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Case Report

An Integrated Model for Pollution Prevention, Ecological Integration and Sustainability of Surface Water: Case of Awetu River, Jimma City, South-Western Ethiopia

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Abstract

There are complex relationships among water quality, ecological integration and sustainability of surface water resource. Several factors are interacting in these three things, making them complex for understanding and managing, while the integration of these three is very important for sustainable development, environmental sustainability and public health. To increase the understanding of this complex relationship, appropriate tool is needed. Modeling is considered as an appropriate tool to simplify the understanding of this concept. The objective of this study is developing an integrated conceptual model for pollution prevention, ecological integration and sustainability of Awetu River basin. To develop this model, a preliminary study was conducted in the study area, which includes water quality status, its ecological condition, settlement in the river area, identifying pollution sources, and an on-going project in the river basin. Based on this information, and general environmental scientific knowledge, a conceptual model was developed. This conceptual modeling was passed through the four broad steps; each step involved several key activities that support developing an integrated model. Three correlated sub-models were developed first; finally, one integrated conceptual model was developed. Developing and application of an integrated model for Awetu river basin is very important to improve the current situation of the river. Achieving this needs an integrated work of all stakeholders and concerned bodies. Stakeholders recommended applying this model, whereas researchers recommended evaluation and modifying the model more. The model is also applicable for most rivers and surface water, particularly for waters with similar situations.

Keywords

Conceptual Model, Integrated Model, Pollution Prevention, Ecological Integrity, Sustainability

1. Introduction

Nowadays, in different countries of the world, because of the rapid development of the urban economy, the rapid increase of urban population, the increase of the urban water consumption and the discharge of river pollutants, the deepening of the degree of industrialization, the self-purification of rivers, and ecological compensation of the regulation ability decline, water quality has significantly deteriorated [1]. Globally, with the exception of very few countries, there are no countries that have river systems that have remained in their natural ecological condition with a

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high level of connectivity from source to sea, representing functional biodiversity along their latitudinal and longitudinal zones [2]. As a result of fresh water quality deterioration and ecological change, there is a sharp decline in freshwater biota. This sharp decline in freshwater species and complex habitat requirements is commonly attributed to water alteration and extraction globally [3].

Different factors affect river quality and its ecological condition. This includes alteration in water quantity (flow), quality (e.g., nutrients, temperature load and pH), and levels of connectivity [4]. As a result of the flow characteristics of river water, river ecology is more susceptible to external pollution; once pollution happens, it can easily spread to the whole river basin [1]. In addition to river quality deterioration and natural ecological change, misuse of this important natural resource leads to a lack of equity and a loss of economic, social and recreational purposes that are expected to be gained from this resource. Protection and restoration of water-related ecosystems is one of the sustainable developmental goals (SDG) goals. SDG target 6.6 focuses on the protection and restoration of water-related ecosystems. Targets of the post-2020 global biodiversity framework focus on changes in the extent, and integrity of ecosystems, connectivity and, listing 21 action-oriented targets to be achieved by 2030 with the aim of reaching outcome-oriented goals by 2050 [2].

With the growing severity of water pollution and its ecology, the prevention and control of water pollution and its ecological integrity have become highly complicated and challenging [5]. This requires exploring the ways of river pollution control, ecological integration and its natural condition preservation and restoration, as well as sustainability of the river.

One way of understanding and solving this type of complex problem is to develop a model. Modeling is a very important tool in modern science to increase our understanding. Models can represent the dynamic relationship between natural and human systems and have been applied to describe the transport of water and sediment, fate, sources, and transport of contaminants in watersheds and river basins [6]. Even though water quality modeling is challenging due to several constraints, it is a very important tool that supports policymakers and managers in multiscale integrated water resources and environmental management [7].

