kanpur, the physico-chemical water quality of the Ganges reaches the most deteriorated OECD water quality class. The Sisamau nala, Jajmau industrial tannery zone and the Jajmau wastewater treatment plant effluent are the major pollution sources of Kanpur into the Ganges. Besides these major wastewater drains, a significant amount of smaller drains are diffusively discharging untreated domestic- and tannery wastewater into the Ganges.

1. Introduction

The Ganga (or Ganges river) is a 2525 km long river crossing the northern part of the Indian craton. The Ganges river basin houses about 40% of the Indian population (Ganga River Basin Environment Management Plan, 2012d). In 2000, approximately 500 million people were living in the Ganges river basin (Markandya & Murty, 2004). It is expected that this number will grow to 1 billion by 2030 (Markandya & Murty, 2004). The 15th National census survey, conducted by the official Census Organization of India, estimated the Indian population at 1,210,854,977 and decadal growth rate 17.64% in 2011 (census2011.co.in). Based on UN data, India's 2018 population is estimated at 1.35 billion (worldpopulationreview.com). The Ganges river provides a wide range of ecosystem services which are essential to support the livelihoods of a large number of people in the basin. Due to the monsoon, the discharge of the Ganga has extreme seasonal variations (Singh et al., 2007). In addition, Ganges river flow is highly regulated by various human interventions, such as dams and barrages for domestic water supply and irrigation. The river is heavily polluted due to anthropogenic activity. Urban wastewater, industrial effluents and pollutants from several othe. However, compared to the size and importance of the Ganga, the amount of research is still limited. In addition, many of these studies are already outdated, due to the rapid increase in Indian waste and wastewater emission, and do not represent the current situation anymore. Both the Ganga River Basin Environment Management Plan (2012d) and Haentjens (2017) provide a long term analysis of Ganges water quality along its entire course. These datasets will be discussed in detail later on. The water quality of the Ganges river deteriorates downstream. Indian cities, such as Kanpur and Varanasi, are local hotspots of pollution and poor water quality. Downstream of these cities, the river's water quality improves but never restores to its original state (Haentjens, 2017). Ganges water quality is a major study subject, however, a thorough analysis of the anthropogenic pollution along Kanpur city is still missing. This master dissertation aims to fill this knowledge gap. The objective of this master dissertation is twofold: 1. Identify and quantify the major sources of pollution in the Ganga along Kanpur city as a consequence of urban activity. 2. Search for an existing standardized method which can analyze Ganges ecological quality based on a biotic index. If not existing, provide recommendations for the construction of such a method. The first objective will be achieved through literature research and through the analysis of a dataset obtained during a sampling campaign on the Ganga during February 2018. This sampling campaign consisted of analyzing water samples from the surface of the Ganga at approximately the middle of the river. About 16 sampling locations were chosen on an approximately 18 km long transect along Kanpur city. These water samples were analyzed for 7 dissolved oxygen (DO), temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), ortho-phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), chemical oxygen demand (COD) and biological oxygen demand (BOD5). An approximately 14 km long transect of the Ganga upstream of Kanpur was analyzed in order to quantify the physico-chemical water quality of the Ganga before entering Kanpur. The second objective will be achieved by obtaining information from local, Indian researchers and through literature research. 2. Regional setting Ganges river The Ganga (or Ganges river), one of the world's major rivers, flows from the Himalayan mountains, over the Indian subcontinent, towards the Bay of Bengal (Singh et al., 2007; Singh, 2009). The Ganga river basin covers an area of 1086 x 106 km2 , encompassing the Himalaya orogenic belt, northern Indian craton and the Ganga alluvial plain (Singh et al., 2007). The Ganga river drainage network comprises a wide range of rivers acting as tributaries (Singh et al., 2007). Based on their source area, these rivers can be classified in three categories: 1. Himalayan source rivers, 2. Ganga alluvial plain source river, and 3. Northern Indian craton source rivers (Singh, 1996, 2004). The main tributaries of the Ganges originate from the Himalayan mountains (Singh et al., 2007; Singh, 2009). Discharge in the Ganga increases rapidly downstream due to significant inputs from these tributaries (Singh et al., 2007).

