Environmental sustainability of grey water footprints in Peshawar Basin: Current and future reduced flow scenarios for Kabul River

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Abstract: Assessing water pollution at basin level is a challenging task. In this study, the environmental sustainability of grey water footprints (WF_{grey}) of Peshawar Basin in Pakistan was analysed. The release of nitrogen (N) and phosphorus (P) from point and non-point sources during the period 1986 to 2015 were studied. Water pollution level (WPL) for normal and 10%-50% future reduced runoff in Kabul River as a result of construction of dams was considered. Methodologies described in Water Footprint Assessment Manual and Grey Water Footprint Accounting Guidelines were followed. Results showed that 30-year annual average of N and P discharges were 24.5×10^3 t/a and 10.9×10^4 t/a respectively. The discharge of N and P from non-point sources contribute 97% and 99% respectively. N related WF_{grey} was 50×10^8 m^3/a and 50×10^9 m^3/a for P. WPL of N was within the sustainable limit for all reduced runoff scenarios while P-related WPL for normal runoff exceeded sustainable limits and was worse in each reduced runoff scenario. This study confirms the deteriorated water quality of Kabul River and the findings may be helpful for future planning and water resource management of the basin.

Keywords: sustainability, grey water footprint, nitrogen, phosphorus, water pollution, Kabul River, Pakistan
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1 Introduction

Water Pollution is a worldwide environmental issues[1]. Fresh water resources have been severely affected by agricultural runoff, sewage and industrial effluents in many regions[2-8]. The release of N and P into surface water constitute an important component of nutrients cycle, however over discharge of these nutrients may lead to eutrophication[9]. Rivers play an important role to assimilate agriculture runoff, industrial and sewage effluent besides water supply and power generation[10]. A large amount of N and P fertilizers are added to soil, in which a very small portion is taken up by plants while the rest enter into water bodies through leaching and runoff[11]. The global annual anthropogenic N and P load from agriculture, domestic and industrial sources are 32.6 and 15 million t/a respectively[11,12]. In developing countries the discharge of N and P will increase by a factor 2.5 to 3.5 respectively till 2050[9].

Like other developing countries Pakistan is also facing severe water scarcity and pollution problem. Water quality of rivers and streams are deteriorated due to direct discharge of untreated effluents into rivers[13]. It has been reported that pollution level in River Ravi has been increased 4-6 times from 1960 due to low flow in river after 'Indus Water Treaty'. River Ravi receives 21 m^3/s of untreated effluents and became the most polluted river in Pakistan[14]. Water quality of Kabul River has also been deteriorated due to lack of wastewater treatment facility. It receives about 1 m^3/sec of industrial effluents directly without prior treatment[15-19]. Pakistan and Afghanistan both share water resources of Kabul River and any reduction in flow will have drastic impact on water quality of river. The Government of Afghanistan has developed a comprehensive future plan for power generation and irrigation on Kabul River[20,21] (See appendix). These hydropower projects will result a significant reduction in volume of water to Peshawar Basin that will adversely affect capacity of Kabul River to assimilate pollutants loads[22].

Earlier studies on Kabul River mainly focused on physico-chemical characteristics of water quality (summarized in Table 1). Some studies analysed heavy metals concentrations in water while others have determined the impacts of water pollution on fish and wheat irrigated with river water[23-46]. However, reports on the capacity of Kabul River to assimilate pollutants load and downstream impacts of future reduced flow on water quality as a result of construction of dams in Afghanistan have not been discovered.

The objectives of this study were (1) To analyse the environmental sustainability of WF_{grey} and WPL in relation to N and P release from artificial fertilizers, animal manure, households and industrial sources during a period of 1986 to 2015 and (2) To determine the likely impacts of future reduced runoff from an increased use of water in Afghanistan. The concept of water footprints has been widely used in assessing environmental sustainability of blue water footprint of industrial parks, urban area and river basins[47-51]. The novelty of this study is that for the first time WPL was assessed for future reduced flow as a result of upstream use of water besides analysing environmental sustainability of WF_{grey} at the basin level.