Different studies conducted on Awetu River show that the river has been contaminated via human and animal faucal materials waste disposed from households, hotels and small-scale industries. This is due to the lack of waste treatment facilities in the city and the discharge of waste into the nearby water bodies without treatment [8]. All the heavy metals in the Awetu stream sediment were found above the permissible limit set by the WHO and EU [8]. Similarly, another study shows that the toxic metal concentrations in the Awetu watershed pose a high risk to the ecosystem [8]. The pollution of the Awetu River also affects vegetables cultivated using the river water. Heavy metals in all vegetables irrigated by the Awetu River were above the permissible safe limit of WHO, except Cu [9]. Consumption of such a type of vegetable could pose a health risk. These indicate that searching for solutions for the river pollution control and its sustainability is very important issue.

In this study, an integrated conceptual model was developed for the Awetu River basin and its ecosystem. This includes three sub-models, namely Awetu River pollution prevention sub-model, Awetu River ecological integrity sub-model, and the Sustainability of Awetu River Basin sub-model, and one an integrated model. A conceptual model is essential for ecology, because it identifies ecological universities across diverse taxonomies and geographies. Particularly, it plays a significant role in shaping our understanding and managing river ecosystems at different scales and often informs management practices for stakeholders [10]. If conceptual underpinnings accurately represent a substantial element of the river network and its ecology, management and policy decisions can easily achieve desired outcomes. These three concepts and their interconnection are very important for holistic understanding and sustainable solutions. This model is not useful only for the study area, but also for other rivers of similar status. This study contributes in achieving SDG6 which deals with clean water and sanitation.

2. Method

2.1. Description of the Study Area

Awetu River is one of the smallest rivers in South-Western Ethiopia. It is found in Jimma Zone, crossing Jimma City, the administrative city of Jimma Zone. It lay between 7°38′00′ N and 7°48′00″ N latitude and 36°40′00″ E and 36°56′00″ E longitude. The river crosses Jimma City, which is located 352.4 km from the capital city of Ethiopia - Addis Ababa. The elevation of the city is 1,780 m (5,840 ft). The Jimma City is the largest city in the South-Western Oromia Region of Ethiopia and the capital city of Jimma zone. The city was established in 1830 and very important political and business center.

The region (South-Western Ethiopia) is mostly characterized by a humid tropical climate and heavy rainfall, especially during the four months: June, July, August, and September, locally known as Ganna or Kiramt (Summer). The average annual rainfall and temperature in the area are, 1425mm and 20.9 ℃, respectively [11].

The city has a poor sewer system where the runoff from roads and wastewater from different sources discharges to the Awetu stream and its tributary streams like Dololo and Kito without prior treatment. This causes a big challenge for the Jimma municipality, which has a limited budget to undertake the collection of solid waste and control liquid waste in an integrated manner and cope with the fast-growing population

[11].

Besides the Awetu River, there are four tributary streams in the city: Shonkore, Frustale, Kito and Dololo. Awetu bisects the center of the city, Shonkore and Frustale join Awetu at the upper stream, Kito flows at the western end and joins Awetu at Bore Bridge; Dololo flows at the eastern part of the city and joins Awetu River at Bore Wet-land in Bore Keneni or Bar-kume area, after which they join Gilgel Gibe River below the intake point of the water treatment plant of Jimma City (See figure 1).

