Ecological Modelling 455 (2021) 109654

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Sustainability assessment of agriculture production systems in Pakistan: A provincial-scale energy-based evaluation

Syed Mahboob Shah [a], Gengyuan Liu [a,b,*], Qing Yang [a,e], Marco Casazza [c], Feni Agostinho [a,d], Biagio F. Giannetti [a,d]

[a] State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China
[b] Beijing Engineering Research Center for Watershed Environmental Restoration & Integrated Ecological Regulation, Beijing 100875, China
[c] University of Napoli 'Parthenope', Department of Science and Technology, Centro Direzionale, Isola C4, 80143, Naples, Italy
[d] Paulista University (UNIP), Post-Graduation Program in Production Engineering, Brazil
[e] Key Laboratory for City Environmental Safety and Green Development of the Ministry of Education, Institute of Environmental and Ecological Engineering, Guangdong University of Technology, Guangzhou, 510006, China

ARTICLE INFO

Keywords:
Agricultural production
Agriculture sustainability
Emergy
Pakistan

ABSTRACT

Agriculture production in Pakistan is one of the main economic and social sector. It contributes about 20–25% to the country GDP and provides more than 60% employment opportunities for rural peoples, playing a backbone role in the country economy and food security. However, sustainable production of the agricultural system is very important to address a societal concern for environmental impacts and nutritional value, while maintaining an economically feasible production system for farmers. Therefore, this study used various indicators based on emergy accounting method to analyze the sustainability of the agriculture production systems in Pakistan from 2001 to 2015 in four provinces namely Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan are investigated. The analysis indicates that (1) in all selected provinces the maximum portion among all inputs are purchase non-renewable inputs and purchase renewables input. Among in purchase non-renewable comprise inputs the largest portion are for labors, agriculture machinery and fertilizer inputs, while in purchase renewables comprise inputs the largest share are for water that used during irrigation purposes in all provinces. (2) In Punjab and Sindh, among purchase non-renewable comprise inputs the labor, pesticides and diesel were found decreased, while in Khyber-Pakhtunkhwa and Baluchistan the pesticides, diesel and electricity were found declined. The efficiency of overall output agriculture production in selected provinces are in the order of Punjab > Sindh > Kbyber-Pakhtunkhwa > Baluchistan. The output emergy share of the agriculture production increased by 66% in Punjab, 34% in Sindh, 110% in Khyber-Pakhtunkhwa and 72% in Baluchistan in the study period. (3) The analysis of overall agriculture performance through emergy based indicators indicates that the NRP% (non-renewable portion) ratio for Punjab declined by 12% while for Sindh, Khyber-Pakhtunkhwa and Baluchistan increased by 1%, 8% and 1%, respectively. That is why the EIR (emergy investment ratio) value is lower in Punjab and higher in other selected provinces. (4) The ESI (emergy sustainability index) values were declined for Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan by 18.91%, 16.19%, 35.51% and 11.21% respectively, with average values of 0.51, 0.11, 0.22, and 0.21 indicates increased in Punjab than other provinces. We believe this study provides the policy makers and producers the understanding of the important drivers influencing agricultural system productivity and environmental, social and economic sustainability, and to create more adaptable and responsive management practices and strategies for truly sustainable agricultural production systems in Pakistan.

1. Introduction

Agriculture is considered one of the important sector, providing various relevant commodities, through which food security of the countries is dependent (Gasparatos, 2011). The sustainable management of agriculture production system is very fundamental and

* Corresponding author.
E-mail address: liugengyuan@bnu.edu.cn (G. Liu).

https://doi.org/10.1016/j.ecolmodel.2021.109654
Received 29 November 2019; Received in revised form 7 February 2021; Accepted 12 June 2021

significant. Based on the latest estimation of World Food Programme of Hunger Statistic, about 925 million people live in a state of hunger in the world (Eldakak et al., 2013; Caira and Ferranti, 2016). It is also estimated that another 2000 million humans will be included to this list by 2050. Therefore, sustainable management of agriculture production system is essential for achieving the goal of sustainable development and for providing enough food to humans. Further difficulties arise from some wrong management practices, which negatively affect the long term production ability. Therefore, it is very important to integrate present scientific knowledge with farmers' knowledge for better understanding and improving of sustainable agricultural practices (Harpinder and Sandhu, 2007).

Researchers in sustainable agriculture system trying to understand how to increase agriculture production by using environmental friendly technologies and practices without degrading the environment. The assimilation of ecological and biological processes, such as nitrogen cycling, nutrient cycling, parasitism, soil formation process and predation are among the principles of sustainable agriculture (Pretty, 2008; Wasiak, 2017). The word "sustainability" in the agriculture context currently captures the attention of environmentalists, ecologists, industrialists, scientists, government officials and economists (Campbell and Garmestani, 2012). The comprehensive importance of sustainability in agriculture ecosystem is to fulfill human requirements for food, enhance the environmental sustainability, improve the economic sustainability and promote social sustainability. A well-managed or sustainable agricultural ecosystem should provide abundant services that can be equitable, feasible and suitable (Tanguay et al., 2010). According to the main aim of the Sustainable Development Goals (SDG), sustainable agriculture is ultimately aimed at fulfilling the needs of peoples for a long period of time, without degrading the environment and renewable resources, using a lower amount of non-renewable resources, sustaining and improving both the economic capability and life quality (DeClerck et al., 2016). Therefore, human requirements and agriculture conservation should be balanced for agriculture production at macro scale (Tendall et al., 2015; Bullock et al., 2017; Kazemi et al., 2018). Such an objective needs the implementation of novel production patterns, based on practices that can ensure the agriculture production without damaging the environmental quality (Clark and Tilman, 2017; Gomiero et al., 2011; Qi et al., 2018b).

Especially considering the developing nations like Pakistan, agriculture is a fundamental economic sector, playing a key role in poverty reduction, food security and economic growth (Timer, 2002). In Pakistan, agriculture contributes to about 25% of the whole country GDP (Gross Domestic Product), engaging almost 50% of the country labor force (Pakistan Bureau of Statistics, 2015). Considering a total area of 79.6 Mha, 21.2 Mha is cultivated, out of which 4.21 Mha is irrigated . The irrigation system of Pakistan is the world largest one (Basharat, 2019). Moreover, Pakistan is among the top-producers of wheat, sugarcane, rice, cotton, mango, etc.

Even with such an incredible development, according to World Food Program (WFP), Pakistan is striving with enormous levels of insecurity in food and more than 48% people struggling with food insecurity (United Nations World Food Program, 2009). According to the Pakistan population census 2017, such insecurity is due to the rapid increase in population, having a growth rate of 2.4%, and wasteful usage of water resources. In fact, almost 90% of the existing water resources are used for the agriculture. Conversely, it is estimated that per capita availability of fresh water was 1500 m^3, which is amongst the lowermost in Asian countries. According to the latest estimations, Pakistan will become a water scarce country between 2020 and 2035 (Mekonnen and Hoekstra, 2016). In addition, the country is often hit by several disasters (man--made and natural), such as droughts, floods, landslides and earthquakes, that affect the agricultural development on a huge scale. Pakistan government is currently supporting the development of agriculture, taking various measures to improve the storage and efficient use of water, to provide good-quality crops and low-cost electricity, to reduce the prices of fertilizers and such initiatives will develop the agriculture sector in coming years.

In order to support the development of informed policy actions, this study focuses on a sustainability evaluation of agriculture sector in Pakistan at provincial scale. In particular, the aim of this work is to evaluate the agricultural sustainability through emergy accounting analysis of four provinces of Pakistan during the period 2001–2015.

2. Material and methods

2.1. Study area

For agriculture production system sustainability assessment this study chooses Pakistan more specifically its four provinces such as Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan (as shown in Fig. 1) as study cases. The different climatic, environmental and socio-economic features in each selected province result in a distinct agriculture production system. In Pakistan almost in each province wheat, rice, cotton, sugarcane and maize are considered as the major's crops in terms of its large area, large production, large export. Among all selected provinces, Punjab province is considered as the heart of Pakistan due to its large agriculture areas which accounts for 72.82% followed by Sindh accounts for 14.20%, Khyber-Pakhtunkhwa 8.39% and Baluchistan 4.67% of total agriculture area (GOP, 2015; Zulfiqar and Thapa, 2017). In agriculture sector of Pakistan highest amount of labor force is engage more specifically is one of the main income source of rural peoples living all provinces of Pakistan. The highest percentage of labor force about is 60% in Punjab province followed by 24% in Sindh province, 11% in KPK and 4% in Baluchistan. The synthetic fertilizers such as nitrogen based fertilizers, potash fertilizers and phosphate fertilizers are consumed in Punjab in agriculture production system about 71% followed by 20% consumed in Sindh, 6% in Khyber-Pakhtunkhwa and 4% in Baluchistan province.

2.2. Emergy accounting analysis of agriculture production system

2.2.1. Emergy accounting

The concept of emergy was proposed by the system ecologist H. T. Odum. He defined emergy as "the available energy either in one or in different form involved directly or indirectly through a process to make a product or a service" (Odum 1996; Odum 1988). The emergy value of any resource reveals the amount of available energy supported by nature in supporting any process. The "emergy method" can be used to evaluate the interactions among environmental, economic and social systems, by aiming to attain the sustainability in systems (Brown and Ulgiati, 2004). This method provides the clear assessment techniques such as weighting factors to judge the systems and to remove errors. Professional weighting factor that is use for environmental indicators includes variable knowledge, unclear information and such factors may damage clearly of the analysis and leads wrong ideas (Almeida et al., 2007).