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Table 1 Water pollution studies on Kabul River in Peshawar Basin in Pakistan

Year	Temp/°C	pH	Cond /μs·cm^{-1}	Alkalinity /mg·L^{-1}	SO_4^{2-} /mg·L^{-1}	DO /mg·L^{-1}	BOD /mg·L^{-1}	COD /mg·L^{-1}	NO_3^- /mg·L^{-1}	PO_4^{3-} /mg·L^{-1}
1982-83	8.75	8.4		284		3.79	0.44	20.81		
1990	19.2	8.07	316							
1994	22.22	7.58	362.98	117.68	44.32	6.43	3.1	81.75	4.91	0.52
1997	25	7.65	265	92	31	6.3	2.6	78	1.26	0.3
1999	15.5	8	290	154.54	115.02	9.48	3.32	47.57	0.51	
2008				159.23	140.61		4.27	122.26	1.64	0.17
2009		7.6	467.56		66.06	6.12			3.2	
2010	23.33	7.55	206.4	123.86	163.99		3.77		1.28	0.11
2011						7.86				
2013		7.6				5.6		116	10.3	
2014	30.12	8.22		232					0.32	
2015	18.44	8.17	212.62		80.94				3.03	0.43
2017		8.08	335.66	148.66	14.4	7.2			0.75	

2 Study area

Peshawar Basin is a sub-basin of Indus River Basin. It extended from 71°15′ to 72°45′ East longitude and from 33°45′ to 34°30′ North latitude in the province of Khyber Pakhtunkhwa, Pakistan (Figure 1)[23]. The basin covers an area of 5623 km^2 with a population of 9.78 million[52]. The last 30 years of land use show that Peshawar Basin consist of 60% agricultural land, 27% pasture, 10% buildup, 1% water bodies and 1% barren land. Kabul River is the main river flowing through Peshawar Basin that originates from Unai Pass of Hindukush Mountains in Afghanistan. It runs approximately 700 km distance from Unai pass up to Indus River. The river flows about 560 km in Afghanistan and 140 km in Pakistan. In Afghanistan, it contributes about 26% of surface water flow[53].