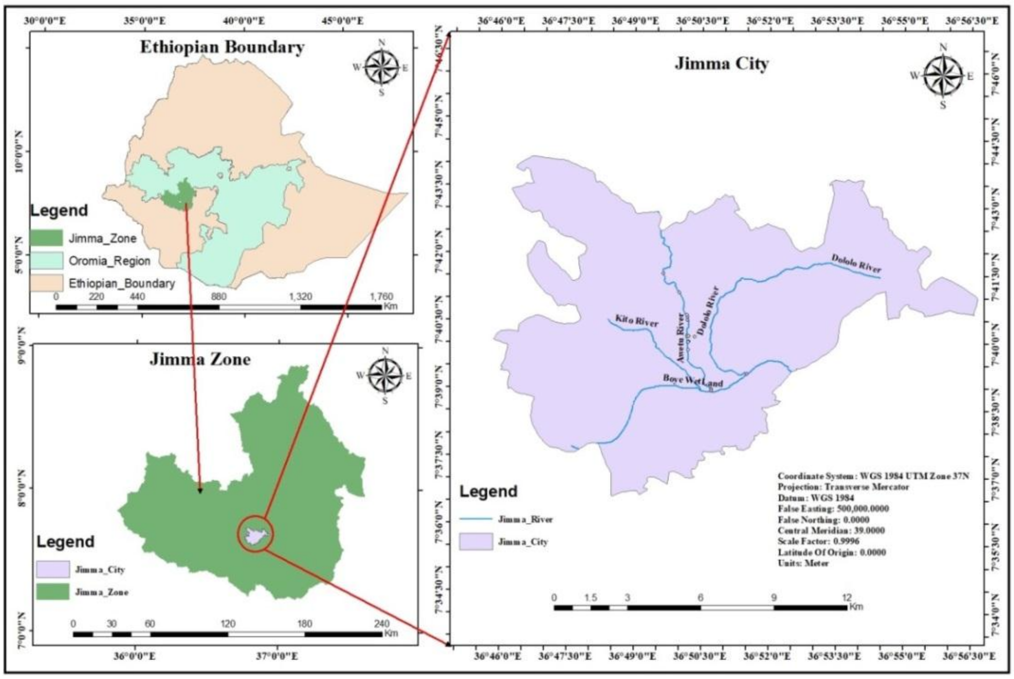

Figure 1. Map of the study area.

2.2. Methodological Approach

A System dynamic approach was used in this study. Systems dynamic approach is an approach used to study the non-linear behaviour, time delay, and multi loop structures of complex and dynamic systems [12, 13]. It helps to improve system understanding of the decision-making process and foster system thinking skills and knowledge integration for modellers and end-users [12].

In this study, before developing the models, a preliminary study was conducted in the study area, which includes water quality status, its ecological condition, settlement in the river area, identifying pollution sources, and an on-going project in the river basin. Based on this information, and general environmental scientific knowledge, a conceptual model was developed. This model is a solution based conceptual model. Cause-effect is not directly mentioned, but it is understood from elements mentioned as solution.

Three correlated sub-models were developed first; finally, one integrated conceptual model was developed. This conceptual modeling was passed through the four broad steps; each step involved several key activities that support developing an integrated model. A description of each step is described below. (See Figure 2).

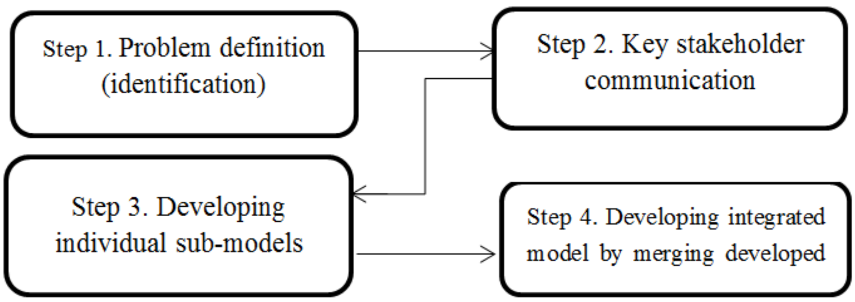

Figure 2. Main steps of the proposed modelling approach of Awetu River basin.

2.2.1. Problem Definition

The first step in model building is identifying the problem, setting its boundary, and stating the specific objectives of the modelling. The same method is followed by Nyam [12]. In this study the problem was first identified during the preliminary study of Awetu River basin. River quality status, pollution factors and sources, ecological condition, and current on-going changes in the river basin – including the river channelization project- were identified.