Emergy methodology is based on the thermodynamics principles and environmental evaluation tool deals the economic examination to a biophysical alternative as well as it reflects the reliance of exterior resources, resources yield and usage efficiency, measure the environmental load and calculate the sustainability of a system (Odum, 1996; Ulgiati et al., 1993). For examples, in agriculture ecosystem emergy method analyze and shows the efficiency of agriculture ecosystem through simple energy utilizations. The emergy method also directly and indirectly calculates free environmental services and its role and functions to the economic sector of the human beings (Odum, 1996). The system diagram helps to understand the process and flows of different energies and its functions, helps to assess the sustainability in various ecosystems, offers knowledge about the usage of different types of resources (Almeida et al., 2007; Giannetti et al., 2006). The indices of emergy is used to assess the ecological, societal and economical sustainability of the ecosystem by using the P-S-R framework (pressure

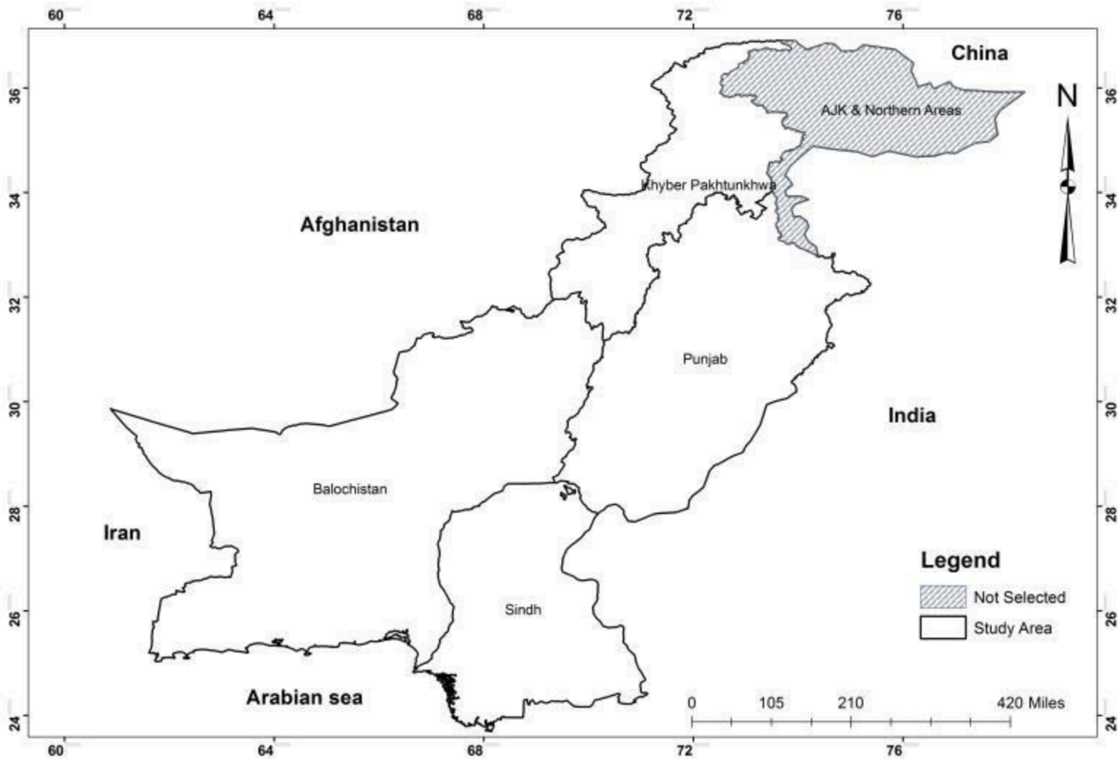

Fig. 1. Maps indicates location of the case study.

state response) (Zhang et al., 2012).

Numerous researcher evaluates the sustainability in agriculture ecosystem by using various types of indicators such as the sustainability of Italian agriculture was calculated by using environmental accounting tools such as emergy (Ulgiati et al., 1993). Assessing the inputs of energy for agriculture production by using environmental accounting methodology (Pimentel,2009). Agriculture grain production in china was evaluated by (Wang et al., 2014), demand of energy in agriculture ecosystem in Iran by using time services evaluation by (Farajian et al., 2018), (Franzese et al., 2013) assessed the efficiency and sustainability in agriculture ecosystem by using emergy based in indicators in Brazil. The average agriculture productions as indicator used by (Hayati et al., 2011; Rasul and Thapa, 2003), social equity as an indicators used by (Rasul and Thapa., 2003) and rural life quality improve as indicator for analyzing social sustainability in agriculture ecosystem by (Van Cauwenbergh et al., 2007). Environmental performance or sustainability was assessed by using indicator of diversification in crops, organic fertilizers, pesticides, synthetic fertalizers and soil erosion (Nambiar et al., 200; Hayati et al., 2011; Van Cauwenbergh et al., 2007; Bosshard, 2000).

Emergy environmental accounting tools that measure the nature effort together with human efforts that generate products and service expressed in sej (solar emergy joules) which means that solar emergy equivalent that require to produce a product or services by means of conversions of energy in ecosystem and economy (Zhao et al., 2005). The energy conversion factors in emergy methodology which transform energy form to sej is called transformities, defined as the amount of solar emergy that involved directly or indirectly to produced one joule of a product (Brown and Ulgiati, 2004).

2.2.2. Data input and unit emergy values

This research is based on the secondary data collected from various government sources, such as Pakistan country agriculture statistic yearbook collected from Pakistan bureau of statistic, Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan statistic yearbooks collected from the country provincial statistical bureau.

The UEVs, collected from published papers, are detailed in Table 1. All the UEVs used in the calculation process of this paper are based on the latest global emergy baseline (GEB), which is fixed at 12.0E+24 seJ/yr (Brown and Ulgiati, 2016).

2.2.3. System diagram representation

As shown in Fig. 2, the system diagram of agriculture production system that indicates key components of involved in the agriculture production system, the flows of various energies and process. All the inputs are divided into four categories, including renewables (R) and purchased renewables resource inputs (F_R), non-renewable (N) and purchased renewables resource inputs (F_N) and the inputs belong in each category along with the output of the agriculture productions (Y)

Table 1
UEVs of agriculture products along with its source.

No	Items	Unit	UEVs	References
Reneweble sources (R)				
1	Sunlight	J	1.00E+00	(Brown and Ulgiati, 2016)
2	Wind	J	7.90E+02	(Brown and Ulgiati, 2016)
3a	Rain chemical potential	J	7.00E+03	(Brown and Ulgiati, 2016)
3b	Rain geopotential	J	1.28E+04	(Brown and Ulgiati, 2016)
4	Geothermal Heat	J	4.90E+03	(Brown and Ulgiati, 2016)
Non-renewable source (N)				
5	Top Soil Loss	J	9.40E+04	(Ghisellini et al., 2014)
Purchased Non-Renewable Sources (F_N)				
6	Fertilizer (N)	g	4.84E+09	(Ghisellini et al., 2014)
7	Fertilizer (P)	g	4.97E+09	(Ghisellini et al., 2014)
8	Fertilizer (K)	g	1.40E+09	(Ghisellini et al., 2014)
9	Pesticides	g	4.58E+09	(Ghisellini et al., 2014)
10	Diesel	J	1.81E+05	(Bastianoni et al., 2009))
11	Agri-Machinery	J	1.33E+10	(Campbell et al., 2005)
12	Electricity	J	2.20E+05	(Sweeney et al., 2009)
13	Labor	J	6.38E+05	(Yang et al., 2018)
Purchased Renewable Sources (F_R)				
14	Irrigating Water		5.77E+05	(Ghisellini et al., 2014)
15	Seeds	J	2.55E+05	(Zhang et al., 2007)

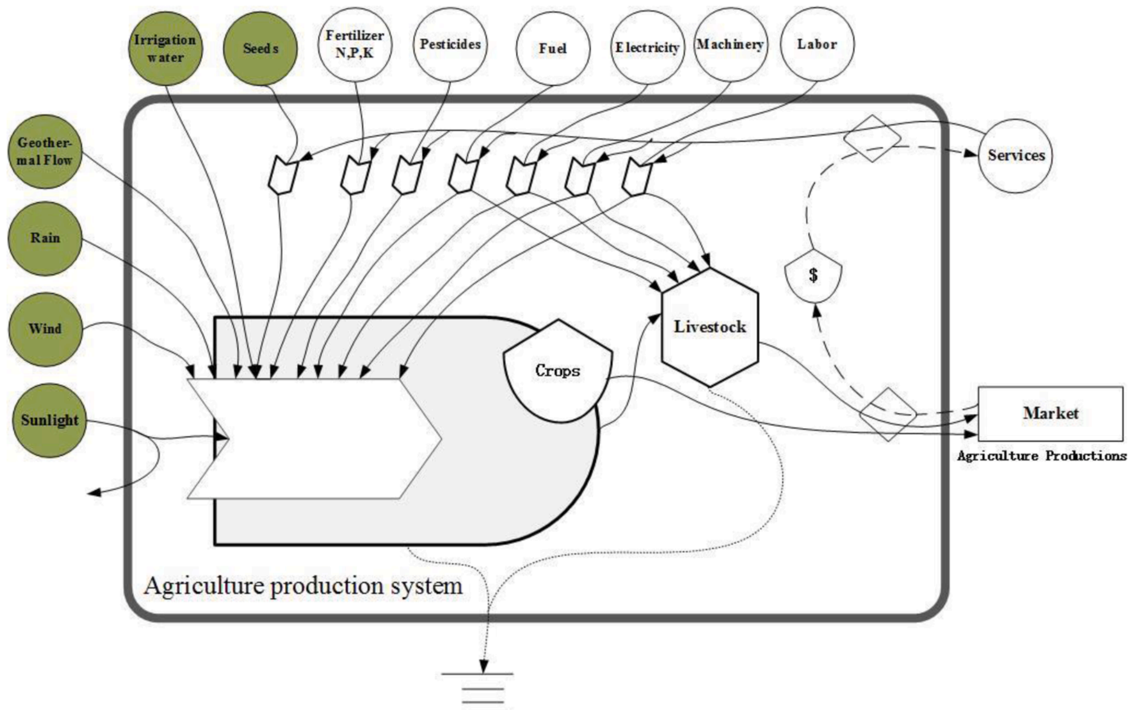

Fig. 2. The emergy diagram of agriculture production system.

Table 1. The water use for irrigation, labor and seed was consider as F_R belong inputs as which was did by previous studies (Zhang et al., 2016; Liu et al., 2019; Ali et al., 2019)

2.3. Emergy based indicators used for evaluation overall performance of agriculture system

2.3.1. Nonrenewable portion (NRP,%)

Agriculture ecosystem requires different types of resources and energy inputs in the form of renewables as well as non-renewables inputs to perform it functions and processes. The sustainable agriculture ecosystem is the one that reduce or less dependent on non-renewables resources because mostly such non-renewables resources harmful for the environment (Pretty, 2008; Liu et al., 2019). Therefore, NRP is used as the indicator to compare the sustainability of the selected agriculture cultivating ecosystems and the equations are as follows:

$$NRP\% = (F_N + N)/U \times 100 \quad (1)$$

where: NRP is the renewable and non-renewables portions in (%); *F_N and N* mean non-renewables and purchased non-renewable emergy used in agriculture production system respectively (sej/yr); U means total emergy used in agriculture production system (sej/yr).