Kanpur city Kanpur is a major industrial city located in the state of Uttar Pradesh, in the center of northern India. Zia & Devadas (2007) state that the urban agglomeration of Kanpur covered an area of 298.98 km2 in 2001, and this will increase to 340.23 km2 by 2021. Kanpur's population size is highly uncertain. In 2001, Kanpur urban agglomeration had a population of 2.71 million, which rose to 3.1 million in 2006 (Dimitriou, 2006; Zia & Devadas, 2007). Dimitriou (2006) estimated that the population would reach 4.31 million by 2015. However, based on the 15th National census survey, Kanpur city had a population of 2,765,348 and Kanpur's metropolitan area a population of 2,920,067 in 2011 (census2011.co.in). Based on Dimitriou (2006), Kanpur has a yearly population growth of ±3.3%. However, the 15th National census survey reports a decadal growth rate of 9.92%. The World Population Review website states that Kanpur would reach a population size of 3,109,000 and a growth of 0.96% in 2018 (worldpopulationreview.com). Together with Lucknow, Kanpur belongs to the two biggest cities of Uttar Pradesh and the top 12 largest cities of India (census2011.co.in and Zia & Devadas, 2007). With a per capita income of 159 US dollars in 2001, Kanpur is one of the poorest cities in India (Uttar Pradesh State Planning Institute, 2002). Kanpur, often referred to as 'Manchester of the East', has a highly inefficient waste management system due to reasons such as poor management, lackadaisical approach towards waste management practices, public apathy, lack of political will, urbanization patterns, populations growth, poverty, etc. (Zia & Devadas, 2007). In addition, waste generation is still increasing (Zia & Devadas, 2007). The main sources of wastewater are domestic (about 426 MLD, Million Liter per Day) and tannery effluents (about 50 MLD) (Vedala et al., 2013). Most of which is ending up untreated in the Ganga river (Beg & Ali, 2008; Khwaja et al., 2001; Uttar Pradesh Jal Nigam et al., 2017; Vedala et al., 2013). It has been estimated that the domestic wastewater production will increase to 672 MLD by 2025 and to 1035.85 MLD by 2040 (Vedala et al., 2013).