2.2.2. Key Stakeholder Communication

Based on the field observation and analysis of the preliminary study, key informants, particularly Jimma City municipality and the water and sewer authority of the city were interviewed.

2.2.3. Developing Individual Sub-Models

In this step, three sub-models that are correlated were developed. This is very helpfull in developing an integrated model that is more complex. Furthermore, it helps for deep investigating driving factors and elements in each sub-model.

2.2.4. Developing an Integrated Model by Merging The Sub-Models

In this step, an integrated model was developed by merging sub-models to create holistic understanding and propose holistic problem solving in the river basin (an integrated model for prevention of pollution, ecological integration, and sustainability of Awetu River basin).

The elements or parameters included in sub-models and an integrated model were selected based on their impact on the intended goal (Awetu River pollution prevention, ecological integration, and sustainability of water). The elements were selected after identification of their direct or indirect impact on the river.

3. Result

3.1. Awetu River Pollution Prevention Sub-Model

Three conceptual sub-models and one an integrated model ware developed. The first one is Awetu River pollution prevention sub-model. It represents the sub-model having 16 variables (elements) namely: Pollution source identification and quantification; pollution load estimation, separated sewer system for liquid waste, storm and flood, waste control at the at the source, law enforcement and commitment, regular monitoring and situation documentation, waste water treatment at source, reduce the pollution degree of polluted water, pollution management plan and implementation, involving all stakeholders, awareness creating, reducing the pollution degree of polluted water, environmental based projects (technology selection), local pollution rule and regulation, enhance natural self-purification of the river, local pollution rule and regulation, clear authority and responsibility sharing, tributary rivers quality and plane and standard based settlement. See figure 3.

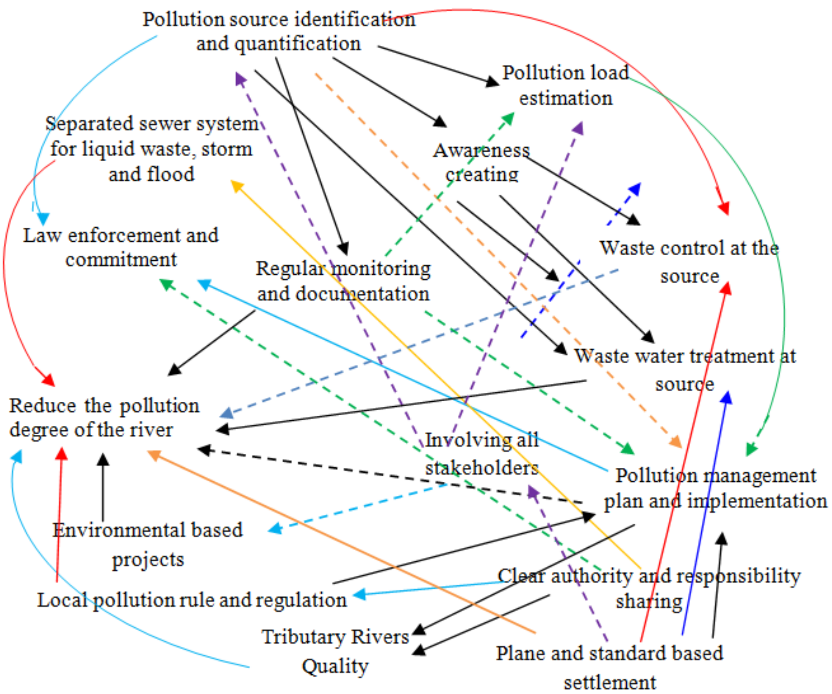

Figure 3. Awetu River pollution prevention sub-model.

3.2. Awetu River Ecological Integrity Sub- model

The second model was Awetu River ecological integrity sub-model, see figure 4. It contains 15 variables namely: holistic understanding and management of river ecosystems, river wave concept, riverscape ecology, ecological corridors, river basin (ecological) restoration and preservation, law enforcement (environmental law), maintaining river water quality, environmental based projects, preserving pollution sensitive taxa, plane and standard based settlement, human interference reduction, regular monitoring and situation documentation, management plan and application, and urban sewage prevention.