2.3.2. Emergy investment ratio (EIR)

Emergy investment ratio (EIR) is defined as the emergy resources utilized from economy divided by renewable emergy and non-renewable resources utilize (nature). This indicator assesses the investment by which economy made while consuming local resources (Ohnishi et al., 2017). The higher values of this indicator, the higher economic development; while the smaller value, the lower economic cost. Yet too much higher values mean highly dependent on economic system and too small value indicates the system is in underdevelopment.

$$EIR = (F_N + F_R)/(N + R) \quad (2)$$

2.3.3. Emergy yield ratio (EYR)

The EYR indicator quantifies the capacity of production system to consumed the resources both renewable resources and non-renewable resources. The higher values of EYR indicator shows higher productions each invested of emergy (Zhong et al., 2018).

$$EYR = U/(F_N + F_R) \quad (3)$$

where: U means total emergy utilized by the system such as renewables including purchased renewables and non-renewables including purchased non-renewables in (sej/yr); F_N and F_R means the purchased renewable and non-renewable resource use in agriculture production system (sej/yr).

2.3.4. Environmental loading radio (ELR)

The ELR indicator measures the environmental performance such as the environmental pressure through resources utilizations by the system and is the ratio of renewables and non-renewables emergy. The higher value indicates the higher environmental load while lower value indicates the lower environmental load (Zhang et al., 2016).

$$ELR = (F_N + N)/(F_R + R) \quad (4)$$

2.3.5. Environmental sustainability index (ESI)

The ESI indictor is quantify the overall sustainability of the system through considering the efficiency of the system and environmental load and it the ratio EYR divided by ELR. The lower values indicate the lower sustainability of the system and higher values indicates higher sustainability of the system (David et al., 2018):

$$ESI = EYR/ELR \quad (5)$$

3. Results

3.1. Overall status and emergy values of (R, N, F_n and F_R) resources input

Fig. 3 displays the overall emergy values of (R, N, F_N and F_R) inputs for four provinces, Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan for the year 2001 to 2015.

The total average annual emergy input value of Punjab agriculture

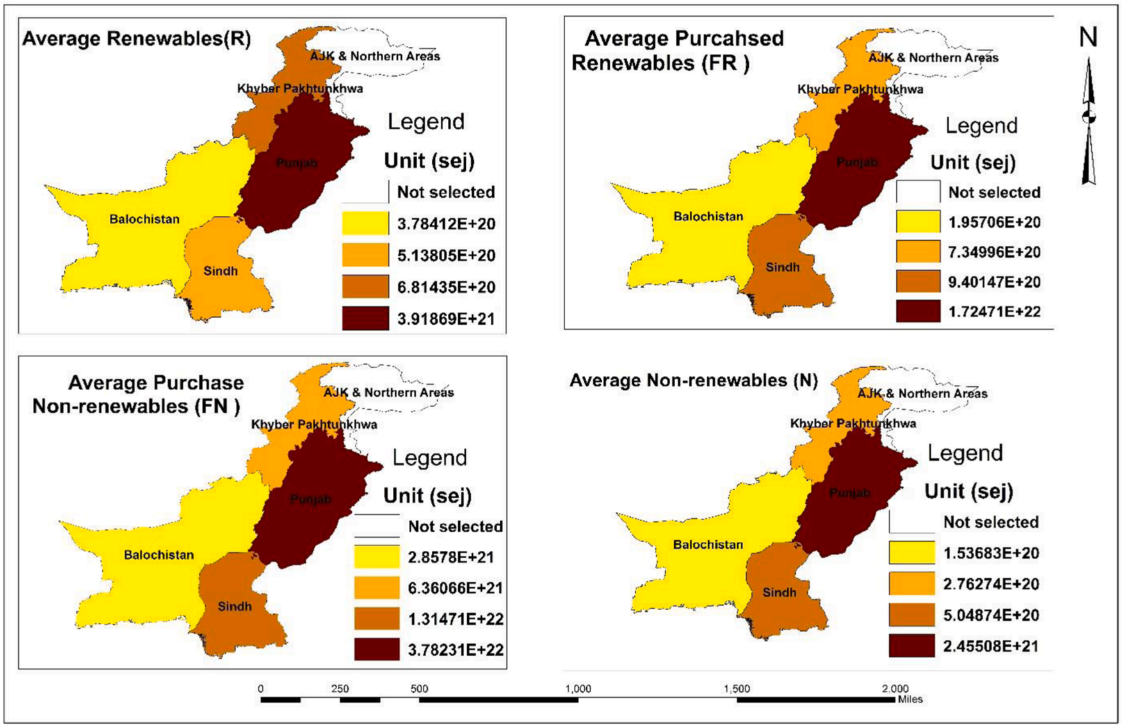

Fig. 3. Maps indicates the average emergy values of R, N, F_N and F_R in selected provinces.

production is 3.65E+21 sej with annual increase rate of 25.31% and an average annual growth rate of 2%. The average values of R, N, F_N, and F_R among all the inputs for Punjab are 2.29E+20 sej, 4.04E+19 sej, 3.01E+21 sej and 6.26E+20 sej respectively, and their average annual portion is 6.40%, 4.06%, 61.44% and 28.14% respectively. Furthermore, the comparative emergy portion of R, N, and F_R were decrease by 8.80%, 8.97% and 5.66% respectively, while that of F_N, the comparative emery portion increase by 4.60%. likewise, the absolute emergy percentage of R, N, F_N, and F_R increase by 57.88%, 2.80%, 36.60% and 7.08% respectively. For Sindh province as shown in Fig. 3, the total average emergy of agriculture production is (1.51E+22 sej) with an annual increase of 36.56%. The average values of R, N, F_N, and F_R among all the inputs are 5.14E+20 sej, 5.05E+20 sej, 1.31E+22 sej and 9.40E+20 sej respectively, and their average annual portion is 3.40%, 3.36%, 87.00% and 6.23% respectively. The combine share of emergy of F_N increase by 2% while that of R, N and F_R the portion were reduce to 20%, 24% and 9% correspondingly. The absolute emergy values increase for R, N, F_N, and F_R by 9%, 4%, 40% and 25% respectively.

For Khyber-Pakhtunkhwa province, the total average emergy value is 8.1E+21 sej with the annual increase rate of 17%. The average values of R, N, F_N, and F_R inputs among all the inputs are 6.81E+20 sej, 2.76E+20 sej, 6.36E+21 sej and 7.35E+20 sej respectively, and their average annual share is 8.49%, 3.44%, 78.88% and 9.17% respectively. The comparative emergy share decrease for R, N and F_R by 25%, 22% and 30% respectively, whereas the absolute emergy share was also decrease by 12%, 8% and 17% respectively. Similarly, the combine and absolute emergy portion for F_N is increase by 9% and 29% respectively. For Baluchistan province, the total average emergy value is 3.586E+21 sej with the annual increase rate of 26%. The average input values of R, N, F_N, and F_R among all the inputs are 3.784E+20 sej, 1.53E+20 sej, 2.85E+21 sej and 1.95E+20 sej respectively, and their average annual percentage are 10.61%, 4.28%, 79.06% and 1.96% respectively. The combine emergy percentage for F_N, and F_R increase by 2% and 27% in the study period respectively, whereas only emergy shares of R, N, F_N and F_R increase by 2%, 26%, 28% and 60% respectively.

3.2. *The status of R and F_r belong inputs*

In more specific details (Fig. 4) shows the comparative portion and the trend of various inputs belong to R inputs composition such as solar, wind, rain and geothermal energy for a selected time period. The total emergy value of R belong inputs were 3.79E+21 sej in 2001 and 4.64E+21 sej in 2015 with an annual growth rate of 23% in Punjab. More specifically the annual average emergy value and percentage share of R belong inputs such as solar, wind, rain and geothermal were 7.36E+20 sej/yr (18.99%), 4.89E+20 sej/yr (12.61%), 2.54E+21 sej/yr (64.61%) and 1.54E+20 sej/yr (3.97%) respectively. The annual emergy of wind, rain and geothermal were increase in the period while except solar energy which was decrease (% change of −6%). The F_R (purchase renewable inputs) comprise inputs and their average annual emergy share for the agriculture production in Punjab, were irrigation water 1.66E+22 sej/yr (96.37%) and seeds 6.30E+20 sej/yr(3.63%). Among these inputs the irrigation water increase the F_R input 3% on average annually.

For Sindh province, the total emergy value of R belong inputs were 5.28E+20 sej in 2001 and 5.74E+20 sej in 2015 with an annual growth rate of 9%. More specifically, among all the inputs composition in the R, the solar inputs comprise the largest portion of (32.66%) with an annual emergy value of 1.64E+20 sej/yr, followed by wind (31.09%) 1.56E+20 sej/yr, rain (29.90%) 1.62E+20 sej/yr and at last geothermal input (6.33%) 3.17E+19 sej/yr. The combine emergy share of solar, wind and geothermal were decrease during the period with a change of 5% each. Whereas for absolute emergy term, shares of all the inputs of R increase in which highest increasing change was found in rain 16%. The F_R comprise inputs and their average annual emergy share was 8.33E+20sej (88.33%) for irrigation water and 1.07E+20sej (11.33%) for seeds. The irrigation water inputs increase the F_R inputs 5% while seed inputs increase it 2.3% annually. Similarly, For Khyber-Pakhtunkhwa province, the total emergy value of R belong inputs were 7.67E+20 sej in 2001 and 6.72E+20 sej in 2015. More specifically, the rain had the biggest portion of (80.76%) with an average annual emergy value of 5.52E+20 sej/yr, followed by solar (12.22%) 8.25E+19 sej/yr. The emergy share of R belongs inputs were found decrease in