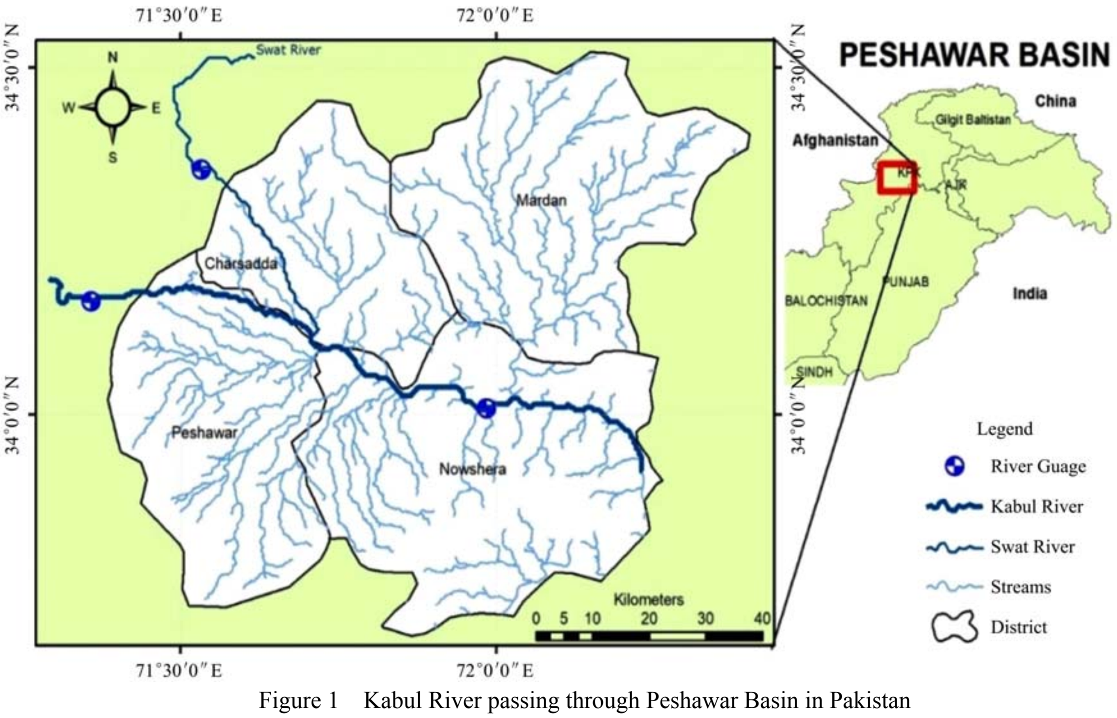


Figure 1 Kabul River passing through Peshawar Basin in Pakistan

3 Materials and methods

3.1 Data description

Artificial fertilizers data for the period of 1986 to 2015 was obtained from Pakistan's National Fertilizer Development Centre (NFDC) annual reports[54]. NFDC annually reports N and P nutrients in the form of urea, calcium ammonium nitrate (CAN), diammonium phosphate (DAP), single and triple superphosphate (SSP) and sulphate of potash (SOP) in the country. The N and P loads from livestock manure were calculated by multiplying livestock population by animal-specific excretion rates[55]. Livestock censuses data of 1986, 1996, and 2006 were converted to annual figures by interpolation while 2007 to 2015 population data was obtained from local livestock department. The slaughtered weights of animals in Pakistan for the years 1980, 1990 and 2000 are shown in Table 2[56,57] and animal excretion rates were taken from Sheldrick et al.[58] Ammonia volatization rates for cattle and poultry (36%), and for buffaloes, sheep and goat (28%) were taken from Bouwman et al.[59] Human population censuses of 1981, 1998 and 2017 were converted into annual population by interpolation[52]. The N and P loads from households and industrial sources were calculated from daily protein intake per capita following Van Drecht et al.[9,11,12] The daily protein intake for Pakistan during the period 1986 to 2015 was taken from

FAOSTAT[60].

Table 2 Slaughtered weight and N and P contents in various livestock categories

Livestock type	Slaughtered weight/kg	Nutrient/kg (per slaughtered weight per year)		Slaughtered weight in Pakistan/kg		
		Nitrogen	Phosphorus	1980	1990	2000
Cattle	250	50	10	126.9	164	190.9
Buffaloes	250	50	10	88.5	117.1	133.1
Horse	250	45	8			
Asses		45	8			
Mules		45	8			
Sheep	15	10	2	10.7	17.4	17
Goats	12	10	2	9.6	15.5	17
Camels	456	50	10	456		
Poultry	2	0.6	0.19	0.7	1	1.1

The intake protein contains 16% of N, about 97% of this intake is excreted while 3% is lost via hair, blood, skin etc.[9,61-64] Since, Peshawar basin has no wastewater treatment plant to remove the N[65], population connected to public sewerage system and removal of N and P through wastewater treatment was presented accordingly. Furthermore, the N load that enter the surface water is only 10% of 97%. The P load from point sources were taken from N intake based on N: P ratio of 10:1. The industrial P load were taken as 15% of the urban household P loads[10,12]. Runoff data (m^3/a) of Kabul River were obtained from Water and Power Development Authority[66]. In the absence of standard setup for surface water in Pakistan regarding maximum concentration (C_{max}) and natural concentration (C_{nat}) for both N and P, the C_{max} of 2.9 mg/L and C_{nat} of 0.4 mg/L for N and C_{max} of 0.02 mg/L and C_{nat} of 0.01 mg/L for P were taken from Mekonnen and Hoekstra[11,12].

3.3 Grey water footprint

WF_{grey} was calculated using Global Water Footprint Assessment Standard and Grey Water Footprint Accounting Guidelines[67,68]. WF_{grey} (m^3) was computed by dividing N and P loads (t/a) to the difference between the maximum acceptable concentration C_{max} and the natural background concentration C_{nat} of N and P[11,12,67,68].

$$WF_{grey} = \frac{L}{(C_{\max} - C_{nat})}$$

where, L is pollution load, t/a; $L=\alpha\times$application of N and P, t/a; α is leaching-runoff fraction; C_{max} is maximum allowable concentration, t/m^3; C_{nat} is natural background concentration, t/m^3.