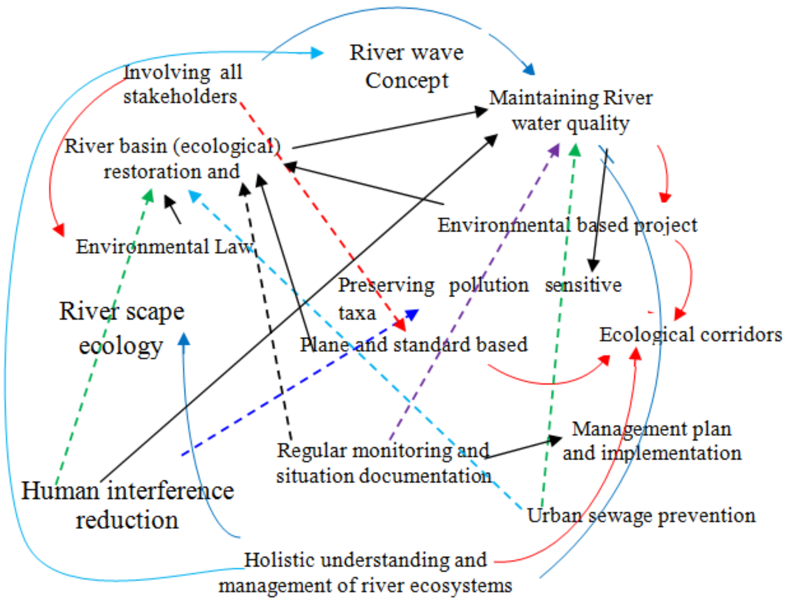

Figure 4. Awetu River ecological integrity sub- model.

3.3. Awetu River Basin Sustainability Sub-model

The third Sub-model developed in this study was Awetu River Basin Sustainability sub-model. It contains twenty elements or factors that support the achievement of Awetu River basin sustainability. These elements were mentioned in figure 5.

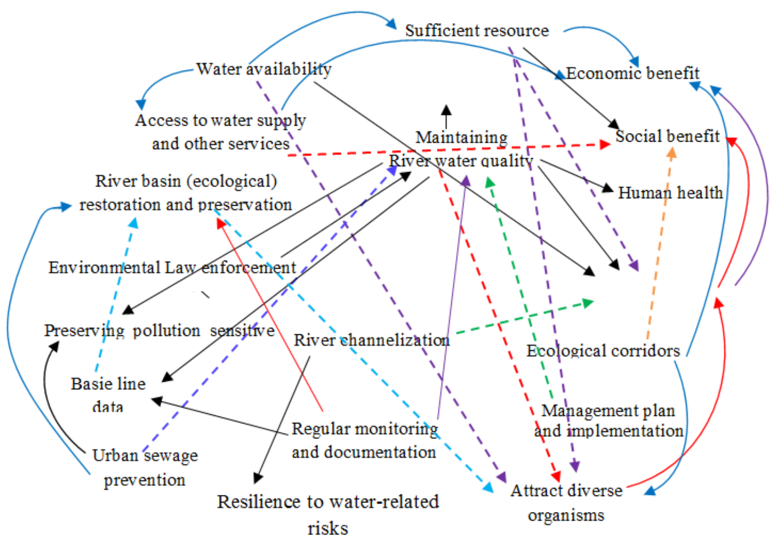

Figure 5. Sustainability of Awetu River basin sub-model.

3.4. An Integrated Model for Prevention of Pollution, Ecological Integration and Sustainability of Awetu River Basin

An integrated model for prevention of pollution, ecological integration, and sustainability of Awetu River basin was developed by merging sub-models to provide holistic understanding, and solve the river basin problems. This model contains 34 elements, as mentioned in the figure below. See Figure 6.