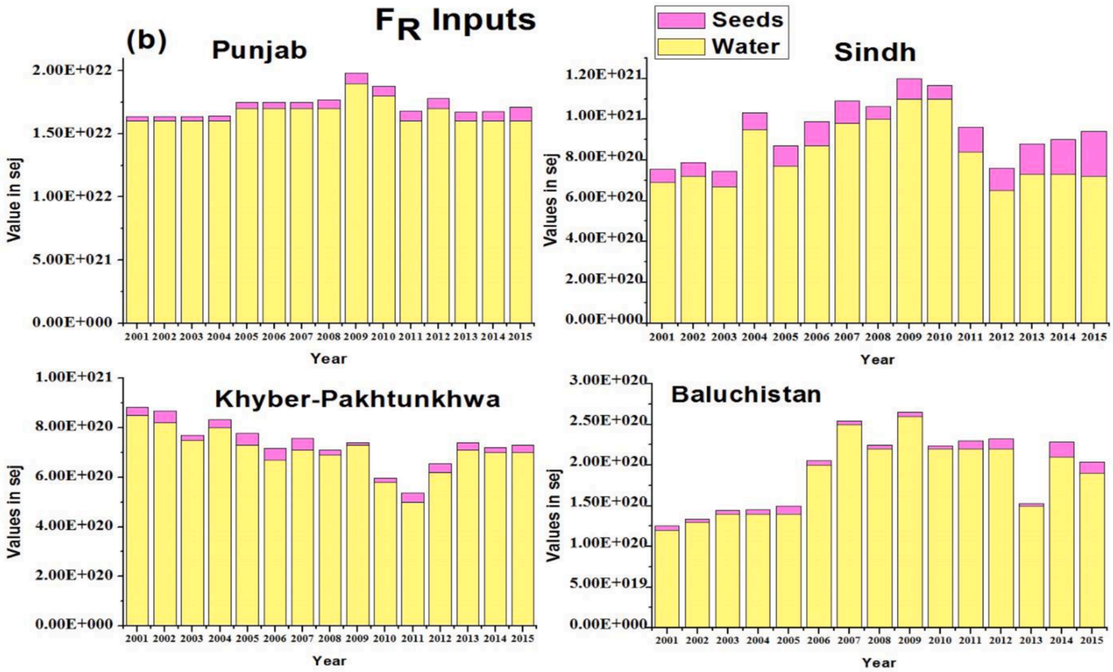

Fig. 4. The trends of R and F_R comprise inputs in Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan province in selected duration.

which the highest change was found in solar energy decreases by 22%. Among the F_R comprise inputs the irrigation water inputs had the maximum average annual emergy share of 7.04E+20 sej/yr (95%) followed by seed 3.12E+19 sej/yr (5%). For Baluchistan province, the total emergy value of R belong inputs were 3.75E+20 sej in 2001 and 3.83E+20 sej in 2015 with an annaual growth rate of 2%. More specifically, among all the input in composition to R the rain got the highest annual average emergy share of 2.26E+20sej/yr (59.63%), followed by wind 8.37E+19 sej/yr (22.08%) and solar 5.18E+19 sej/yr (13.68%). The combine and absolute emergy share of solar and wind increases with a % change of 25%, 23% and 27%, 26% respectively, whereas for the rain and geothermal its share were decrease. Among the FR include inputs the irrigation water shares the maximum portion of (96%) with an annual average emergy value of 1.88E+20 sej/yr followed by seeds inputs (4%) 7.12E+18 sej/yr. The combine emergy share of irrigation water input increase by 54% with the average annual emergy value of 1.88E+20 sej/yr.

3.3. The status of F_n and n comprise inputs

As shown in the (Fig. 5), In the F_N comprise inputs in Punjab province, the emergy share of nitogen fertilizers increase 44% from 2001 to 2015, with an average annual emergy value of 9.56E+21sej/yr, whereas the emergy share of phosphate fertilizers rise to 48% with the average annual emergy value of 2.71E+21 sej/yr. Similarly, the average annual emergy share of potash fertilizers, pesticides, agriculture machines, electricity and agriculture labor grow by 27%, 16%, 73%, 69%, and 34 respectively, except for diesel which decrease by 81% with an average annual emergy value of 7.36E+20 sej/yr. The N input belongs to top soil loss and their emergy share increase by 3% with an average annual value of 2.46E+21 sej/yr. Similarly, in Sindh province, the emergy share of F_N consist inputs such as nitrogen fertilizers, phosphate fertilizers, potash fertilizers, pesticides, agriculture machines, electricity and agriculture labor increase by 53%, 22%, 72%, 16%, 12%, 33% and 34% with the average annual values of 2.93E+21 sej/yr, 7.96E+20 sej/yr, 6.72E+18 sej/yr, 4.41E+19 sej/yr, 3.43E+20 sej/yr, 5.87E+20 sej/yr and 8.28E+21 sej/yr respectively. Whereas the emergy share of diesel is reduced by 78% with an average annual emergy value of 1.44E+20 sej/yr. The emergy value of N belong input was rise by 4% with an average annual emergy value of 5.05E+20 sej/yr.

For Khyber-Pakhtunkhwa, the emergy share of the F_N comprise inputs such as nitrogen fertilizers, phosphate fertilizers, potash fertilizers, pesticides, agriculture machines, electricity and agriculture labor was increase by 20%, 53%, 18%, 16%, 43, 16% and 34% except the diesel which shows change of 75% decrease and their average annual emergy value is 9.29E+19 sej/yr. The emergy value N comprise input was decrease by 8% during the study period with an average emergy value of 2.76E+20 sej/yr. For Baluchistan, the emergy portion of the F_N include inputs such as nitrogen fertilizers, phosphate fertilizers, potash fertilizers, pesticides, agriculture machines and agriculture labor was increase by 10%, 13%, 12%, 16%, 34% and 34% except the diesel and electricity inputs which decrease by 81% and 59% respectively. The value of N belongs input in Baluchistan, was grow by 26% with an average annual emergy value of 1.54E+20 sej/yr.

3.4. Total emergy output of agriculture production

3.4.1. Emergy output for Punjab province

The total average annual emergy value for agriculture production is 2.01E+23 sej/yr and decline annually with a decline rate of 34% are provided in tables (supplementary materials). Among its composition the highest output of average combine emergy percentage of agriculture productions includes maize (31.96%), followed by cotton (19.21%) and for the least emergy percentage production include hemp (0.00006%) followed by tobacco (0.02%) in Punjab. The combine share emergy percentages increase for maize, sugarcane, millet, potato, meat, poultry, eggs and inland fish production while the rest of agriculture production shows decrease change. The minimum change in the rice production declined by 2%; while the maximum change is for hemp production declined by 99%. In absolute emergy share of agriculture productions was increase for all the agriculture product except the barely, beans and vegetables. Such decline was due to the fewer attentions of policy makers and farmers (Ali et al., 2019).

3.4.2. Emergy output for Sindh province

The average annual emergy of the agriculture production of Sindh is

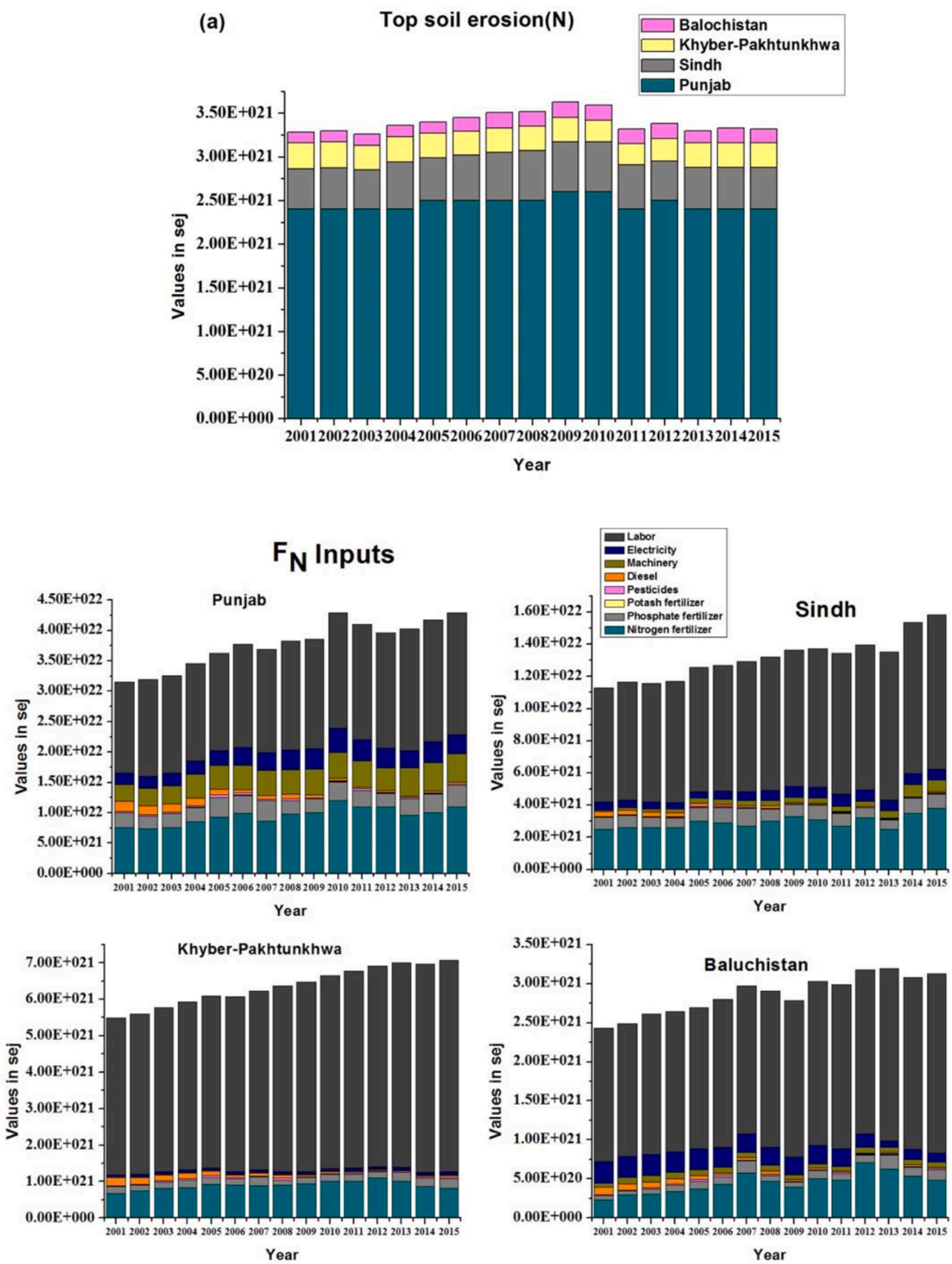

Fig. 5. Trends of N and F_N comprise inputs in selected provinces for year 2001–2015.

4.94E+22 sej/yr in which in terms of relative emergy shares of all the other outputs of agriculture was decrease except cotton (3%), oil cops (9%), poultry (92%) and eggs (40%) are provided in tables (supplementary materials). Among decline relative emergy portion of agriculture productions barley and millet decrease by 65% each. The average highest combine emergy portion for the agriculture outputs are cotton 24.63%, followed by wheat 23.19%, whereas the lowest average emergy share was for potato and tobacco 0.0001% each in Sindh. On the other hand, the annual average emergy share was declined for maize (23%), barely (44%), beans (68%) and potato (37%) while the for the rest the their absolute emergy value was increase.