3.4 Water pollution level

WPL was used for environmental sustainability analysis of WF_{grey}. WPL is the ratio of total WF_{grey} in a basin to the actual runoff (R_{act}) of river. A 100% value of WPL indicate that waste assimilation capacity has been completely consumed and WF_{grey} is unsustainable[67].

$$WPL = \frac{\sum WF_{grey}}{R_{act}} \times 100\%$$

where, R_{act} is actual runoff, m^3/a.

3.5 Reduced runoff scenarios

The 30 years annual average (1986-2015) of WF_{grey} and runoff of Kabul River were taken as reference value. The reference runoff is reduced by 10%, 20%, 30%, 40% and 50% to analyse the effect of flow on WPL for each reduced runoff ($R_{reduced}$) scenario keeping the reference WF_{grey} constant.

4 Results

4.1 Application of N and P fertilizers

The application of N and P fertilizers in Peshawar Basin from 1986-2015 are given in Figure 2. The data revealed that community has been using chemical fertilizers in huge amounts for intensive agricultural activities across the basin. Every passing year witness an apparent increment in application of N and P nutrients. The application of N & P fertilizers show that the water pollution level of N and P in river water is substantially attributed to the use of artificial fertilizers in Peshawar Basin.

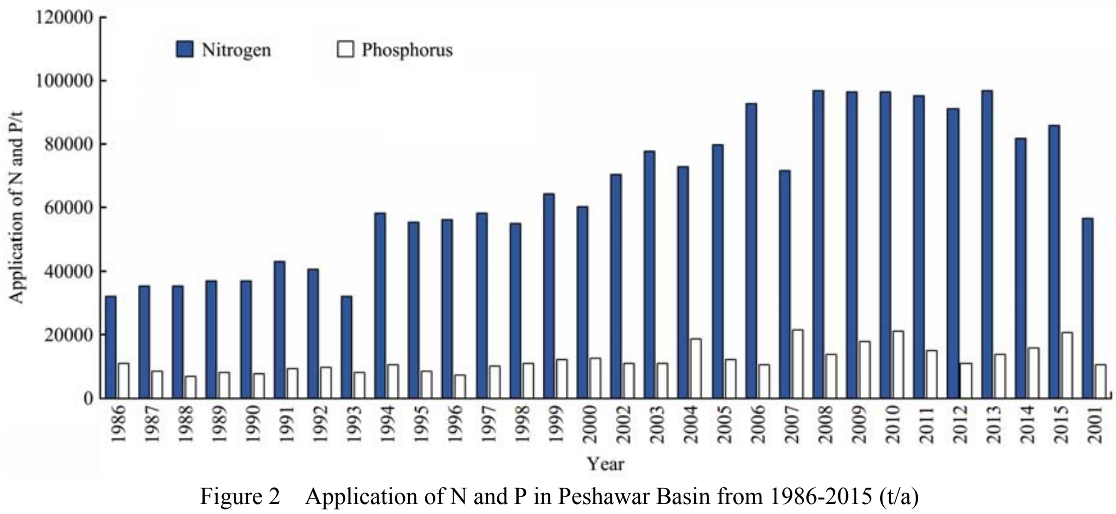


Figure 2 Application of N and P in Peshawar Basin from 1986-2015 (t/a)

4.2 N and P loads from livestock manure

N and P loads from livestock manure were measured by multiplying livestock population by manure production. During 30-years period, average N and P loads from livestock manures in Peshawar Basin have been highly depended on the animal species. For instance, cattle manure contributed 50% to the N input of the basin, buffaloes 19%, goat 16%, equine 8%, sheep 4% and camels 1%. For P load, cattle manures contributed 37%, sheep 28%, buffaloes 14%, goat 12%, equine 5% and camels 1% (Figure 3). Changes in the N and P inputs could be attributed to the innate concentrations of these nutrients in manures as well as excretion rate per livestock.