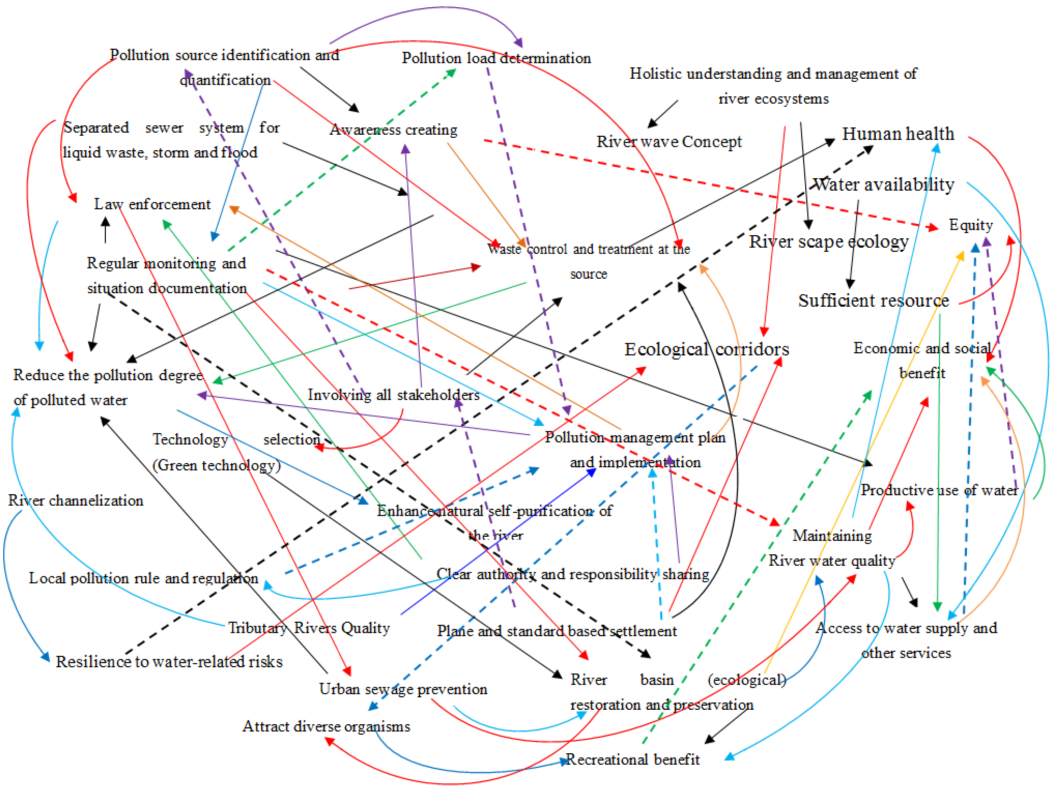

Figure 7. *An integrated model for prevention of pollution, ecological integration and sustainability of Awetu River basin.*

4. Discussion

Pollution source identification, quantification, and characterization are very important measures for river pollution prevention. Identifying pollution sources of river water is a basis for effectively improving water pollution and sustainable water quality management. This is because it is helpful for waste water treatment and control at source, urban sewage prevention, regular monitoring and situation documentation, as well as pollution management. Identifying and quantifying the sources of pollution is vital for the development of pollution mitigation and prevention strategies to protect public and environmental health [14]. Furthermore, detailed quantitative and qualitative information of pollutants is very important for pollution load estimation [15]. This why it connected with these elements (water treatment and control at source, urban sewage prevention, regular monitoring and situation documentation, and pollution management) in the sub-model one in figure 3.

Pollutant load estimation is crucial for water quality monitoring and management. To control pollution sources and prioritize the reduction strategies of pollution, estimating the pollution load and preventing the entry of pollution into the water resources plays a significant role [15]. Preparing a separated sewer system for liquid waste, storms, and floods is crucial for urban sewage prevention and reduction of river pollution degree; this in turn enhances the natural self-purification of the river.