3.4.3. Emergy output for Khyber-Pakhtunkhwa province

The average annual emergy values for agriculture production for Khyber-Pakhtunkhwa is 7.642E+22 sej/yr are provide in Tables (supplementary materials). Among all agriculture output according to the relative or combine emergy share of some agriculture products increase such as wheat (5%), poultry (99%), eggs (44%) and inland fish production (651%) while all other agriculture products declined. The highest percentage increase change is found in fish production which increase 651% while the lowest increase change is found in wheat production which is 5%. The highest emergy percentage is 22.62% for maize production whereas the lowest emergy percentage 0.00003% for hemp. Move on the specific emergy values which increase for all the agriculture products except for oil crops, barely, millet, beans, hemp, potato and fruit productions which was in state of decline.

3.4.4. Emergy output for Baluchistan province

The average annual emergy value for agriculture production is 2.25E+22 sej/yr of Baluchistan province are provided in tables (supplementary materials). The average combine shares of agriculture products increase such as millet (168%), beans (72%), vegetables (37%), meat (4%), poultry (98%) and eggs (43%) whereas all other agriculture productions declined. The highest production is recorded as 28.87% for fruit production while the lowest is recorded as 0.003% for millet production. The absolute average emergy share of agriculture production increase for all agriculture products except for sugarcane, oil crops, barely and potato which declined by 2%, 49%, 35% and 50% respectively.

3.5. Emergy-based indicators

Fig. 6 and 7 show the trends of selected emergy based indicators for the selected provinces during the selected time period. In Punjab, the situation of EYR ratio was 1.12 in 2001 and 1.11 in 2015 with an annual decrease of 1.06% . Similarly, the ELR ratio was 1.71 in 2001 and 2.09 in the year 2015 and increase with an annual growth rate of 1%. The annual average value of EIR was 8.6 and increase annually with a growth rate of 1%. The ESI, NRP% and N-ESR annual average values was 0.5, 34.34% and 0.07 respectively, and declined as 18.91%, 12.20% and 3.26% respectively. In Sindh province, the average annual value of EYR, ELR, EIR, ESI, NRP%, N-ESR ratio were 1.07, 9.5, 13.9, 0.11, 90.36%, 0.03 respectively. The ELR, EIR and NRP% ratio was increase by 17%, 31% and 1% respectively. Whereas the EYR, ESI and N-ESR ratio was declined by 2%, 16% and 22% respectively.

In Khyber-Pakhtunkhwa province, the annual average value for the selected emergy indicator such as EYR, ELR, EIR, ESI, NRP%, N-ESR ratio are 1.13, 4.78, 7.52, 0.24, 82.32% and 0.09 respectively. In Khyber-Pakhtunkhwa, the emergy ratio such as EYR, ESI and N-ESR decrease by 4%, 36% and 28% respectively, while the ELR, EIR and NRP % increase by 49%, 38% and 8% respectively. Similarly, in Baluchistan province, the average annual value for the selected emergy base indictors are 1.17%, 5.26%, 5.73%, 0.22%, 83.97% and 0.12 for EYR, ELR, EIR, ESI, NRP%, N-ESR ratio respectively. The emergy ratio such as EYR, ESI and N-ESR for Baluchistan were decline by 3%, 11% and 21% respectively, whereas the ELR, EIR and NRP% were rise by 10%, 20% and 1% respectively.

4. Discussion

4.1. Emergy inputs

This study express that among all major inputs the largest emergy share is for F_N inputs followed by F_R inputs for all selected provinces. The average percentage of F_N inputs for Punjab, Sindh, KPK and Baluchistan was 61.44%, 88.82%, 80.88% and 79.59% with an average annual increase of 4%, 2%, 9% and 2% respectively. Such increase was due to the area under cultivation of each province such as Punjab

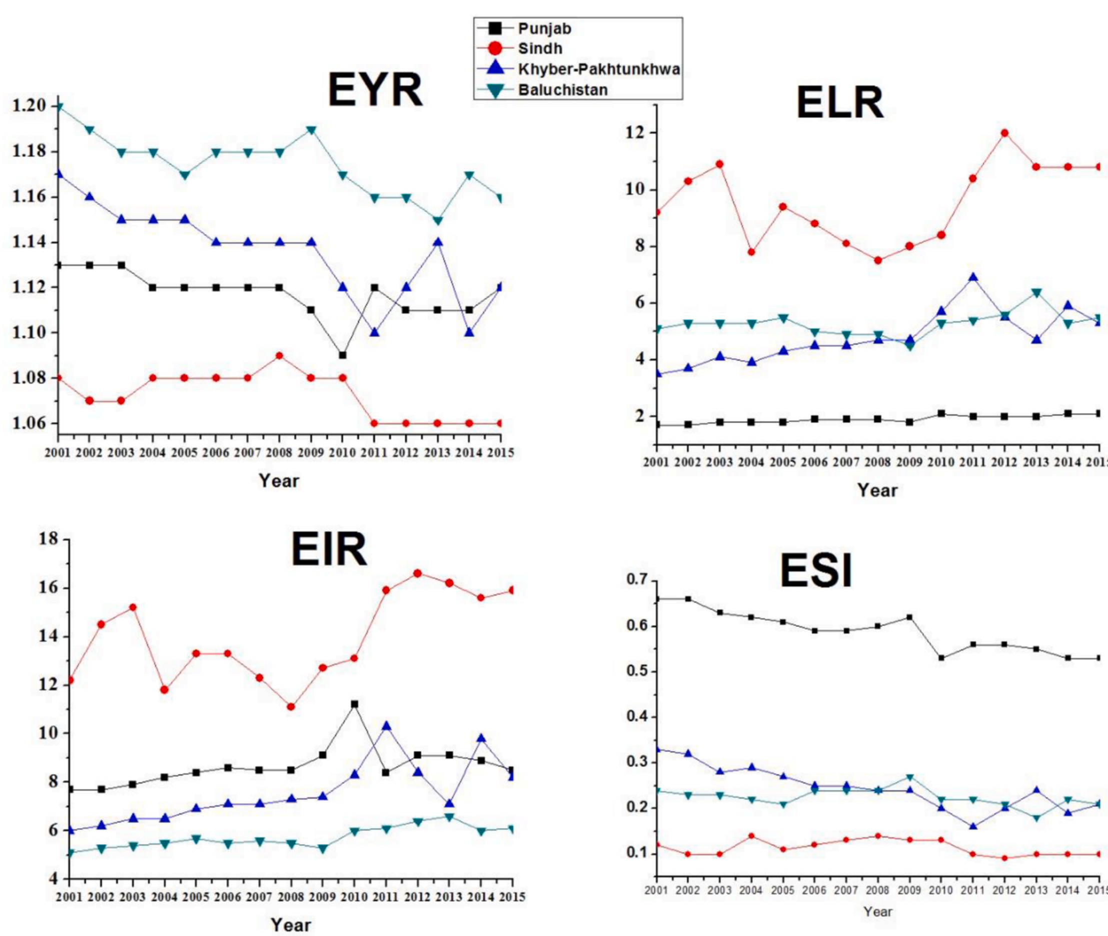

Fig. 6. The results of different emergy based indicators.

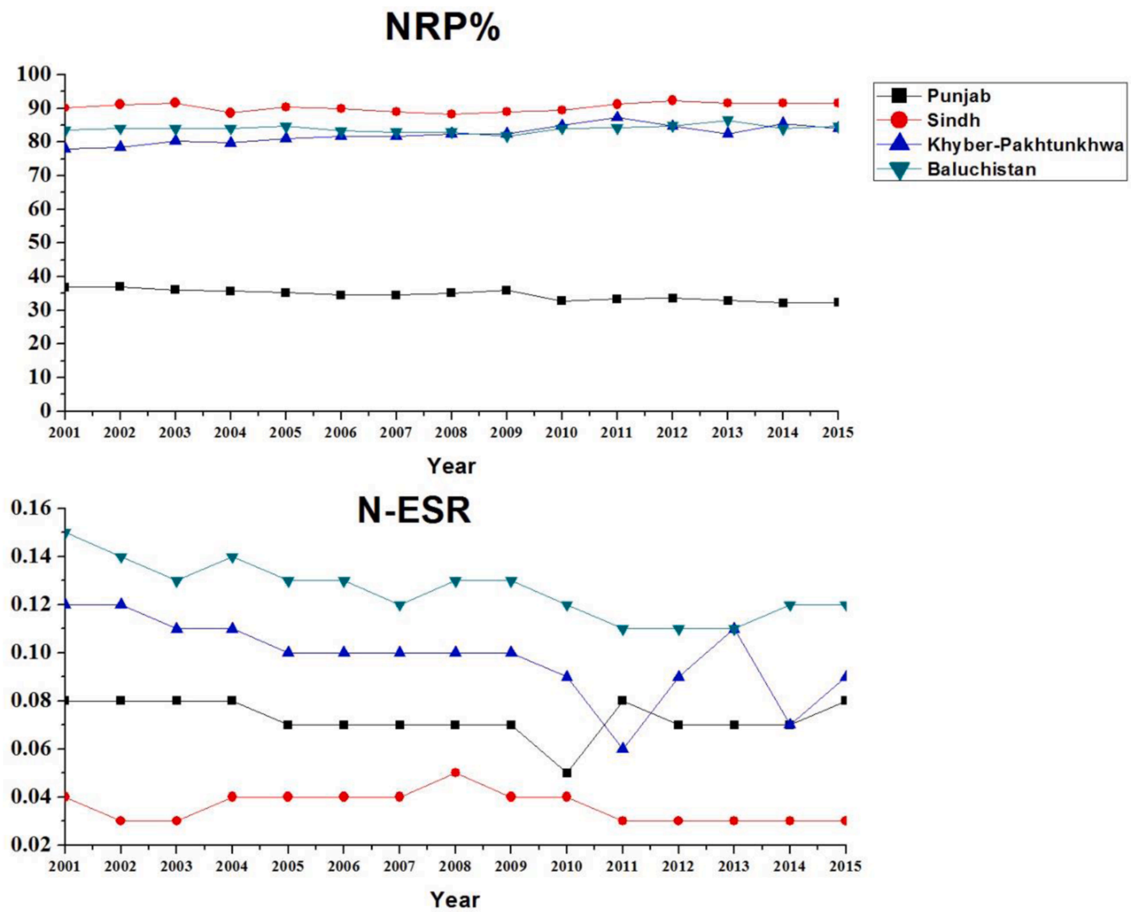

Fig. 7. The results of emergy based indicators.

accounts 73% of arable land, Sindh account 14%, Khyber Pakhtunkhwa account 7% and Baluchistan account 5% (GOP, 2015a). In addition, the agricultural production of Pakistan is mainly from Punjab followed by Sindh that is the reason Pakistan focused its all agricultural modernization measure in Punjab and Sindh followed by Khyber Pakhtunkhwa and Baluchistan (Khan, 2012; GOP, 2015a,b; Zulfiqar and Thapa, 2017). Among all the F_N belong inputs the average percent of consumptions of diesel input for Punjab, Sindh, KPK and Baluchistan decline by 81%, 78%, 75% and 81% respectively such decrease in diesel consumption is due to increasing trends of electrification in agriculture (Ali et al., 2019). Whereas the average annual percent of all other F_N belongs inputs were increase for all provinces especially the labors as agriculture is main source of income for rural population in Pakistan (Rehman, 2012), agriculture machinery for agricultural mechanization (Khan, 2012) followed by fertilizers inputs for maximum agricultural production (Hussain, 2012) . The average annual emergy percent of F_R inputs for Punjab, Sindh, KPK and Baluchistan were 28.14%, 6.23%, 9.17% and 5.41% respectively. The largest emergy percent share from F_R belongs inputs was water consumptions for irrigation purposes which was 96%, 88%, 95% and 96% for Punjab, Sindh, KPK and Baluchistan and their annual average share was increase by 3%, 5%, 0.001% and 55% respectively. Such increasing trends is mainly because, presently around about 90% of Pakistan fresh water is consumed in agricultural purpose and according the estimate the country between 2020 and 2035 will become water scarce (Altaf et al., 2009; Mekonnen and Hoekstra, 2016).