4.3 WF_{grey} of N and P

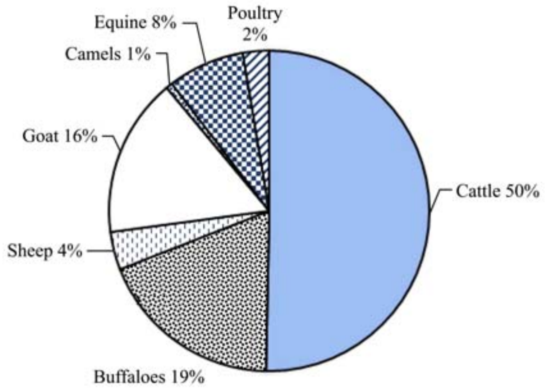
Average of 30-years N-related WF_{grey} in Peshawar Basin showed that artificial fertilizer contributed 61%, livestock manure 36%, household sources 2% and industries 1%. For P-related

WF_{grey}, the contribution from artificial fertilizer, livestock manure and household sources were 50%, 49% and 1%, respectively. The contribution from industrial sources was found as negligible (Figure 4).

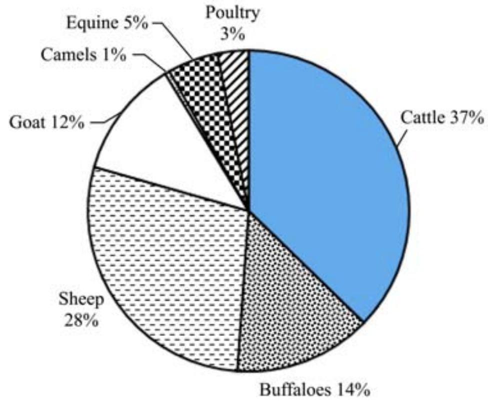
Both N and P-related WF_{grey} in Peshawar Basin were steadily increased over the period of 1986-2015. P-related WF_{grey} exhibited higher values than N-related WF_{grey}. During 1986, the N-related WF_{grey} was less than 30×10^8 m^3/a whereas P-related WF_{grey} was slightly above 40×10^8 m^3/a. However, after 30 years period the average N-related WF_{grey} exceeded the amount of 50×10^8 m^3/a and P-related WF_{grey} over the study period reached a level of 50×10^9 m^3/a (Figure 5).

4.4 WPL of N and P

Environmental sustainability of grey water footprint was analyzed using WPL. WPL for N and P were substantially enhanced during the period of 1986-2015. In the last 15 years, the increase in the water pollution was higher and fluctuated during the subsequent years. The consistent higher values of WPL in the last decade could be associated with the excessive human activities in the form of intensive agriculture, raising of livestock, industrialization and urbanization. The N-related WPL was within the sustainability limit of 100% for each passing year during the study period, whereas P-related WPL has exceeded the sustainability limit (Figure 6).

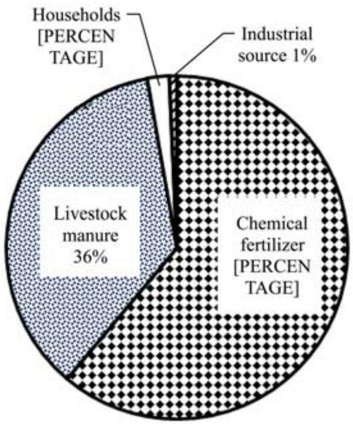


a. Nitrogen (%) contributed by livestock manures

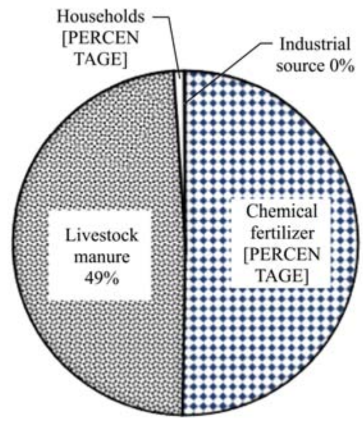


b. Phosphorus (%) contributed by livestock maures

Figure 3 Input of N and P by different livestock in Peshawar Basin (average of 30 years)



a. Nitrogen



b. Phosphorus

Figure 4 **S**ource to WF_{grey} (%) in Peshawar Basin (30 years average)