International and national environmental law enforcement and commitment for its implementation, drafting local pollution rules and regulations, and implementation are very important for pollution reduction and, in turn, enhance the natural self-purification capacity of the river. When the river restored its self-purification capacity, it could easily restore its natural condition. Some environmental problems occur locally on microlevels. Such types of problems can be solved by local decision-makers and holders [16]. For this reason, local pollution rule and regulation is considered as one factor or element in the model. Law enforcement in the environmental field can be categorized into three categories, namely state administration environmental law enforcement, criminal environmental law enforcement and civil environmental law enforcement [17]. But it may be some difference from one country to another country.

The reform of environmental management systems is one key element improving environmental pollution treatment and green technology innovation [18]. Regular monitoring and situation documentation is important for pollution management plan and implementation, law enforcement and commitment, waste control and waste treatment at the source, as well as pollution load estimation. Water management encompasses many complex and multidisciplinary internal and external factors involving various stakeholders in the decision-making process, it includes an economic aspect [19], ecological, environmental, and health aspect.

Involving all stakeholders and creating awareness creating is very crucial. Every human being is a component of society that should have equal rights, obligations, and roles in terms of environmental prevention and management [17]. Many society groups lack environmental awareness, many of them do not understand about environmental cleanliness, negative impact of environmental pollution; so they easily generate household waste [20]. Not only household wastes, but also industrial and other types of wastes. Stakeholders include administrative bodies at different levels, waste producers, researchers and environmentalists, influential individuals, and public figures. If all stake holders participate and play their role, complex and huge problems may easily be solved. Participation of all stakeholders in policy development and decision-making is very important and forms a crucial part of Integrated Water Resource Management (IWRM) [12]. IWRM is an important approach used in water management issues to be solved holistically with active stakeholder involvement [12]. Technology selection (Green technology) and environmental based projects is another important factor which supports river pollution prevention and ecological integrity. Todays, technology and how humans use it is one of the major causes of environmental problems, because technology can be both the source and remedy of environmental problems [16]. Most of the technology is in use nowadays and projects are considered as one factor of river pollution and ecological disturbance. The environmental impacts of technology depend on what technologies are used and how they are used [16]. Selecting Green Technology and environmentally friend projects can partially solve or improve environmental problems.

Clear authority and responsibility sharing are also considered as one important factor that has an impact on river pollution prevention and ecological integrity generally and for Awetu River particularly. As preliminary studies indicate, the reason why separate sewer systems for liquid waste, storm and flood – even though Awetu Developmental Project is going on- is lack of clear authority and responsibility sharing among administrative bodies, as well as lack of cooperative work. Thus, solving this problem can change the situation in the river basin.

Tributary Rivers Quality also has a great impact on the Awetu river quality. There are four tributary rivers of different volume that join Awetu River. Some of these tributaries are considered as the main pollution sources of the river. This is proved by studies conducted prior to develop these models. The remaining tributary rivers have considerable impact now, but expected to have a high negative impact on the Awetu River as the population and different projects increase more and more in the area. Another factor that has a great negative impact on the Awetu river quality and its ecological integrity is unplanned settlements which are built on the the river side, throwing their solid waste and discharging liquid waste directly to the river without any prior treatment. Allowing only plane and standard-based settlement plays a great role in improving the current Awetu River basin situation.

Ecological integrity includes structural components such as organisms, physical conditions and resources; and functional components including a variety of ecological processes [21].

Holistic understanding and management of river ecosystems is a primary requirement for ecological integrity, preservation, restoration and management. It means, understanding complex interactions within river ecosystems, considering both natural processes and human impacts. This holistic understanding need to consider a few key concepts related to river ecological integration. These are: River wave Concept, River scape ecology and Ecological corridors. The river wave concept proposes that river flow can be conceptualized as a series of waves varying in shape, wavelength, frequency and amplitude, traveling longitudinally and laterally. Different positions on the river wave govern the source of organic inputs or production, the storage, transformation, and transport of energy and material [22]. The nature of river waves is influenced by climate, geomorphology, geology and anthropogenic regulation; in turn, influencing biodiversity, productivity, and the composition of riverine biota [22].