4.2. Emergy outputs

On average, the agriculture productions output in Punjab province such as wheat, rice, cotton, oil-crops, barley, tobacco, beans, hemp, vegetables and fruits are among the highest percent share of 77.32%. Whereas the remaining 22.67% shares are for maize, sugarcane, millet, potato, meat, poultry, egg and inland fish productions. The highest increased was recorded annually for maize production which is about 10 time more increase followed by poultry and sugarcane. This is because the primary focused of farmers to increase the production of cereal crops leads to meet the local demands of food security of a country as mainly the Pakistan main agriculture production is from Punjab and also the soil characteristics of the province which is clay loam and sandy loam attributed for the production of such crops (GOP, 2015a; Khan, 2004). The annual output decrease change was recorded for hemp which was recorded as 99% decrease fallowed by barley and beans such decrease in selected crops was due the poor crop diversification only reliant on cereal crops (Sajjad and Parasad, 2014; Zulfiqar and Thapa, 2017). SIn Sindh province, among all the agriculture production outputs, wheat, cotton, oil-crops, poultry and eggs got the highest share of 63.93% and their annual share increase by 1%, 3%, 9%, 92% and 40% respectively. Whereas the remaining agriculture productions output is around 37% and also their annual percent share decline mainly because growing of cereals crops for country food security and shifting of famers towards cash crops such as cotton etc. (GOP, 2013a). In KPK province, the highest share of outputs is 59.11% for wheat, cotton, meat, poultry, eggs and inland fish production and their annual share also increase while all other agriculture outputs are around 40% and their annual share declined in which hemp decline by 88%. In KPK around 70% of land is use for cultivation of wheat use for household consumption leading the lowest crop diversification also the area is biophysically diverse which lead to not cultivated crops for commercial scale as well as unavailability of agricultural inputs, weak network of transportation and weak transportation and unavailability of water for irrigation purposes (GOP, 2011; GOP, 2015; Khan, 2012). In Baluchistan province, the highest percent shares of agriculture output are 53.27% for cotton, millet, beans, vegetables, meat, poultry and eggs and their annual output share for each product also increase in which millet output was increase maximum of 168% followed by poultry and eggs production. Whereas the rest of outputs was on around 46% and their annual percent share for each outputs was declined in which the maximum declined rate was for potato production which was around 68% followed by oil-crops. Similarly, Baluchistan province is a mountainous area having similar biophysical characteristics of KPK where mostly the area is rain fed. The adverse environmental situation such droughts and less rain in sowing period in past couple years lead decrease in the production of cereal crops such as wheat, maize, rice etc. (GOP, 2010; GOP, 2013a).

4.3. Comparisons among selected provinces and other previous studies

As shown by Table 2, the average value of EYR during the years 2001–2015 for Punjab, Sindh, KPK and Baluchistan are 1.11, 1.07, 1.13 and 1.17 respectively which are almost the same as this indicator shows the production contributions to the economic sector of the country/regions (David et al., 2018). The comparison with other studies were based on the similar application of emergy based indicators and same agriculture inputs classification such as R, N, F_R and F_N. When comparing with previous studies evaluates by various researchers for different countries and regions almost greater than the selected regions such as 1.43 for India for the 2002–2012 (Ali et al., 2019), 1.34 average value for Hainan, China (Liu et al., 2019), 1.16 for Campania, Italy for the year 2010 (Ghisellini et al., 2014). The average value of ELR indicator for the year 2001–2015 for the Punjab, Sindh, KPK and Baluchistan are 1.9, 9.55, 4.78 and 5.26 respectively. It shows that Punjab province is under the minimum environmental pressure and Sindh province is under the maximum environmental pressure from the non-renewable resource exploitation (Liu et al., 2019). When comparing with previous studies of different regions the highest value of ELR is 32.65 in Luancheng county, China due the maximum usage of non-renewable resources (Ma et al., 2015) and 10.43 in Italy in 1989 (Ulgiati et al., 1993) whereas in other regions the ELR indicator values was somehow similar level to this study such as 8.345 ELR value in Ansai, Shaanxi, China for corn-soybean crop rotation (Liu et al., 2019). The value of EIR indicator for Punjab, Sindh, KPK and Baluchistan are 8.65, 13.99, 7.52 and 5.73 respectively. When comparing the EIR indicator value of this with other previous studies for different regions such as 13.1 for Denmark (Rydberg and Haden, 2006), 24.7 for India (Ali et al., 2019), which shows that the agriculture productions of this study was well in the market due to their lower economic cost (Ma et al., 2015). The average value of ESI indicator for the year 2001–2015 for Punjab, Sindh, KPK and Baluchistan are 0.59, 0.11, 0.24 and 0.22 respectively, indicating almost similar when comparing with previous studies of different regions except Yanchi, China (8.55) (Wang et al., 2014) and Jiangsu, China (1.11) (Liu and Li, 2005) as higher values of this indicators indicates the higher sustainability (Ghisellini et al., 2014; Liu et al., 2019). The average NRP% indicator value of Punjab, Sindh, KPK and Baluchistan are 34.54%, 90.36%, 82.32% and 83.97% respectively, showing that Punjab Province is more sustainable and Sindh is unsustainable, as sustainable agriculture supports less use/dependent on non-renewable resources (Liu et al., 2019).

4.4. Agriculture challenges and policy implications

Agriculture sector in Pakistan is one of the main income source for rural peoples and also plays an important role in the country economy. Agriculture depends upon humans' inputs (mainly purchased renewables and non-renewable inputs) to properly functions and provide the agriculture products (Swinton et al., 2007; Zhang et al., 2016). Among such inputs in the selected provinces i.e. Punjab, Sindh, KPK and Baluchistan the average fertilizers usage was found to be 32%, 28%, 17% and 18% respectively, which shows an increasing trends of usage during the selected years. On one hand their excessive usage produces more agriculture production but on the other hand it degrades land and water resources which is reflected in case of Pakistan where such excessive usage of synthetic fertilizers environmental related problems and effects sustainability of the agriculture production system (Zulfiqar and Thapa, 2017). Agriculture machinery increases by 27% in Punjab and almost increase two fold in Sindh province. Whereas, in KPK and Baluchistan provinces the agriculture machinery share are 2% each which has

Table 2
Emergy indicators values of agriculture production system in different regions.

Countries/regions	Year	Emergy based Indicators						References
		EYR	ELR	EIR	ESI	NRP%	N-ESR	
Punjab	2001–15	1.11	1.9	8.65	0.59	34.54%	0.071	This study
Sindh	2001–16	1.07	9.55	13.99	0.11	90.36%	0.03	This study
KPK	2001–17	1.13	4.78	7.52	0.24	82.32%	0.09	This study
Baluchistan	2001–18	1.17	5.26	5.73	0.22	83.97%	0.12	This study
Yanchi	2001	–	0.45	0.35	8.55	–	–	Wang et al., 2014
Jiangsu	2001	–	3.75	3.52	1.11	–	–	Liu and Li, 2005
China	2000	–	2.72	1.11	0.77	–	–	Chen et al., 2006
Switzerland	1996	–	4.5	4.1	0.28	–	–	Pillet et al., 2001
Italy	1989	–	10.43	8.52	0.11	–	–	Ulgiati et al., 1993
Denmark	1999	–	0.56	13.1	1.92	–	–	Rydberg and Haden, 2006
Japan	2005	–	1.26	11.3	0.87	–	–	Gasparatos, 2011
Pakistan	2002–11	0.46	4.99	28.87	0.11	–	–	Ali et al., 2019
India	2002–12	1.43	3.32	24.7	0.43	–	–	Ali et al., 2019
China	2010	1.68	2.1	7.77	0.8	–	–	Zhang et al., 2016
Beijing	2015	1.23	5.76	–	0.22	–	–	Liu et al., 2019
Tianjin	2015	1.18	7.18	–	0.17	–	–	Liu et al., 2019
Hebei	2015	1.18	7.29	–	0.16	–	–	Liu et al., 2019
Shaanxi	2015	1.27	4.7	–	0.28	–	–	Liu et al., 2019
Inner Mangolia	2015	1.24	5.7	–	0.22	–	–	Liu et al., 2019
Shanghai	2015	1.28	4.27	–	0.3	–	–	Liu et al., 2019
Henan	2015	1.24	5.25	–	0.24	–	–	Liu et al., 2019
Hainan	2015	1.34	3.37	–	0.41	–	–	Liu et al., 2019
Luancheng	2008	1.22	32.65	6.2	0.04	–	0.03	Ma et al., 2015
Emilia Romagna, Italy	2010	1.15	7.05	6.83	0.16	–	–	Ghisellini et al., 2014
Campania, Italy	2010	1.16	6.08	6.08	0.16	–	–	Ghisellini et al., 2014
Ansai, Shaanxi, China	2013	1.166	8.345	–	0.14	89.30%	–	Liu et al., 2019

Note: (-) means data not available.