Tanneries make up the primary industrial activity in Kanpur, which is mainly concentrated in the Jajmau district. In 2012, about 400 tanneries were located in Jajmau. This makes Jajmau the largest cluster of tanneries in India (Central Leather Research Institute (CLRI), 2012). These tanneries mostly process hides and about 90% practices chrome tanning (Beg & Ali, 2008; CLRI, 2012). 30 - 50% of the used chromium ends up in the tannery effluents and eventually in the Ganges (Beg & Ali, 2008; Khwaja et al., 2001). This chromium pollution is a major environmental problem and harmful to both humans and aquatic fauna and flora (Beg & Ali, 2008; Khwaja et al., 2001; Sharma et al., 2012). Existing studies on Ganges river water quality As mentioned in the introduction, research on Ganges water quality is limited compared to the size and importance of the river. In addition, a significant amount of these studies is already outdated due to rapid changes in the water quality status of the Ganges. Semwal & Akolkar (2006) provide an extensive analysis of Ganges water quality in the state of Uttarakhand, where the Ganges originates. This analysis includes bacterial indicators, physico-chemical parameters, pesticides and metals. In addition, a bio-monitoring study was performed (Semwal & Akolkar, 2006). Baghel et al. (2005), Chaudhary et al. (2017), Kumar et al. (2010) and Sood et al. (2008) provide additional studies of Ganges water quality in Uttarakhand. Already in Uttarakhand, fecal contamination is omnipresent (Baghel et al., 2005; Kumar et al., 2010; Sood et al., 2008). In addition, organic-, nutrient- and metal pollution increases downstream and culminates at Haridwar (Chaudhary et al., 2017; Kumar et al., 2010; Semwal & Akolkar, 2006; Sood et al., 2008). Haritash et al. (2016) analyzed Ganges water quality in Rishikesh, a city located in the upper part of the Ganges basin near the foot of the Himalaya. Haritash et al. (2016) assumed that pollution from urban activity was absent upstream of Rishikesh. In Rishikesh, a relatively good water quality was observed (Haritash et al., 2016). Arora et al. (2013) analyzed the water quality in terms of bacterial load, pH, alkalinity, chlorine, total dissolved solids (TDS) and total suspended solids (TSS) during the religious mass bathing event 'Maha Kumbha' in Haridwar in 2010. During such events, pilgrims dispose milk, curd, ghee, flowers, coins, idols, human ashes, body hairs, plastic bags and other non-biodegradable materials in the river (Arora et al., 2013). Due to the bathing event, pH decreased and chlorine, TDS and TSS increased (Arora et al., 2013). Probably, the most problematic was the major increase in fecal coliforms (Arora et al., 2013). Arora et al. (2013) concluded that the river water was extremely contaminated and not suitable for drinking water production during the mass bathing event. Along the entire course of the Ganga, such religious mass bathing events take place. In addition, people bath daily in the Ganga. Chaudhary et al. (2017) observed severely contaminated Ganges river water between Haridwar and Garhmukteshwar due to nutrients and heavy metals. In this river stretch, pollution was more severe during pre-monsoon compared to post-monsoon (Chaudhary et al., 2017). Probably, due to lower river discharge and less dilution during pre-monsoon (Chaudhary et al., 2017). The quality of Ganges water and sediment in the vicinity of Kanpur has already been studied by Beg & Ali (2008), Khatoon et al. (2013), Khwaja et al. (2001), Sankararamakrishnan et al. (2005), Thareja et al. (2011) and Trivedi et al. (2010). Besides identifying the detrimental impact of Kanpur's domestic- and industrial wastewater on the Ganges, all these studies fail to identify and quantify the urban and industrial pollution sources along Kanpur city. Trivedi et al. (2010) observed a better water quality of the Ganges along Kanpur during the monsoon season, compared to the winter season. Again, this is probably due to a decrease in river discharge and dilution during the dry seasons. At Allahabad, the Ganges confluences with the Yamuna river. Sharma et al. (2014) analyzed several physico-chemical parameters on Ganges- and Yamuna water samples, considerable deterioration of the water quality was observed. Based on a water quality index (WQI; Hameed et al. (2010)) of post-monsoon water samples, Sharma et al. (2014) concluded that Ganges water quality at Allahabad is of 'poor' quality. Gupta et al. (2009) studied the occurrence and bioaccumulation of certain heavy metals (Cu, Cr, Cd, Pb and Zn) in Ganges river water, sediments and cat fish at Allahabad. Gupta et al. (2009) concluded that Zn was the most occurring and accumulating metal. Shweta & Satyendra (2015) investigated the increase in water pollution in the Ganga and Yamuna rivers during mass bathing events in Allahabad. Shukla et al. (1988 &1989), Sikandar (1987) and Tiwari (1983) studied the water quality at Varanasi . However, these studies are already obsolete. Recent studies of the water quality near Varanasi are limited. Rai et al. (2010) measured heavy metals, BOD, DO and fecal coliforms in the effluent of three sewage treatment plants disposing in the Ganga near Varanasi. These treated effluents were still heavily polluted, and as a consequence severely degrading Ganges water quality (Rai et al., 2010). Yadav & Srivastava (2011) studied the water quality of the Ganges at Ghazipur, a small city between Varanasi and Patna . Most of the pollution indicators had the highest values in summer (Yadav & Srivastava, 2011). Probably, this is due to the lower river discharge and higher water temperatures resulting in lower oxygen solubility during the Indian summer. In addition, less dilution results in higher pollution concentrations and more DO consumption. Tiwari et al. (2016) compared Ganges water quality between Kanpur, Allahabad and Varanasi, probably the three most polluting Indian cities along the Ganges. The lowest DO content and highest BOD- and COD content were observed at Kanpur (Tiwari et al., 2016). Tiwari et al. (2016) concluded that the water quality at Kanpur was very poor compared to Varanasi and Allahabad, which is supported by the analysis of Haentjens (2017). Near the border of India and Bangladesh, the Ganges river splits into the Padma and Hooghly river The Hooghly river, ca. 280 km, is the lower tidal stretch of the Ganges river, a partially mixed estuary (Sarkar et al., 2007). Calcutta is the most polluting city along the Hooghly river (Sarkar et al., 2007). Purkait et al. (2009) analyzed the sewage-water and sewage-sludge of Calcutta for organic pollution-, physico-chemical-, fecal contamination- , heavy metal- and pesticide parameters. Purkait et al. (2009) concluded that without treatment the sewage-water and sewage-sludge cannot be used for irrigation and fertilization, respectively, in agriculture. In addition, the disposal of these sewage products in the Ganges leads to severe water quality deterioration (Purkait et al., 2009). Aktar et al. (2010) analyzed the pollution level in the surface water of the Ganges around Calcutta, and came to the same conclusion as Purkait et al. (2009).