River scape Ecology is integrating concepts from landscape ecology into understanding and managing riverine ecosystems [23]. It emphasizes on interactions among processes at different scales and their consequences for valued ecosystem components, including riverine organisms like fishes. River ecological corridor includes the meander belt of a river and its buffer zone (usually 50 feet wide) [24]. It enforces the interaction and connection of core river areas with adjacent rivers, parks, grasslands, wetlands, forming, stable, and an integrative and equilibrium river ecosystem [25]. River corridors integrate the active channels, geomorphic floodplain and riparian areas, and hyporheic zone while receiving inputs from the uplands and groundwater and exchanging mass and energy with the atmosphere [26].

Regular monitoring and situation documentation is one key element in ecological integrity. It is useful for baseline data documentation, maintaining river water quality, river basin (ecological) restoration and preservation, management plan and implementation, river basin (ecological) restoration and preservation. Restoration and maintenance of biological integrity is a fundamental goal in law and offers an inspiring framework for communication and engagement of different parties, such as resource managers, law- and policymakers, scientists and the public [27].

Monitoring and reporting changes in the river ecosystem extent need to be complemented with documentation of changing trends in river ecological conditions. This is because changes in river ecosystems are mostly not quantified as changes in extent (e.g. complete loss of a river), rather as changes in their ecological condition or integrity [2]. Lack of baseline data and timely documentation of river quality and its ecology is one of the main problems and challenges. Even, there is no baseline data for the current ongoing Awetu River side developmental project except photographic records for the physical part. If evolution of the project is needed based on base line, there is no evidence (data) for baseline. In the same way, reducing human interference in the river basin helps river basin (ecological) restoration and preservation, preserving pollution-sensitive taxa and maintaining river water quality.

Maintaining river water quality assists in preserving pollution-sensitive taxa. This helps sustaining biodiversity in the river basin and ecology. Not only that, it also helps using water resources for different productive uses. Sustainable environmental management influences the availability of water resources, food security and energy to support the achievement of sustainable development goals (SDGs) (20). Focusing on environmental based projects and law enforcement also plays a crucial role in river basin (ecological) restoration and preservation.

Five key elements that more describe sustainability of river system were included in Awetu River basin Sustainability sub-model. These are: sufficient resources, productive use of water, access to water supply and other services, resilience to water-related risks, and fairness between different users and generations (equity) [28]. Achieving sustainability of river basin needs sustainable management. The sustainable management of river basins is a comprehensive management including environmental quality and socio-economic as well as health aspects [19].

River channelization is also an important element for sustainability of the river. Allowing the river channel helps the river to “heal itself” through setting aside a channel migration zone, is the most sustainable strategy for ecological restoration and integrity [29]. Flood risks in the Awetu river basin were repeatedly recorded; channelization can solve the flood risk of the river.

5. Conclusion and Recommendation

Developing and application of an integrated model for Awetu river basin is very important to improve the current situation of the river. Achieving this needs integrated work of all stakeholders and concerned bodies. Stakeholders recommended applying this model, whereas researchers recommended evaluation and modifying the model more. The model is not applicable for Awetu river only, but also applicable for most rivers and surface water, particularly for waters with similar situations.

Abbreviations

SDG Sustainable Developmental Goals

Author Contributions

Mohammedsalih Kadir Gobana: Conceptualization, Investigation, Writing – original draft

Alemayehu Haddis Getahun: Formal Analysis, Supervision, revision

Desalegn Dadi: Formal Analysis, Supervision, revision

Conflicts of Interest

The authors declare no conflicts of interest.

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