slightly increase over the selected periods. All these machinery was just limited to the tractors with cultivators in Pakistan which sometime are not present during a specific time of cultivation for poor farmers because of their unaffordable prices and lack of such proper agriculture technologies negatively affects agriculture productions (Devendra et al., 2008; Tewari et al., 2012). The pesticides usage in all selected provinces decrease due to the awareness in farmers as previously it was due to the farmer's wasteful usage (Ali et al., 2019). The water use for irrigations purposes in Punjab, Sindh, KPK and Baluchistan among all inputs are 30%, 5%, 9% and 4% respectively. In Pakistan, for agriculture purposes fresh water is used but actually the water is one of the scarce resources and according to the experts the country will be water scarce in future if significant conservation and protection measures were not established (Altaf et al., 2009; Ali et al., 2019). In addition, the country did not have modern ways irrigation resulting maximum quantity of water loss mainly due to fading and leaching (Azam and Shafiq, 2017). Another issue in Pakistan is the salinity mainly due to excessive usage of ground water for agriculture purposes especially in Sindh and Baluchistan provinces (Memon and Thapa, 2010). Pakistan ranks 8th in term of salinity affected countries (FAO, 2006). Along with salinity areas Pakistan also faces natural disasters such as drought in Baluchistan and floods during monsoon season which mostly destroy the agriculture crops thereby causing damages to the agriculture productions and also increase economic cost (Zulfiqar and Thapa, 2017; GOP, 2015; Shah et al., 2019). In Pakistan, 2010 the most devastating floods in the history of Pakistan, destroy billion acres of arable land and agricultural loss of 2.9 billion (Azam and Shafiq, 2017). The electricity usage increase and diesel usage decrease during the year which as due to the unaffordable price of diesel and also due to the decrease of electricity consumptions prices for farmers by government. Weak infrastructure such as lack of storage facilities and insufficient transportation facilities is another problem faced by Pakistan which create agriculture growth disturbance and also create difficulties for farmer's to transport the agriculture products to markets (United Nations Development Program, 2003).

In Pakistan, various projects were initiated by the new government (federal and provincial government) including five-year national plan for enhancing, conservation, development of agriculture, water sectors and reduced poverty (GOP, 2015). The new government in Pakistan, initiated 13 agriculture and water developmental projects that will increase the yield of major crops for export to reduce the food security in a country and also to construct the water dams (both small and large) for electricity as well as to conserve and store the water for irrigation, flood control and drought related emergency disaster (The express tribune, 2019). A project titled "Prime minister agriculture package" was also initiated to support the small farmers, through providing direct money soft loan for enhancing and prosper the life of small farmers. Under such projects the various agriculture facilities will be provided for the farmers such as better quality of seeds, cheaper electricity for tube wells, LNG (liquefied natural gas) for fertilizers companies and many more to achieve the goals of agriculture productions per hectare and minimize the usage of minimum agriculture inputs (GOP, 2015). Several other projects related to agriculture are under progress with the collaborations of Chinese government to bring the poor people out of poverty and also to attain the goals of food security (DAWN, 2017; Ali et al., 2019). Along with such projects educational related projects will also to be need to develop the skill, knowledge of farmers regarding sustainability (Ali et al., 2018). Besides it will reduce the agriculture related issues in the country, enhances the agriculture productions, reduced poverty through providing jobs opportunities for rural people, and will help in food security through achieving higher amount of yields

5. Conclusion

In Pakistan, agriculture is considered the backbone of the country's economy and provides more than 60% of employment opportunities for rural peoples. In this study, we evaluated the sustainability of the agriculture production system in four provinces of Pakistan including Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan through emergy accounting analysis from the period of 2001 to 2015. The main finding of the study was, in all provinces, the maximum portion among all inputs were F_N (purchase non-renewable inputs) and F_R (purchase renewables input). Among in F_N comprise inputs the largest portion was for labors, agriculture machinery and fertilizer inputs while in F_R comprise inputs the largest share was for water use for irrigation purposes in all provinces. In Punjab and Sindh, among F_N comprise inputs the labor, pesticides and diesel were found decreased while in Khyber-Pakhtunkhwa and Baluchistan the pesticides, diesel and electricity were found to decline. This indicates that in a selected time period farmer's awareness leads to the reduction of the use of pesticides, the decline of labor indicates a lack of proper facilities for farmers to get efficient agriculture production, diesel dependency leads due to the unavailability of facilities of electricity in regions. The agriculture performance through emergy based indicators in which the NRP% ratio for Punjab was declined by 12% while for Sindh, Khyber-Pakhtunkhwa and Baluchistan it seems to increase by 1%, 8% and 1% respectively that's why the EIR values were lower in Punjab while it was higher in other selected provinces. The ESI values were a decline for Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan by 18.91%, 16.19%, 35.51% and 11.21% respectively with an average value of 0.51, 0.11, 0.22, and 0.21 respectively indicates an increase in Punjab than other provinces. This study was basically based on the secondary data collected from various governmental reports, Statistical yearbooks for each province, agriculture statistics and various other reports. All the calculation was based on such data and specific UEVs was collected from various literatures (which was the limitation of the study) to calculate the averages emergy values of specific agriculture products. Based on such emergy values the overall performance including sustainability, environmental load etc. was evaluated in each province through emergy based indicators in a selected time period. As the emergy methods assess the overall efficiency and sustainability of agriculture productions system by means of resources usage, contribution of nature and human, evaluates the cost of environment and helps the policy makers to find the important role of ecosystem on agriculture production system. Therefore, this study will provide resource utilization in agriculture that will help for the policy makers and government agencies on their ongoing agriculture related challenges and projects related to improve the efficiency of the agriculture production systems, poverty reduction (providing employment in agriculture) and food security (increase the production efficiency of agriculture).

CRediT authorship contribution statement

Syed Mahboob Shah: Methodology, Validation, Writing - original draft. **Gengyuan Liu:** Supervision, Conceptualization, Project administration, Writing - original draft, Writing - review & editing. **Qing Yang:** Data curation, Investigation. **Marco Casazza:** Data curation, Investigation. **Feni Agostinho:** Data curation, Investigation. **Biagio F. Giannetti:** Data curation, Investigation.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (No. 52070021) and the 111 Project (No. B17005).

References

Ali, M., Marvuglia, A., Geng, Y., Chaudhry, N., Khokhar, S., 2018. Emergy based carbon footprinting of household solid waste management scenarios in Pakistan. Resour. Conserv. Recycl. 131, 283–296.

Ali, M., Marvuglia, A., Geng, Y., Robins, D., Pan, H., Song, X., Sun, H., 2019. Accounting emergy-based sustainability of crops production in India and Pakistan over first decade of the 21st century. J. Clean Prod. 207, 111–122.

Almeida, C.M.V.B., Barrella, F.A., Giannetti, B.F., 2007. Emergetic ternary diagrams: five examples for application in environmental accounting for decision-making. J. Clean Prod. 15 (1), 63–74.

Altaf, S., Kugelman, M., Hathaway, R.M., 2009. Running On Empty: Pakistan's Water Crisis. www.wilsoncenter.org/sites/default/files/ASIA_090422_Running%20on%20Empty_web.pdf [accessed: …].

Azam, A., Shafiq, M., 2017. Agriculture in Pakistan and its impacts on economy. A review. Inter. J. Adv. Sci. Technol 103, 47.

Bastianoni, S., Campbell, D., Ridolfi, R., Pulselli, F., 2009. The solar transformity of petroleum fuels. Ecol. Model. 220 (1), 40–50.

Basharat, M., 2019. Water Managementin the Indus Basin: challenges and oppertunities. Indus River Basin. Elesvier, pp. 375–388.

Bosshard, A., 2000. A methodology and terminology of sustainability assessment and its perspectives for rural planning. Agric. Ecosyst. Environ. 77 (1), 29–41.

Brown, M.T., Ulgiati, S., 2004. Energy quality, emergy, and transformity: HT Odum's contributions to quantifying and understanding systems. Ecol. Modell. 178 (1–2), 201–213.

Brown, M.T., Ulgiati, S., 2016. Emergy assessment of global renewable sources. Ecol. Model. 339, 148–156.

Bullock, J., Dhanjal-Adams, K., Milne, A., Oliver, T., Todman, L., Whitmore, A., Pywell, R., 2017. Resilience and food security: rethinking an ecological concept. J. Ecol. 105, 880–884.

Caira, S., Ferranti, P., 2016. Innovation For Sustainable Agriculture and Food Production. ??? (incomplete reference).

Campbell, D.E., Brandt-Williams, S.L., Meisch, M.E.A., 2005. Environmental Accounting Using Emergy: evaluation of the State of West Virginia. EPA/600/R-02/011. USEPA. Office of Research and Development, Washington, DC, p. 116.

Campbell, D.E., Garmestani, A.S., 2012. An energy systems view of sustainability: emergy evaluation of the San Luis Basin, Colorado. J. Environ. Manage. 95 (1), 72–97.

Chen, G.Q., Jiang, M.M., Chen, B., Yang, Z.F., Lin, C., 2006. Emergy analysis of Chinese agriculture. Agric. Ecosyst. Environ. 115, 161–173.

Clark, M., Tilman, D., 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency and food choice. Environ. Res. Lett. 12 (6), 1–11.

David, L.H.C., Pinho, S.M., Garcia, F, 2018. Improving the sustainability of tilapia cage farming in Brazil: an emergy approach. J. Clean Prod. 201, 1012–1018.

DAWN, 2017. Exclusive: CPEC Master Plan Revealed. Online: www.dawn.com/news/1333101 [accessed: ….].

DeClerck, F.A.J., Jones, S.K., Attwood, S., Bossio, D., Girvetz, E., Chaplin-Kramer, B., Zhang, W, 2016. Agricultural ecosystems and their services: the vanguard of sustainability? Curr. Opin. Environ. Sustain. 23, 92–99.

Devendra, C.B., Ganesh, C.B., 2008. Energy demand forecast for mechanized agriculture in rural India. Energy Policy 36, 2628–2636.

Eldakak, M., Milad, S.I.M., Nawar, A.I., Rohila, J.S., 2013. Proteomics: a biotechnology tool for crop improvement. Front. Plant Sci. 4–35.

FAO (Food and Agricultural Organization of the United Nations), 2006. TerraSTAT Database.

Farajian, L., Moghaddasi, R., Hosseini, S., 2018. Agricultural energy demand modeling in Iran: approaching to a more sustainable situation. Energy Rep 4, 260–265.

Franzese, P.P., Cavalett, O., H€ ayha, T., D'Angelo, S., 2013. Integrated environmental € assessment of agricultural and farming production systems in the Toledo river basin (Brazil). In: Published By the United Nations Educational, Scientific and Cultural Organization (UNESCO), vol. 71, 978-92-3-001138-3.