Major drains of Kanpur In January 2017, a collective of four organizations, i.e., Uttar Pradesh Jal Nigam, Uttar Pradesh Pollution Control Board, National Mission for Clean Ganga and Central Pollution Control Board, submitted a report about drains discharging wastewater in the Ganges river to the National Green Tribunal of India (Uttar Pradesh Jal Nigam et al., 2017). This collective identified 15 drains discharging wastewater from Kanpur into the Ganges river. In the report, two types of wastewater are identified, i.e., domestic- and mixed wastewater. Mixed wastewater is a combination of domestic- and industrial wastewater (Uttar Pradesh Jal Nigam et al., 2017). In Kanpur, the industrial wastewater mainly originates from the tannery industry (Khwaja et al., 2001). 11 of these drains discharge domestic wastewater into the Ganges river. Only in the industrial area of Jajmau, southeastern part of Kanpur, mixed wastewater is discharged into the Ganges. Drain n°12 discharges 'Kanpur city sewage' into the Ganges, based on the report this consists mainly of domestic waste (Uttar Pradesh Jal Nigam et al., 2017). Per drain the report provides a dataset of relevant pollution parameters, i.e., BOD, COD, TDS, TSS, pH, Cl- , N-NH3, NO3 - , SO4 2- , S and P (Table 2.3). This dataset includes two flow measurements per drain: 1. average flow data from Uttar Pradesh Jal Nigam (expressed as MLD), and 2. a flow measurement (expressed as MLD) done during a drain survey, performed by a team of representatives of the four organizations, this survey is referred to as the 'joint inspection' (Uttar Pradesh Jal Nigam et al., 2017).

During the field campaigns, white foams were observed in Permiya nala and these were entering the Ganga (Appendix A). Probably, these foams originated from the overflow of the drinking water production plant (Arvind Ashish, IIT Kanpur lab assistant, personal communication, February 28 th 2018). In addition, drain n°16 was observed).Before entering the Ganga, this drain flows next to the

Jajmau WWTP. Based on field observations and on a personal communication with Arvind Ashish (IIT Kanpur lab assistant, February 28th 18 2018), this drain partly discharges the sefffluent of the Jajmau WWTP into the Ganga. However, this was denied by Ajay Kanaujza (Jajmau WWTP representative, personal communication, February 22nd 2018). Based on the pollution concentration parameters and both flow parameters the daily load of pollution from each drain into the Ganges was calculated. Based on this daily pollution load data, the Sisamau nala (domestic wastewater) and the drains of the Jajmau industrial area (mainly tannery wastewater) can be identified as the major sources of pollution into the Ganges river along the city of Kanpur (Table 2.4 and 2.5) (Uttar Pradesh Jal Nigam et al., 2017). The wastewater of the 15 reported drains is discharged into the Ganges without treatment (Khwaja et al., 2001; Uttar Pradesh Jal Nigam et al., 2017). The presence of a significant number of unreported, small drains discharging wastewater from Kanpur into the Ganges is highly probable. However, these drains will not contribute as much to Ganges pollution as the Sisamau nala and the drains from the Jajmau industrial area do. Khwaja et al. (2001) investigated the impact of untreated tannery effluent on Ganges river water quality along Kanpur. Increases in BOD, COD, chromium, sulfides, chlorides, TDS, TSS and conductivity, and decreasing pH were observed (Khwaja et al., 2001). However, since only two locations were sampled, i.e., Bithoor (upstream of Kanpur) and a site downstream of Kanpur, the exact sources of pollution could not be identified by this study. In addition, this study provides a physico-chemical characterization of tannery wastewater in Kanpur. Depending on the season and tanning process, Kanpur tannery wastewater can be characterized as follows (Khwaja et al., 2001): 1. BOD: 230±20 to 6200±300 mg/L 2. COD: 980±30 to 2500±1200 mg/L 3. Chromium: below detection limit to 1060±40 mg/L 4. Sulfides: 9±4 to 279±12 mg/L 5. Chlorides: 2060±40 to 13,900±200 mg/L 6. TDS: 12,900±600 to 76,500±1200 mg/L 7. TSS: 480±30 to 16,800±300 mg/L 8. pH: 2.6±0.1 to 8.1±0.1 9. Conductivity: 310 to 2520 µmho/cm Durai & Rajasimman (2011) provide a more recent study on tannery wastewater characteristics. Durai & Rajasimman (2011) confirm the high variability in tannery wastewater characteristics, which depend on the size of the tannery, used chemicals, used amount of water and type of end-product. In general, tannery wastewater is alkaline (pH: 7.5 to 10), highly saline, dark brown, rich in organic substances (high COD- and BOD content) and has a high chromium-, ammonium- and sulfate content (Durai & Rajasimman, 2011)