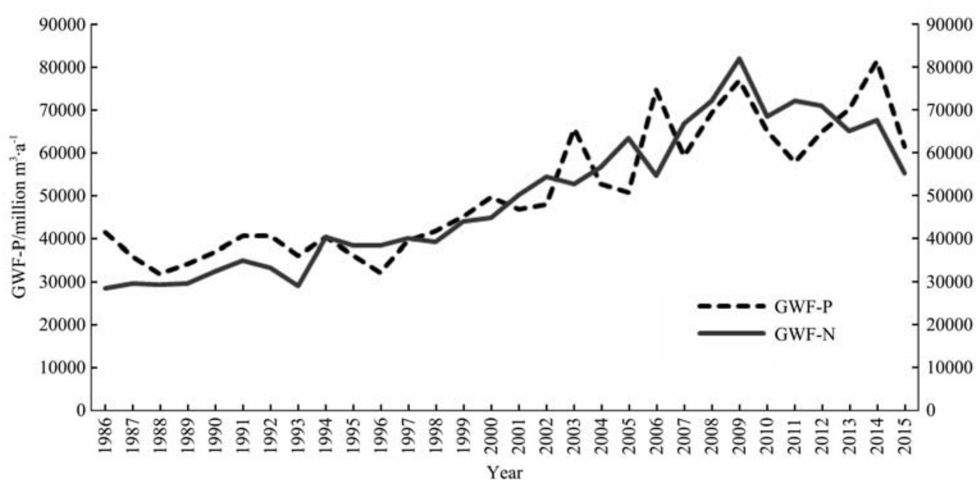


Figure 5 N and P-related WF_{grey} in Peshawar Basin during 1986-2015

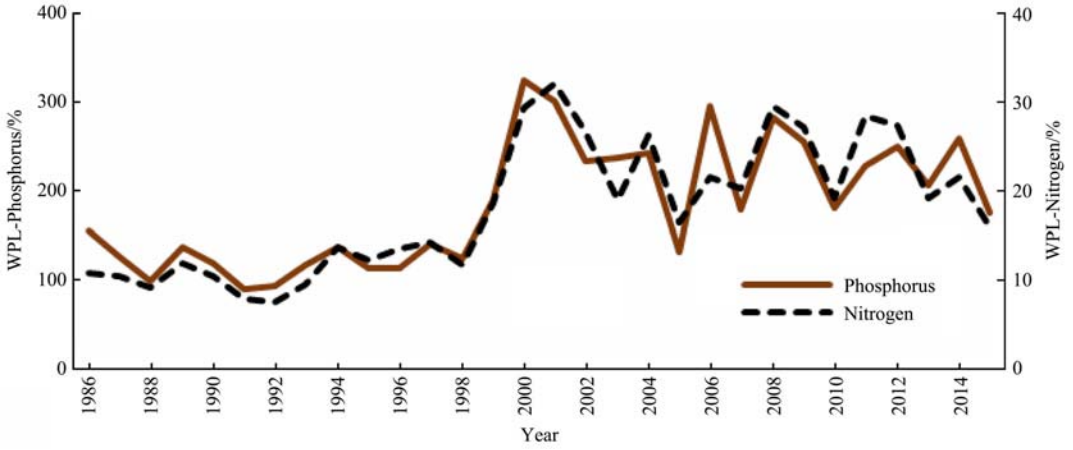


Figure 6 WPL in Kabul River in Peshawar Basin during 1986-2015

4.5 WPL for reduced runoff scenarios

The results of the N and P related WPL for the future reduced runoff scenarios of 10%, 20%, 30%, 40% and 50% are given in Figure 7. N-related WPL for the five simulated runoff scenarios were 19%, 21%, 24%, 28% and 34%, respectively. All these values remained within the sustainability limit of 100%. P associated WPL exceeded the sustainability limit for each scenario. The WPL-P values were calculated in the following pattern 194%, 218%, 249%, 291% and 349% respectively (Figure 7). Since P has exceeded the sustainability limits, decrease in the quantity of water or increase in the magnitude of P release may further exacerbate the quality of water in Kabul River. This situation could be harmful to ecosystem in terms of water quantity and quality after mixing of drainage water, untreated industrial and municipal wastewater with river water.