Gasparatos, A., 2011. Resource consumption in Japanese agriculture and its link to food security. Energy Pol. 39 (3), 1101–1112.

Ghisellini, P., Zucaro, A., Viglia, S., Ulgiati, S., 2014. Monitoring and evaluating the sustainability of Italian agricultural system. An emergy decomposition analysis. Ecol. Model. 271 (Suppl. C), 132–148.

Giannetti, B.F., Barrella, F.A., Almeida, C.M.V.B., 2006. A combined tool for environmental scientists and decision makers: ternary diagrams and emergy accounting. J. Clean Prod. 14, 201–210.

Gomiero, T., Pimentel, D., Paoletti, M.G., 2011. Is there a need for a more sustainable agriculture? Crit. Rev. Plant Sci. 30 (1–2), 6–23.

GOP, 2010a. Agricultural Census 2010-11. Agricultural Census Organization, Statistics Division. Government of Pakistan.

GOP, 2011a. Agricultural Statistics of Pakistan 2010-11. Ministry of Food and Agriculture (Economic Wing), Finance Division. Government of Pakistan, Islamabad.

GOP, 2013a. Agricultural Statistics of Pakistan 2012-13. Ministry of Food and Agriculture (Economic wing), Finance Division. Government of Pakistan, Islamabad.

GOP, 2015a. Agricultural Statistics of Pakistan 2014-15. Ministry of Food and Agriculture (Economic Wing), Finance Division. Government of Pakistan, Islamabad.

GOP, 2015b. Agricultural Statistics of Pakistan 2014-15. Ministry of Food and Agriculture (Economic Wing), Finance Division. Government of Pakistan, Islamabad.

Sandhu, Harpinder S., W., S.D., Cullen, Ross, 2007. From poachers to gamekeepers: perceptions of farmers towards ecosystem services on arable farmland. Int. J. Agric. Sustainability 5, 39–50.

Hayati, D., Ranjbar, Z., Karami, E., 2011. Measuring agricultural sustainability. Biodivers. Biofuels Agrof. Conserv. Agric. 73–100.

Hussain, A., 2012. The green revolution. In: Jalal, A. (Ed.), The Oxford Companion to Pakistani History. Oxford University Press, Karachi.

Kazemi, H., Klug, H., Kamkar, B., 2018. New services and roles of biodiversity in modern agroecosystems: a review. Ecol. Indicat. 93, 1126–1135.

Khan, A.G., 2004. Technical Report On: the Characterization of the Agro Ecological Context in Which Fangr (farm Animal Genetic Resource) Are Found. Development and Application of Decision Support Tools to Conserve and Sustainably Use Genetic Diversity in Indigenous Livestock and Wild Relatives. National agricultural research centre (NARC), Islamabad, Pakistan.

Khan, M.A., 2012. Agricultural development in Khyber Pakhtun Khwa, prospects, challenges and policy options. Pakistaniaat 4 (1), 49–68.

Liu, J.Z., Li, P.P., 2005. Emergy analysis for agroecosystem of Jiangsu province. Syst. Sci. Compr. Stud. Agric. 21, 29–36 (in Chinese).

Liu, W., Wang, J., Sun, L., Wang, T., Li, C., Chen, B., 2019a. Sustainability evaluation of soybean-corn rotation systems in the Loess Plateau region of Shaanxi, China. J. Clean. Prod. 210, 1229–1237.

Liu, Z., Wang, Y., Geng, Y., Li, R., Dong, H., Xue, B., Wang, S., 2019b. Toward sustainable crop production in China: an emergy-based evaluation. J. Clean Prod. 206, 11–26.

Ma, F., Eneji, A.E., Liu, J., 2015. Assessment of ecosystem services and dis-services of an agro-ecosystem based on extended emergy framework: a case study of Luancheng County, North China. Ecol. Eng. 82, 241–251.

Mekonnen, M.M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Sci. Adv. 2 (2), e1500323.

Memon, J.A., Thapa, G.B., 2010. Impacts of upstream irrigation development on deltaic landscape, resources and livelihood-a case of Indus delta in Sindh province. Pakistan. Int. J. Environ. Rural Dev. 1 (2), 67–72.

Nambiar, K., Gupta, A., Fu, Q., Li, S., 2001. Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. Agric. Ecosyst. Environ. 87 (2), 209–214.

Odum, H.T., 1988. Self-organization, transformity, and information. Science 242 (4882), 1132–1139.

Odum, H.T., 1996. Environmental accounting: Emergy and Environmental Decision Making. Wiley.

Ohnishi, S., Dong, H., Geng, Y., Fujii, M., Fujita, T., 2017. A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methodsdcase of Kawasaki, Japan. Ecol. Indicat. 73, 513–524.

Pakistan Bureau of Statistics, 2015. Agriculture Statistics of Pakistan 2010–11. Online: www.pbs.gov.pk/content/agriculture-statistics-pakistan-2015-16 [accessed: 12/01/19].

Pillet, G., Maradan, D., Zingg, N., Brandt-Williams, S., 2001. Externalities: theory and assessment. In: Brown, M.T. (Ed.), Emergy Synthesis: Theory and Applications of the Emergy Methodology. Proceedings of the First Biennial Emergy Analysis Research Conference, Gainesville, FL, USA, pp. 39–51.

Pimentel, D., 2009. Energy inputs in food crop production in developing and developed nations. Energies 2, 1–24.

Pretty, J., 2008. Sustainable Agriculture and Food; History of Agriculture and Food. Earthscan publishers, UK.

Qi, X., Fu, Y., Wang, Yu, R., Ng, Nam, Cho, Dang, H., He, Y., 2018b. Improving the sustainability of agricultural land use: an integrated framework for the conflict between food security and environmental deterioration. Appl. Geogr. 90, 214–223.

Rasul, G., Thapa, G.B., 2003. Sustainability analysis of ecological and conventional agricultural systems in. Bangladesh. World Dev. 31 (10), 1721–1741.

Rehman, H.U., 2012. The problem of unemployment in Pakistan: (A case of study of Khyber Pakhtunkhwa). Int. J. Hum. Soc. Sci. 2 (8), 237–243.

Rydberg, T., Haden, A.C., 2006. Emergy evaluations of Denmark and Danish agriculture: assessing the influence of changing resource availability on the organization of agriculture and society. Agric. Ecosyst. Environ. 117, 145–158.

Sajjad, H., Parasad, S., 2014. Analyzing spatiotemporal pattern of crop diversification in Jalandhar district of Punjab. India. Asian J. Agric. Rural Dev. 4 (3), 242–256.

Shah, S.M., Liu, G., Yang, Q., Wang, X., Casazza, M., Agostinho, F., Ginevra, V.L., Giannetti, B.F., 2019. Emergy-based valuation of agriculture ecosystem services and dis-services. J. Clean Prod. 239, 118019.

Sweeney, S., Cohen, M., King, D., Brown, M., 2009. National Environmental Accounting Database. http://www.cep.ees.ufl.edu/nead/.

Swinton, S.M., Lupi, F., Robertson, G.P., Hamilton, S.K., 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecol. Econ. 64 (2), 245–252.

Tanguay, G.A., Rajaonson, J., Lefebvre, J.-F., Lanoie, P., 2010. Measuring the sustainability of cities: an analysis of the use of local indicators. Ecol. Indic. 10 (2), 407–418.

Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Kruetli, P., Grant, M., Six, J., 2015. Food system resilience: defining the concept. Glob. Food Secur. 6, 17–23.

Tewari, V.K., Kumar, A.A., Kumar, S.P., Nare, B., 2012. Farm mechanization status of West Bengal in India. Basic Res. J. Agric. Sci. Rev. 1 (6), 139–146.

THE EXPRESS TRIBUNE, Pakistan. By Haseeb Hanif Published: March 14, 2019. Online: tribune.com.pk/story/1928915/1-project-worth-rs180bn-planned-water-conservation/[*accessed*: …].

Timer, C.P. 2002. "Agriculture and Economic Development in BL gardener & GC Rausser (ed), Handbook of Agriculture Economics, Amsterdam, North Holland, Vol. 2A, pp. 1487–546.

Ulgiati, S., Odum, H.T., Bastianoni, S., 1993. Emergy analysis of Italian agricultural system. The role of Energy quality and environmental inputs. Trends Ecol. Phys. Chem. 187e215.

United Nations Development Program, Pakistan Human Development Report, 2003.
United Nations World Food Program (WPF), Benin, Fact Sheet 2009.
Van Cauwenbergh, N., Biala, K., Bielders, C., Brouckaert, V., Franchois, L., Garcia Cidad, V., et al., 2007. SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. Agric. Ecosyst. Environ. 120 (2), 229–242.
Wang, X., Shen, J., Zhang, W., 2014. Emergy evaluation of agricultural sustainability of Northwest China before and after the grain-for-green policy. Energy Policy 67, 508–516.
Wasiak, A.L., 2017. Effect of biofuel production on sustainability of agriculture. Procedia Eng. 182, 739–746.
Yang, Q., Liu, G., Hao, Y., Coscieme, L., Zhang, J., Jiang, N., Giannetti, B.F., 2018. Quantitative analysis of the dynamic changes of ecological security in the provinces of China through emergy-ecological footprint hybrid indicators. J. Clean Prod. 184, 678–695.
Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and disservices to agriculture. Ecol. Econ. 64, 253–260.
Zhang, X.H., Zhang, R., Wu, J., Zhang, Y.Z., Lin, L.L., Deng, S.H., Peng, H., 2016. An emergy evaluation of the sustainability of Chinese crop production system during 2000–2010. Ecol. Indic. 60, 622–633.
Zhang, X.-.H., Zhang, R., Wu, L.-.Q., Deng, S.-.H., Lin, L.-.L., Yu, X.-.Y., 2012. The interactions among China's economic growth and its energy consumption and emissions during 1978–2007. Ecol. Indic. 24, 83–95.
Zhao, S., Li, Z., Li, W., 2005. A modified method of ecological footprint calculation and its application. Ecol. Model. 185 (1), 65–75.
Zhong, S., Yong, Geng, Hainan, Kong, Bin, Liu, Xu, Tian, Wei, Chen, Yiying, Qian, Sergio, U., 2018. Emergy-based sustainability evaluation of Erhai Lake Basin in China. J. Clean Prod. 178, 142–154.
Zulfiqar, F., Thapa, G.B., 2017. Agricultural sustainability assessment at provincial level in Pakistan. Land use policy, 68, 492–502.