Wastewater treatment plants of Kanpur The information presented in this sub-chapter was provided by Ajay Kanaujza (Jajmau WWTP representative, personal communication, February 22nd 2018) during a visit to the Jajmau WWTP (Fig. 2.4) on February 22nd 2018. In addition, Heylen (2018) provides a more detailed analysis of the WWTPs in Kanpur. The Jajmau WWTP has in total three wastewater treatment units: (1) 5 MLD, (2) 130 MLD, and (3) 36 MLD. The 130 MLD unit uses activated sludge technology, the other two units use upflow anaerobic sludge blanket (UASB) technology. In theory, the 5 MLD and 130 MLD units only treat domestic wastewater. However, these units also receive variable amounts of tannery wastewater due to illegal discharge in the sewer network. As a result, the treatment efficiency of these units decreases. The 36 MLD unit is referred to as the 'Combined Effluent Treatment Plant' or CETP, since it treats 27 MLD of domestic wastewater and 9 MLD of tannery wastewater. As such, the Jajmau WWTP has a treatment capacity of 9 MLD for tannery wastewater and 162 MLD for domestic wastewater.

Conclusion

The presented MSc study analyzed the impact of Kanpur's urban activity on the water quality and ecology of the Ganges river. The physico-chemical water quality of the Ganges was successfully quantified along Kanpur city during the winter season, i.e., February 2018. Within the scope of the first research objective, i.e., identification and quantification of Kanpur's major pollution sources, the following conclusions can be made: 1. Based on the drain analysis of Uttar Pradesh Jal Nigam et al. (2017) and the physicochemical water quality data of this study, the Sisamau nala, Jajmau industrial tannery zone and the WWTP drain were identified as the major pollution sources into the Ganges along Kanpur. However, due to the proximity of the WWTP drain to the tannery zone, their impacts on the Ganges could not be distinguished. 2. Based on the concentration data of Uttar Pradesh Jal Nigam et al. (2017), the daily pollution loads of the Sisamau nala and the Jajmau industrial tannery zone were quantified. 3. Based on the data provided by Ajay Kanaujza (Jajmau WWTP representative, personal communication, February 22nd 2018), the COD-, BOD- and TSS loads of the Jajmau WWTP effluents were quantified. 4. The Sisamau nala, Jajmau industrial tannery zone and the WWTP drain have a detrimental impact on the DO content of the Ganges. 5. Along Kanpur, COD reaches the most deteriorated OECD water quality class. 6. The Sisamau nala causes significant peaks in BOD5, NH4 + , NO3 - and NO2 - concentrations in the Ganges. Additional peaks in EC, TDS, PO4 3- and SO4 2- can be observed downstream of the Sisamau nala. 7. The wastewater drains of the Jajmau industrial tannery zone and the WWTP drain cause significant peaks in BOD5, SO4 2- , PO4 3- and NH4 + concentrations in the Ganges. In addition, pH, EC and TDS increase throughout the tannery zone and downstream of the WWTP drain. 8. Besides these major wastewater drains, a significant amount of smaller drains are diffusively discharging untreated domestic- and tannery wastewater into the Ganges.

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