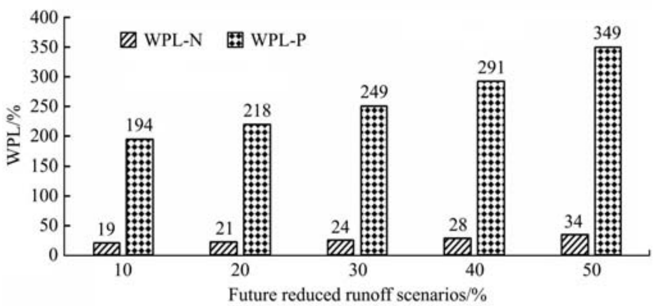


Figure 7 N and P related WPL for five different reduced-runoff scenarios in Peshawar Basin

5 Discussion

WF_{grey} determines the sustainability of water resources. This study investigated WF_{grey} for N and P load originated from different sources in Peshawar Basin during 1986 to 2015. Both N and P-related WF_{grey} were steadily increased during the investigation period. The level of WF_{grey} has been associated with factors like artificial fertilizers, livestock manures, household and industrial sources. WF_{grey} of N and P ascertained that Peshawar basin has adversely affected the river water quality.

Unfortunately, there is no previous research concerning WF_{grey} in Peshawar Basin for comparison. However, according to Mekonnen and Hoekstra[11], N-related WF_{grey} of Pakistan was 288 billion m^3/a in 2002-2010, where 262 billion m^3/a were from agriculture, 23 billion m^3/a from households and 3 billion m^3/a from industries. The Indus river basin has N-related WF_{grey} of 440 billion m^3/a, as agriculture being the main contributor (59%) and households as the second (38%)[11].

Nafees et al[69] reported that 68% of wetlands in Peshawar Basin has been converted to agricultural fields due to low flow in Kabul River. This study showed that high P-related pollution in river over last 30 years lead to eutrophication of wetlands[70] in the basin, and the local community convert these dry lands to agriculture fields that further increases pollution by escalating application of fertilizers. In the absence of any previous published work, this study confirms that environmental pollution has degraded the quality of water in Kabul River. This would render it unsuitable for agriculture or domestic water supply[71].

The reduced runoff scenarios exhibited higher level of N- and P-related WPL and further reduction in volume of river water would certainly aggravate water quality. The proposed hydro projects in Afghanistan would result in reduced water flow to Peshawar Basin. This would adversely affect downstream ecosystems and communities dependent on it[20,21]. Monitoring pollution in Kabul River is an effort for a good water management in Pakistan. Based on the literature review, water in the Kabul River was found to be unsuitable for drinking but fit for the irrigation purpose. The reduced flow in Kabul River would severely affect Peshawar Basin’s current and future water usages for crops and may lead to economic deterioration and health issues.

Since Kabul River is a shared resource of Pakistan and Afghanistan, both countries have the right to use it for their economic up-lift. Factors like climate change, increasing demand for water and concerns for environment would lead to complex disputes between two countries. The issue can be harmoniously resolved through an institutionalized agreement on sharing the Kabul river water equitably between the two riparian states. In Kabul river water treaty, optimal quality and quantity of water must be considered. Governments of both countries should take measures for the protection and conservation of water for sustainable economic and ecological activities such as fisheries, eco-tourism, recreation and watershed management. The deteriorating and depleting water resources of Kabul river system also suggest that the water resources of Kabul River should be safeguarded to avoid future conflicts.

6 Conclusions

It is concluded that both N and P-related WF_{grey} in Peshawar Basin were steadily increased during the last 30 years. In all reduced runoff scenarios the WPL-N value was within sustainability limits whereas WPL-P value has exceeded the sustainability limit. The deteriorating and depleting water resources of Kabul River suggested that the river must be safeguarded to avoid water quality and quantity issues. This study may serve to be a baseline in constituting any treaty to share water resources of Kabul River between Pakistan and Afghanistan.

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